PEACEFUL USES OF ATOMIC ENERGY

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PEACEFUL USES OF ATOMIC ENERGY
UN, NEW YORK, AND IAEA, VIENNA, 1972

FOREWORD

The Fourth International Conference on the Peaceful Uses of Atomic Energy, held at Geneva from 6 to 16 September 1971 under the Presidency of Glenn T. Seaborg, was jointly sponsored by the United Nations and the International Atomic Energy Agency. The conference sessions were held at the Palais des Nations. During the same period a Governmental Scientific Exhibition on the theme "Atoms for Development" was displayed at the Palais des Expositions in Geneva.

The Proceedings are published in 15 main volumes, fourteen of which contain all the 514 papers presented at the conference. The papers are printed in English, French, Russian or Spanish, and the abstracts in all four languages; the discussions are in English. The fifteenth volume contains a Subject Index, an Author Index (including discussion contributors), a Paper Number Index, a complete Contents List of all volumes, and a List of Delegations. There are three supplementary volumes containing the discussions in French, Russian and Spanish respectively.

The conference, which attracted more than four thousand participants, observers and journalists, was planned to interest not only scientists and technologists but also public officials, economists and planners. It thus had a somewhat broader scope than the conferences of 1955, 1958 and 1964. The main topics were grouped under the following six headings: nuclear power; nuclear fuels and materials; health, safety and legal aspects; isotopes and irradiation; international and administrative aspects; and selected subjects of particular interest to developing countries.

The fourth Geneva Conference proved again to be an exceptional forum enabling those working throughout the world on the peaceful application of atomic energy to exchange the latest information on the discoveries, projects and problems of both developed and developing nations.

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OPENING OF THE CONFERENCE

MESSAGE DE BIENVENUE
du Président de la Confédération helvétique, M. Rudolf Gnägi

C'est un grand honneur et un réel plaisir pour moi d'assister à l'ouverture de la quatrième Conférence internationale sur l'utilisation de l'énergie atomique à des fins pacifiques.

Les autorités fédérales de même que les autorités cantonales genevoises sont heureuses de constater qu'une fois de plus, après les conférences de 1955, 1958 et 1964, Genève a été choisie pour lieu de cette rencontre. Si la raison principale de ce choix devait être que l'atmosphère genevoise se prête particulièrement bien à une réunion «à des fins pacifiques», je ne pourrais qu'exprimer ici ma gratitude pour le certificat ainsi délivré à Genève et à la Suisse. Je ne puis qu'espérer que toutes les conférences qui se tiendront ici viseront toujours, de la même manière, des objectifs pacifiques et humanitaires. La Suisse et Genève n'ont pas de vœu plus cher.

Les trois réunions précédentes ont montré à l'évidence que de telles manifestations donnent l'occasion aux nombreux hommes de science qui y prennent part de procéder tout à la fois à de fructueux échanges d'informations nouvelles et de présenter des travaux sur les progrès réalisés dans les applications pratiques de l'énergie nucléaire. Ces conférences permettent de faire le bilan, au niveau international, des progrès accomplis dans le domaine de l'énergie nucléaire et d'en déterminer l'importance pour l'avenir de l'humanité.

Si notre monde connaît une progression démographique constante, les exigences de tout un chacun s'accroissent également. Les besoins toujours plus impérieux de denrées alimentaires, de produits industriels et de services ne peuvent être satisfaits qu'avec l'aide de la science et de la technique. Il est tout particulièrement évident que les objectifs universels ne peuvent être atteints que si la production d'énergie s'accroît rapidement. Si déjà l'on prévoit que la production d'électricité devra doubler au cours des 10 à 15 prochaines années pour couvrir la consommation des pays fortement industrialisés, le taux de croissance de cette production devra être encore beaucoup plus élevé dans les pays en voie de développement. Pareille évolution ne pourrait être maîtrisée si l'on ne disposait pas de l'énergie nucléaire. Il est particulièrement réjouissant de constater que les problèmes difficiles qui se posaient au début dans la technique nucléaire ont pu être résolus en relativement peu de temps. Cette technique est donc prête aujourd'hui déjà à contribuer, pour une large part, à couvrir les nouveaux besoins considérables en énergie auxquels on doit s'attendre.

Maints phénomènes observés au cours des dernières années ont cependant montré que nous ne devons pas considérer uniquement la croissance. La plupart des nouvelles réalisations techniques n'ont pas que des bons côtés. Il n'est que de considérer la pollution croissante de notre environnement qui menace directement les plantes et les animaux, sans parler des atteintes à notre santé. Tout cela suscite de vives inquiétudes dans de larges milieux de la population. Et l'on se demande en maints endroits si le progrès technique ne conduit pas à des dommages irréversibles d'une ampleur telle qu'ils ne sauraient être compensés par les avantages que peut offrir ce progrès. C'est pourquoi la science et la technique sont de plus en plus considérées avec un certain scepticisme. Ce faisant, l'on oublie cependant souvent que sans elles nous ne pourrions faire face à nos problèmes. Il importe pourtant que nous fassions preuve de plus de prévoyance que par le passé et que tout soit entrepris, sinon pour empêcher, du moins pour limiter les effets préjudiciables. Cette manière de voir n'est d'ailleurs pas nouvelle pour les spécialistes de la technique nucléaire. Il me paraît en effet remarquable que l'on ait exigé dès le début dans les centrales nucléaires, par le moyen de dispositions légales, un degré élevé de sécurité et que l'on ait entrepris des études approfondies sur les effets de la radioactivité. A ce point de vue, le développement de l'énergie nucléaire peut servir d'exemple à maintes autres techniques. Ces efforts visant à déterminer par avance les effets d'un nouveau produit doivent s'étendre dans la mesure du possible à tous les développements et procédés techniques. Mais il importe qu'ils soient également poursuivis tout particulièrement dans le domaine de l'énergie nucléaire, au rythme des progrès réalisés. Les autorités responsables doivent à cet effet pouvoir compter sur l'aide compréhensive des meilleurs spécialistes. Il est de ce fait extrêmement important que les chercheurs ne se limitent pas à obtenir des résultats intéressants du point de vue scientifique. Il leur appartient également d'analyser les applications pratiques de ces résultats et d'étudier les améliorations permettant d'éviter les dommages.

Dans cet ordre d'idée, il me paraît en outre nécessaire que le scientifique se tourne de temps à autre vers le grand public pour l'informer, et pour le rassurer serais-je tenté de dire. L'utilisation de l'énergie atomique à des fins pacifiques et particulièrement la construction de centrales nucléaires pour la production d'électricité font souvent l'objet de contestations. Il importe donc de fournir à l'opinion publique les informations objectives dont elle a besoin. Il est hautement souhaitable que l'examen des questions relatives à une bonne information du public permette de dégager une conception générale, utile à toutes les nations intéressées.

La technique nucléaire ne saurait demeurer stationnaire devant les succès remarquables obtenus de nos jours. Au prix d'efforts considérables, l'industrie, fortement appuyée par des centres de recherche gouvernementaux, est parvenue à mettre sur le marché des centrales nucléaires économiquement rentables et concurrentielles qui ont déjà fait leurs preuves. Tous ceux qui ont contribué à ces réalisations méritent notre pleine reconnaissance. Les préoccupations que suscitent notre environnement comme aussi le sort des générations futures ne nous autorisent pas à nous reposer sur nos lauriers. Les hommes de science sont bien plutôt invités de façon pressante à perfectionner la technique nucléaire de telle sorte que ses applications puissent être étendues et que ses effets sur l'entourage soient encore réduits. Nous pensons plus particulièrement ici à la diminution des exigences de telles installations en ce qui concerne les eaux de refroidissement ainsi qu'à l'utilisation de l'énergie nucléaire pour d'autres besoins énergétiques, tels le chauffage, par exemple. La technique nucléaire réduit notablement

Mr. Nello Celio, Vice-President of the Swiss Confederation, delivering the Message of Welcome from the President of the Swiss Confederation, Mr. Rudolf Gnägi. Behind him, at the presiding table, from left to right: Mr. Philippe de Seynes, UN Under-Secretary-General for Economic and Social Affairs, who presented the Message from U Thant, UN Secretary-General; Mr. Vittorio Winspeare Guicciardi, UN Under-Secretary-General and Director-General of the UN Office at Geneva, representing the UN Secretary-General; Mr. Glenn T. Seaborg, President of the Conference; and Mr. Sigvard Eklund, Director General of the International Atomic Energy Agency.

la mise à contribution de l'air et de l'eau pour la production d'énergie comparativement aux autres méthodes utilisées jusqu'ici. L'importance de l'air pur et de l'eau propre pour la santé des hommes, des animaux et des plantes nous oblige donc à diriger résolument nos efforts dans cette voie, même si cela doit nous coûter quelque chose.

Des travaux de développement importants devront cependant encore être effectués pour tirer pleinement profit de ces possibilités. Une meilleure utilisation des combustibles nucléaires, dont la quantité disponible sur notre planète est limitée, sera par ailleurs nécessaire à long terme. Les efforts considérables requis pour atteindre cet objectif seront rendus plus aisés si l'on recherche, dans toute la mesure du possible, une collaboration internationale permettant d'éviter des duplications inutilement coûteuses. C'est précisément à cet égard que la conférence devrait, nous le souhaitons, donner l'occasion de prendre de nouvelles initiatives.

La Suisse, qui est un petit pays, ne peut naturellement apporter qu'une contribution modeste. Nous sommes cependant fiers de posséder dans notre pays des centrales nucléaires opérant sur une base commerciale et d'avoir une industrie qui fournit déjà toutes sortes de composants de réacteurs aussi bien en Suisse qu'à l'étranger. Nous reconnaissons que nous devons ces réalisations aux contacts nombreux et fructueux que nous avons pu établir, en partie grâce aux premières Conférences de Genève, avec les pays qui étaient à l'avant-garde de la technique nucléaire. Nous fondant sur les expériences acquises au cours des dernières années, nous pensons qu'il nous est possible de fournir une contribution intéressante à la mise en valeur de l'énergie nucléaire dans certains domaines sélectifs de la recherche, et des réalisations industrielles; cette contribution ne sera cependant pleinement valable que si elle s'intègre dans le cadre d'une collaboration internationale. Nous espérons pour cette raison que l'un des résultats de cette conférence sera de renforcer et de multiplier les rapports, au plan international, entre spécialistes de la technique nucléaire, et de contribuer ainsi à maîtriser quelques-uns des nombreux grands problèmes qui se posent pour que l'humanité tout entière soit délivrée de la faim et des privations.

La Suisse poursuit traditionnellement des buts pacifiques et humanitaires. Nous sommes donc particulièrement sensibles aux objectifs fixés par l'Organisation des Nations Unies pour la quatrième conférence de Genève, objectifs qui trouvent leur expression dans le titre de cette Conférence, « Avantages pour l'humanité des utilisations de l'énergie atomique », et dans celui de l'Exposition scientifique gouvernementale, «Les atomes au service du développement».

Le fait que ces rencontres soient présidées par une personnalité scientifique aussi éminente que le Professeur Seaborg, le fait que les chefs des autorités responsables des questions d'énergie atomique, ceux de l'économie électrique et de l'industrie ainsi que de nombreux scientifiques et ingénieurs de premier plan et appartenant à tant de nations soient présents ici, garantissent que la quatrième Conférence constituera, comme les précédentes, l'un des événements les plus importants dans l'histoire du développement de l'énergie nucléaire.

Au nom du Conseil fédéral, je souhaite la bienvenue aux organisateurs de la Conférence et à ses participants. A vous, Messieurs les experts, je souhaite de glaner, dans des dialogues fructueux, des informations utiles, mais aussi une connaissance accrue de vos interlocuteurs, base d'une meilleure compréhension et par là même, d'une entente plus profonde entre nations. Je vous transmets le salut du peuple suisse et le vœu des autorités fédérales que la quatrième Conférence de Genève sur l'utilisation de l'énergie atomique à des fins pacifiques puisse apporter une précieuse et significative contribution au développement du bien-être de tous les peuples.

Translations into English, Russian and Spanish follow.

View of the Assembly Hall at the Opening of the Conference.

MESSAGE OF WELCOME from the President of the Swiss Confederation, Rudolf Gnägi

It is a great honour and genuine pleasure for me to attend the opening of the Fourth International Conference on the Peaceful Uses of Atomic Energy.

The Federal authorities, as well as those of the Canton of Geneva, are happy to note that, following the 1955, 1958 and 1964 Conferences, Geneva has once again been chosen as the venue for the gathering. Should the guiding motive for the choice be that the atmosphere of Geneva is particularly conducive to a meeting "for peaceful purposes", then I must express here my gratitude for the high commendation that Geneva and Switzerland have thereby been accorded. I can only hope that all the conferences held here in future will likewise be directed to peaceful and humanitarian ends. Switzerland and Geneva have no wish more cherished than that.

The three previous conferences have shown that such occasions afford the many men of science attending them an opportunity for a fruitful exchange of new information and also for reporting on the headway made in the practical application of nuclear energy. Such conferences enable us to sum up, on an international plane, the progress made in the nuclear energy field and to assess its significance for the future of mankind.

Our world is witness to a constant increase in population, with a similar increase in the needs of each and every individual. The evermore pressing demand for food, industrial output and services can only be met with the aid of science and technology. It is perfectly clear that universal aims cannot be attained unless the production of power is rapidly increased. While it can already be foreseen that electrical power production will have to be doubled within the next 10 or 15 years if it is to meet the consumption requirements of highly industrialized countries, in the developing countries the growth-rate of power generation will have to be very much higher. A progression of this kind cannot be achieved unless nuclear power is made available. It is especially heartening to see that the difficult problems that arose at the outset in nuclear technology have been overcome within a relatively short time. Thus, today, nuclear technology is in a position to make a substantial contribution to meeting the new and considerable energy requirements that can be anticipated.

Many of the developments observed during the last few years, however, have shown us that it is not only growth that we must consider. Most new technical achievements are not without their drawbacks. In this connection one need think only of the increasing pollution of our environment, which constitutes a direct threat to vegetable and animal life, not to mention its deleterious effect on our health. All this is giving rise to growing concern on the part of the general public, and in many places people are wondering whether technical progress is not leading to irreversible damage on a scale where it can no longer be offset by the gains that such progress has to offer. That is the reason why science and technology are more and more being viewed with a certain degree of scepticism. But, in so doing, people often forget that without them we would not be able to cope with our problems. It is important, however, for us to manifest more foresight than we have done in the past and that every step be taken to limit harmful effects, if not to prevent them altogether. This point of view, moreover, is not a new one for nuclear technologists. I think it indeed worthy of note that at nuclear power stations there has been insistence from the very beginning, through the enactment of statutory provisions, on a high degree of safety and that detailed studies on the effects of radioactivity have been undertaken. Seen in this light, the development of nuclear energy can serve as an example to many other branches of technology. Efforts to predetermine the effects of a new product should, as far as possible, cover all new technical developments and processes. It is important to pursue such efforts, especially those in the field of nuclear energy, at the same pace as the progress achieved. The responsible authorities should be able to count on the unstinted assistance of the most qualified experts. It is therefore vital for research workers not to limit themselves to aiming at results that are interesting from the theoretical point of view. They should also analyse the practical application of their findings and study improvements by which harmful effects can be avoided.

Furthermore, it seems to me essential in this respect that scientists should now and then turn their attention to the public at large in order to keep it informed and, I am tempted to say, to offer reassurance. The peaceful use of atomic energy, especially the construction of nuclear stations for generating electricity, is often a subject of controversy. The public should accordingly be provided with all the unbiased data that it requires. It is highly desirable that the search for effective methods of informing the public should lead to an overall conception of the problem, of use to all the interested countries.

Nuclear technology cannot stand still in the face of the remarkable success which it has achieved so far. At the cost of considerable effort, and with the strong support of governmental research centres, industry has been able to market economically viable and competitive nuclear power stations that have already proved their worth. All those who have made contributions to these attainments deserve our full recognition. However, concern regarding our environment and the fate of future generations prevents us from resting on our laurels. Rather, men of science are urged to improve nuclear technology in such a way that its range of applications can be broadened and its effects on the environment reduced still more. We are thinking more particularly of the reduction of the cooling-water requirements of nuclear stations and the use of nuclear energy to satisfy other power needs, such as heating. In comparison with the other methods that have been employed so far, nuclear technology appreciably diminishes the calls on air and water for power generation. Hence, the importance of clean air and pure water for the health of human, animal and plant life compels us to channel our efforts in this direction even if it involves some expense.

There still remains, however, a considerable amount of development work to be done if we are to exploit these possibilities to the full. Better utilization of nuclear fuels – the quantity of which available on our planet is limited – will likewise be necessary in the long run. The considerable effort required to attain this goal will be eased if we strive to the maximum extent for a level of international collaboration that will enable us to avoid unnecessary and costly duplication. It is just in this respect, we trust, that the Conference will provide an opportunity for fresh initiative.

Being a small country, Switzerland cannot, of course, make more than a modest contribution. We are nevertheless proud that in our country we have nuclear power stations operating on a commercial basis and an industry that already supplies all sorts of reactor components both at home and abroad. We realize that we owe these achievements to the many fruitful contacts that we have been able to establish, partly through the earlier Geneva Conferences, with the countries that are in the forefront of nuclear technology. On the basis of the experience gained in the course of the last few years, we feel ourselves in a position to make a worthwhile contribution to the development of nuclear energy in certain selected research areas, and in connection with certain industrial projects; this contribution, however, will only be of full value if it is made within the framework of international collaboration. We therefore hope that among the results of this Conference there will be a strengthening and expansion, on an international plane, of contacts between nuclear experts, and hence a contribution to surmounting some of the many serious problems that the whole of mankind faces if it is to be free from hunger and want.

Switzerland has traditionally pursued peaceful and humanitarian aims. We are therefore especially responsive to the goals set by the United Nations for the Fourth Geneva Conference as formulated in the Conference theme "Benefits for mankind from the peaceful uses of atomic energy" and the theme of the Governmental Scientific Exhibition "Atoms for development".

The fact that these meetings are presided over by as illustrious a scientist as Professor Seaborg, and likewise the fact that the key figures of institutions concerned with atomic energy, electrical power generation and industrial affairs, as well as many leading scientists and engineers from many countries, are present here is a guarantee that the Fourth Conference, like its predecessors, will be a landmark in the history of nuclear energy.

On behalf of the Federal Council I extend a welcome to the organizers of the Conference and to its participants. I trust that the experts present will glean useful information through their fruitful discussions and that they will also come to know their fellow participants more closely, since this is the basis for a better understanding and, as a result, a closer bond between the nations. May I convey to you the greetings of the Swiss people and give expression to the hope of the Federal Authorities that the Fourth International Conference on the Peaceful Uses of Atomic Energy may make a valuable and significant contribution to the welfare of all peoples.

ПРИВЕТСТВЕННОЕ ПОСЛАНИЕ Президента Швейцарской Конфедерации Рудольфа ГНЕГИ

Для меня большая честь и истинное удовольствие присутствовать на открытии Четвертой международной конференции по использованию атомной энергии в мирных целях.

Федеральные власти, так же как и руководство кантона Женевы, с удовлетворением констатируют, что после Конференций 1955, 1958 и 1964 годов Женева снова выбрана местом для данной встречи. Если определяющим мотивом этого выбора явилось то, что атмосфера Женевы является особенно благоприятной для проведения совещания "в мирных целях", то я должен выразить свою признательность за такую высокую аттестацию Женевы и Швейцарии. Я могу лишь надеяться на то, что все конференции, которые будут проходить здесь в будущем, также будут всегда направлены на осуществление мирных и гуманных целей. Швейцария и Женева не имели какого-либо другого намерения.

Три предшествующие конференции со всей очевидностью показали, что такие встречи дают возможность многим ученым-участникам одновременно осуществлять плодотворный обмен новейшей информацией и представлять доклады об успехах, достигнутых в области практического применения ядерной энергии. Такие конференции позволяют подвести на международном уровне итог успехам, достигнутым в области ядерной энергии, и определить их значение для будущего человечества.

Наш мир является свидетелем непрерывного роста населения, увеличиваются также потребности каждого человека в отдельности. Острая потребность в продуктах питания и промышленных изделиях может быть удовлетворена только с помощью науки и техники. Совершенно очевидно, что общие цели могут быть достигнуты только при быстром росте производства энергии. И если в высокоразвитых в промышленном отношении странах предусматривается увеличить производство электроэнергии вдвое в течение ближайших 10-15 лет, то в развивающихся странах темпы роста производства энергии должны быть еще более высокими. Такой рост не возможен без использования ядерной энергии. Поэтому особенно приятно отметить, что те трудные проблемы, которые возникали вначале в области ядерной техники, решены за сравнительно короткое время. Уже сегодня ядерная техника способна в значительной степени удовлетворять растущие потребности в энергии.

Однако многие явления, наблюдаемые в течение последних лет, показывают, что мы должны уделять внимание не только увеличению производства энергии. Большинство новых технических достижений дают не только одни преимущества. Достаточно указать на увеличивающееся загрязнение окружающей нас среды, которое представляет прямую угрозу растительному и животному миру, не говоря уже об ущербе нашему здоровью. Все это вызывает растущее беспокойство в широких слоях населения. Многие задают себе вопрос, не нанесут ли технические достижения такой невосполнимый ущерб, который не сможет быть компенсирован выгодами, получаемыми в результате этого прогресса. Поэтому успехи науки и техники воспринимаются с определенным скептицизмом. Однако при этом часто забывают о том, что без науки и техники мы не сможем решить наши проблемы. Поэтому нам важно проявлять бо́льшую чем в прошлом проницательность и направлять все усилия на то, чтобы, если не предотвратить, то, по крайней мере, ограничить вредные последствия. Эта точка зрения не является новой для специалистов в области ядерной техники. Я считаю необходимым отметить, что на атомных электростанциях с самого начала эксплуатации требуется высокая степень безопасности, на основе существующих правовых норм, и проводятся глубокие исследования проблем воздействия радиоактивности на окружающую среду. В этом плане ядерная энергетика может служить примером для многих других технических отраслей. Усилия, направленные на предопределение воздействия нового вида энергии, должны, по возможности, распространяться на все новые технические разработки и процессы. Особенно важно, чтобы такие усилия прилагались в области ядерной энергетики. Для этого соответствующие органы должны иметь возможность полагаться на всемерную помощь специалистов высокой квалификации. В этой связи особенно важно, чтобы исследователи не ограничивались получением результатов, представляющих лишь теоретический интерес. Они должны анализировать вопросы практического применения результатов их исследований, а также изучать возможности внедрения усовершенствований, которые позволят избежать вредные воздействия на окружающую среду.

Более того, мне представляется необходимым, чтобы ученые время от времени информировали по этому вопросу широкие слои населения, подготавливая тем самым общественное мнение. Использование атомной энергии в мирных целях, и особенно строительство атомных станций для производства электроэнергии, часто является предметом спора. Поэтому важно предоставить общественности объективную информацию, в которой она нуждается. Весьма желательно, чтобы изучение эффективных методов информации общественности позволило бы выработать общую концепцию, приемлемую для всех заинтересованных стран.

Достигнутые к настоящему времени поистине выдающиеся успехи являются гарантией того, что развитие ядерной технологии остановить нельзя. Ценой огромных усилий промышленность наладила, при мощной поддержке государственных научно-исследовательских центров, сооружение коммерческих атомных электростанций, экономически рентабельных и конкурентоспособных. Все, кто содействовал этому успеху, заслуживают нашей искренней признательности. Однако озабоченность, вызываемая загрязнением окружающей нас среды, и беспокойство за судьбы будущих поколений не дают нам права почить на лаврах. Ученым надлежит настойчиво совершенствовать ядерную технику в целях расширения сферы ее применения, а также в целях уменьшения ее вредного воздействия на окружающую среду. В частности, мы имеем в виду сокращение потребления ядерными станциями воды для охлаждения, а также использование ядерной энергии для удовлетворения других энергетических нужд, таких, как отопление. По сравнению с другими методами, используемыми до сих пор для производства энергии, ядерная технология порождает значительно меньше проблем, связанных с загрязнением воздуха и воды. Важность сохранения в чистоте окружающей среды для растительного и животного мира, а также для здоровья человека, все более возрастает; именно на этом необходимо сосредотачивать наши усилия, даже если это будет связано с определенными расходами.

Кроме того, нужно в полной мере использовать уже имеющиеся у нас возможности. Наиболее рациональное использование ядерного топлива, количество которого на нашей планете ограничено, также будет долго оставаться насущной проблемой. Усилия, направленные на достижение этой цели, будут более плодотворными, если всемерно развивать международное сотрудничество, которое позволит избежать бесполезного и дорогостоящего дублирования. Именно в этом отношении Конференция должна, по нашему мнению, всячески содействовать проявлению любой инициативы.

Швейцария, будучи небольшой страной, может внести, естественно, лишь скромный вклад. Однако мы гордимся тем, что в нашей стране имеются атомные электростанции, эксплуатируемые на коммерческой основе, а ее промышленность уже производит различные узлы реакторов, как для удовлетворения внутренних потребностей Швейцарии, так и на экспорт. Мы понимаем, что обязаны нашими успехами многочисленным и плодотворным контактам, которые мы смогли установить, частично благодаря предыдущим Женевским конференциям, со странами, идущими в авангарде развития ядерной техники. На основе опыта, приобретенного за последние годы, мы думаем, что сможем внести свой вклад в дело использования ядерной энергии в некоторых конкретных областях исследований. Однако этот вклад будет иметь значение лишь в рамках международного сотрудничества. Поэтому мы надеемся, что одним из результатов Конференции будет укрепление и расширение международных связей между специалистами в области ядерной техники, а также содействие решению некоторых важных проблем, – как например, проблемы избавления всего человечества от голода и лишений.

Швейцария традиционно проводит мирную и гуманную политику. Поэтому нам особенно близки цели, поставленные Организацией Объединенных Наций перед Четвертой Женевской конференцией и нашедшие свое отражение в ее девизе – "мирное использование атомной энергии на благо человечества", а также в девизе научно-технической выставки – "атом на службе прогресса", организованной правительствами стран-участниц.

Тот факт, что работа Конференции проходит под председательством такого выдающегося ученого, каким является профессор Сиборг, и что на ней присутствуют руководители национальных ведомств, занимающихся вопросами использования атомной энергии, развития энергетики и промышленности, а также видные ученые и инженеры из многих стран мира, является залогом того, что Четвертая Женевская конференция, как и предшествующие ей конференции, явится важной вехой в истории мирного использования атомной энергии.

От имени Федерального Совета я приветствую организаторов Конференции и ее участников. Я уверен, что присутствующие здесь специалисты извлекут большую пользу из плодотворных дискуссий, ближе узнают друг друга. Именно это является основой взаимопонимания и, в конечном итоге, более тесных связей между отдельными странами. Позвольте передать Вам приветствие от швейцарского народа и выразить пожелание Федерального правительства, чтобы Четвертая Женевская конференция по использованию атомной энергии в мирных целях внесла ценный и значительный вклад в улучшение благосостояния всех народов.

MENSAJE DE BIENVENIDA
del Presidente de la Confederación Helvética, Rudolf Gnägi

Es un gran honor y un verdadero placer para mí asistir a la apertura de la cuarta Conferencia Internacional sobre la Utilización de la Energía Atómica con Fines Pacíficos.

Tanto a las autoridades federales como a las autoridades cantonales ginebrinas les cabe la satisfacción de comprobar que, tras las conferencias de 1955, 1958 y 1964, una vez más se ha escogido a Ginebra para celebrar esta reunión. Si el motivo principal de esta elección es que la atmósfera ginebrina se presta particularmente a una reunión «con fines pacíficos», no puedo por menos que expresar aquí mi gratitud por el título que así se otorga a Ginebra y a Suiza. No puedo esperar, señores, sino que todas las conferencias que tengan lugar en esta ciudad persigan siempre fines tan pacíficos y tan humanitarios. Este es el deseo más ferviente de Suiza y de Ginebra.

Las tres reuniones anteriores demostraron hasta la saciedad que estos acontecimientos facilitan a los numerosos hombres de ciencia que en ellas toman parte la oportunidad de proceder a un fructuoso intercambio de información reciente y de presentar al mismo tiempo trabajos sobre los progresos realizados en la aplicación práctica de la energía nuclear. Estas conferencias permiten hacer un balance, a nivel internacional, de los avances conseguidos en la esfera de la energía nuclear y determinar su importancia para el porvenir de la humanidad.

Si bien es cierto que nuestro mundo actual es testigo de un constante y progresivo crecimiento demográfico, también lo es que igualmente aumentan las exigencias de cada individuo. La necesidad cada vez más imperiosa de alimentos, de productos industriales y de servicios no puede satisfacerse más que con la ayuda de la ciencia y de la técnica. Es especialmente evidente que no pueden lograrse estos objetivos universales si no aumenta rápidamente la producción de energía. Si se prevé ya que la producción de electricidad deberá duplicarse en el curso de los 10 a 15 años venideros para poder cubrir el consumo de los países muy industrializados, la tasa de crecimiento de esta producción deberá ser aún mucho más elevada en los países en desarrollo. No se podría hacer frente con éxito a una evolución de tal naturaleza si no se dispusiera de la energía nuclear. Es motivo de particular satisfacción poder comprobar que los difíciles problemas que se plantearon en un principio en la tecnología nuclear han podido resolverse en un plazo de tiempo relativamente corto. Así, pues, esta tecnología está ya hoy día en condiciones de contribuir en gran parte a cubrir las considerables nuevas necesidades de energía que son de esperar.

Sin embargo, muchos fenómenos que se han observado en estos últimos años han venido a demostrar que no debemos pensar exclusivamente en el crecimiento. La mayoría de las nuevas realizaciones técnicas no poseen solamente aspectos positivos. Basta con considerar la creciente contaminación de nuestro medio ambiente, que amenaza directamente tanto a las plantas como a los animales, por no hablar del atentado a nuestra propia salud. Todo esto suscita vivas inquietudes en amplios sectores de la población y una interrogación surge por doquier: ¿es que el progreso técnico no conduce a daños irreversibles de tal envergadura que no cabe compensarlos con las ventajas que ofrece? Esta es la razón de que la ciencia y la técnica susciten un escepticismo cada vez mayor. Sin embargo, al pensar así olvidamos con frecuencia que sin ellas no podríamos hacer frente a nuestros problemas. Sea como fuere, debemos hacer gala de un mayor espíritu de previsión que en lo pasado y debemos emprender todo lo necesario, si no para impedir, al menos para limitar los efectos perjudiciales. Cabe añadir que este punto de vista no es nuevo para los especialistas de la tecnología nuclear. En efecto, creo indispensable mencionar que desde un principio se ha exigido en las centrales nucleares, a través de las disposiciones legales, un elevado grado de seguridad y que se han emprendido profundos estudios acerca de los efectos de la radiactividad. Desde este punto de vista, el desarrollo de la energía nuclear puede servir de ejemplo a muchas otras tecnologías. Estos esfuerzos encaminados a determinar por anticipado los efectos de un nuevo producto deben ampliarse, en la medida de lo posible, a todos los procedimientos y consecuciones técnicos. Pero interesa especialmente no cejar en este empeño en la esfera de la energía nuclear, al mismo ritmo de los progresos que se realicen. En este sentido, las autoridades responsables deben poder contar con la ayuda incondicional de los mejores especialistas. Por ello, es de suma importancia que los investigadores no se limiten a obtener resultados interesantes desde el punto de vista científico. Les corresponde igualmente analizar las aplicaciones prácticas de tales resultados y estudiar aquellos perfeccionamientos que permitan impedir que se produzcan daños.

En este orden de ideas, me parece también necesario que el científico se dirija de vez en cuando al público en general para informarlo y casi diré que para tranquilizarlo. La utilización de la energía atómica con fines pacíficos y, concretamente, la construcción de centrales nucleares para la producción de electricidad son con frecuencia objeto de controversia. Por lo tanto, interesa facilitar a la opinión pública la información objetiva que necesita. Es muy de desear que el examen de las cuestiones relativas a la debida información del público permita desembocar en un enfoque general que sea de utilidad para todas las naciones interesadas.

La tecnología nuclear no puede permanecer estacionaria ante los notables éxitos obtenidos en nuestros días. Al precio de un esfuerzo considerable, la industria, firmemente apoyada por los centros gubernamentales de investigación, ha llegado a introducir en el mercado centrales nucleares que resultan económicamente rentables y capaces de competir, y que ya han dado prueba de su capacidad. Todos los que han contribuido a estas consecuciones son plenamente merecedores de nuestra gratitud, pero tanto las preocupaciones que suscita nuestro medio ambiente como igualmente el destino de las futuras generaciones son cosas que no nos permiten descansar sobre nuestros laureles. Antes bien, se insta urgentemente a los científicos a perfeccionar las técnicas nucleares de manera que sus aplicaciones puedan difundirse y reducirse aún más sus efectos sobre el medio circundante. Al decir esto, pensamos concretamente en la reducción de las necesidades que este tipo de instalaciones tiene en lo que respecta al agua de refrigeración, así como en la utilización de la energía nuclear para otras necesidades energéticas, como la calefacción, por ejemplo. La tecnología nuclear reduce notablemente la escala en que el aire y el agua participan en la producción de energía, en comparación con los demás métodos utilizados hasta la fecha. La importancia del aire y del agua puros para la salud del hombre, de los animales y de las plantas nos obliga pues a dirigir resueltamente nuestros pasos por este camino, aun cuando ello nos haya de costar algo.

Sin embargo, habrán de realizarse aún importantes trabajos de desarrollo para aprovechar plenamente estas posibilidades. Por otra parte, a largo plazo se impondrá la necesidad de utilizar mejor los combustibles nucleares, ya que es limitada la cantidad de que disponemos en nuestro planeta. El considerable esfuerzo preciso para alcanzar este objetivo será mucho menor si se trata de encontrar, en la medida de lo posible, una colaboración internacional que permita evitar una duplicación de trabajos inútilmente costosa. Precisamente en este sentido la Conferencia debería -y así lo deseamos- proporcionar la ocasión de adoptar nuevas iniciativas.

Suiza, país pequeño, sólo puede aportar naturalmente una modesta contribución. Sin embargo, nos sentimos orgullosos de poseer en nuestro país centrales nucleares en explotación comercial y de contar con una industria que suministra ya todo tipo de componentes de reactores, tanto en Suiza como en el extranjero. Reconocemos que estos logros se los debemos a los numerosos y fructíferos contactos que hemos podido entablar, en parte gracias a las primeras Conferencias de Ginebra, con los países que iban a la vanguardia de la tecnología nuclear. Basándonos en la experiencia adquirida en estos últimos años, creemos poder contribuir en notable medida a la revalorización de la energía nuclear en ciertos sectores escogidos de la investigación y de las realizaciones industriales; sin embargo, esta contribución sólo tendrá un auténtico valor si se integra dentro del marco de una colaboración internacional. Por ello, esperamos que uno de los frutos de esta Conferencia sea el de reforzar y multiplicar las relaciones, en el plano internacional, entre los especialistas de la tecnología nuclear y el de contribuir de esta manera a superar algunos de los muchos y graves problemas que hay que resolver para que la humanidad entera se vea liberada del hambre y de las privaciones.

Tradicionalmente, Suiza persigue fines pacíficos y humanitarios. Por ello nos afectan especialmente los objetivos fijados por las Naciones Unidas para la cuarta Conferencia de Ginebra, objetivos expresados en el subtítulo de esta Conferencia: «Beneficios para la Humanidad», y en el lema de la Exposición Científica Gubernamental «Atomos para el Desarrollo».

El hecho de que esta reunión esté presidida por una personalidad científica tan eminente como el Profesor Seaborg, el que los directivos de las instituciones responsables de las cuestiones de energía atómica, los de la economía eléctrica y los de la industria, así como numerosos científicos e ingenieros de primera fila y pertenecientes a tantas naciones se encuentren presentes aquí, son prenda de que la cuarta Conferencia constituirá, como las anteriores, uno de los sucesos más importantes en la historia del desarrollo de la energía nuclear.

En nombre del Consejo Federal, doy la bienvenida a los organizadores de la Conferencia y a todos los participantes. Sólo me resta desear a Vds., los expertos que en ella toman parte, que adquieran una útil información a través de fructuosos diálogos, pero también un mayor conocimiento de sus colegas, base de una mejor comprensión y por lo tanto de un entendimiento más profundo entre las naciones. Tengo el honor de transmitirles el saludo del pueblo suizo y los votos que las autoridades federales formulan por que la cuarta Conferencia de Ginebra sobre la Utilización de la Energía Atómica con Fines Pacíficos aporte una contribución valiosa e importante para el desarrollo del bienestar de todos los pueblos.

MESSAGE FROM U THANT, Secretary-General of the United Nations

Many of those who wrote about science and its application during the late 19th century looked upon it as a source of solutions to the age-old problems of mankind — want, hunger and sickness. They came to believe that science would free man from superstition, myth and ignorance. Science would permit man to approach his problems empirically and thus create a richer and more rewarding society.

We are now witnessing the initial phase of what one might call the scientific revolution, an era with almost unlimited horizons. But we must also acknowledge that optimism about what science can do for man has recently been somewhat tempered. Its benefits have opened new vistas, but have also brought about some unforeseen and unpleasant side-effects, the significance of which is now being carefully assessed.

The impact of the automobile on the economy, for instance, cannot be over-estimated, but we are now aware of the pollution problems caused by the enormous increase in the use of motor vehicles all over the world. Another problem which we are facing is insecticide residues, to avoid detrimental side-effects, new non-persistent agents have to be developed with highly specific effects. Among possible new techniques, nuclear techniques show promise.

Only by taking fullest advantage of science and technology will mankind be able to cope with the problems of population growth and its related demands on our diminishing resources and to achieve for great masses of people an improved standard of living at the same time.

Over the years the United Nations has given growing importance to its role in promoting scientific co-operation throughout the world. Science recognizes no frontiers, and scientists themselves are essentially internationalists in their outlook and conscious of the vital importance of international co-operation. Science is, therefore, an invaluable means of breaking down political barriers between nations, particularly barriers to the free exchange of information, which we all know is essential for the advancement of science. The first three international conferences on peaceful uses of atomic energy in 1955, 1958 and 1964 were eminently successful in removing artificial restraints that had been imposed on scientific communication. They, therefore, played a valuable political as well as a scientific and economic role.

If the first objective of freedom in the quest for knowledge has been largely achieved, the equally important aim of accelerating the transfer of science and technology to the developing countries is still far from being fulfilled. A major initial step was taken at the United Nations Conference on the Applications of Science and Technology for the Benefit of Less-Developed Areas in 1963. This is not the place to refer to the many endeavours of the United Nations and of its agencies to promote the process of transfer of technology, but it is appropriate to recall to this Conference the comprehensive report the United Nations produced in 1969 on the contribution of nuclear energy to the economic and scientific advancement of the developing countries.

It is also essential to direct more of the effort of science and technology to solving the problems which some of its applications have created. The United Nations Conference in Stockholm in June 1972 will be the first major international meeting to consider the total impact of technology on the human environment.

Nuclear energy now being capable of making a growing contribution to the well-being of the developing countries, it is fitting that this Conference, even more than its predecessors, should be designed to be of interest to economists, planners and statesmen as well as to scientists themselves. I was pleased to learn that many of the papers which will be presented during the Conference which is being opened here today will highlight potential benefits as well as potential dangerous side-effects. They will take into account the interactions between atomic energy and other related scientific fields. They will also give information on cost and financing of nuclear installations which will help individual nations to decide which benefits of nuclear energy will be most useful to them and when they should be introduced.

I understand, for example, that there are many areas of the world in which it would not yet be economic or practicable to construct nuclear power plants, usually because the power demand is still too small to permit the construction of economically sized nuclear power plants or because there are still rich, untapped resources of conventional power available. I am confident that by the end of this Conference, attending government officials will have been able to secure much of the data on which to decide when and under what circumstances it would be appropriate for their government to begin a nuclear power program.

As this Conference begins I would like to take the opportunity to record our debt of gratitude to the scientists who presided with such success and distinction over the first three Geneva Conferences: Dr. Homi Bhabha, who is alas no longer with us, Dr. Francis Perrin and Professor Vassily Emelyanov, former chairman of the USSR State Committee for Atomic Energy who, I am very pleased to say, is attending this opening ceremony.

I wish also to pay a special tribute to the eminent members, both past and present, of the United Nations Scientific Advisory Committee who have unstintingly given their time and their best efforts in organizing these four "Geneva Conferences". Dr. Rabi, the chief architect of the first Conference will be one of the speakers this morning. The idea of a conference of this type originated, I have been told, with Dr. Rabi and Mr. Lewis Strauss in 1953. The Conferences have resulted in greatly increased scientific co-operation in this field and have provided a considerable stimulus to the work of the International Atomic Energy Agency. A beneficial fall-out has been the close working collaboration between the United Nations and the Agency in organizing the meetings.

I have mentioned unwanted side-effects of science and technology. In no other field is this more striking than in nuclear technology, where the potential energy of the atom was first demonstrated in the form of a military weapon. Problems arising from the ambivalence of nuclear technology have not ceased to be the object of intensive work in the United Nations and its organs. I am pleased that some progress in controlling these problems has been made, for example by the Moscow Treaty of 1963 and the Non-Proliferation Treaty of 1968. I have also been encouraged by the success of the IAEA in working out safeguards which are both effective and acceptable and which were endorsed with virtual unanimity by the 50 interested nations that took part in the task. It is, therefore, also appropriate that this Conference will be examining the technical questions of safeguards which are indissolubly linked with the growth and spread of nuclear power.

These achievements do not mean that all is well, and I regret that weapons testing continues. I sincerely hope that an agreement on a complete test ban will be reached in the near future in the Conference of the Committee on Disarmament at present meeting in Geneva.

Nuclear energy properly safeguarded and safely used can bring untold benefits to mankind. The responsibility for its advancement, its safeguarding and its safe use will rest to a considerable extent with the persons who are attending this Conference. I trust that you will all leave this Conference, scientist and non-scientist alike, with a fuller knowledge of what has been accomplished to date by peaceful nuclear energy and what it is likely to accomplish by the end of the twentieth century.

I wish your Conference every success.

Translations into French, Russian and Spanish follow.

MESSAGE DE U THANT, Secrétaire général de l'Organisation des Nations Unies

Beaucoup d'auteurs d'ouvrages consacrés à la science et à ses applications à la fin du siècle dernier pensaient qu'elles permettraient de résoudre les éternels problèmes de l'humanité: la misère, la faim et la maladie. Ils espéraient bien que la science libérerait l'homme des superstitions, des mythes et de l'ignorance. La science devait permettre à l'homme de résoudre ses problèmes empiriquement et de créer ainsi une société plus riche et plus féconde.

Nous assistons maintenant à la phase initiale de ce qu'on pourrait appeler la révolution scientifique; une ère qui nous ouvre des horizons presque illimités. Mais il faut aussi reconnaître que l'optimisme au sujet de ce que la science peut apporter à l'homme s'est depuis peu légèrement atténué. Ses heureux résultats nous ont ouvert de nouvelles perspectives, mais en même temps ils ont produit des effets secondaires imprévus et décevants dont on étudie actuellement la signification avec le plus grand soin.

Par exemple, l'incidence de l'automobile sur l'économie ne peut pas être surestimée, mais on connaît aussi les problèmes posés par la pollution à la suite de l'augmentation énorme du nombre de véhicules à moteur en circulation dans le monde entier. Autre problème: celui des résidus d'insecticides; pour éviter les effets secondaires néfastes, il faut mettre au point des agents non persistants à caractère extrêmement spécifique. Parmi les nouvelles méthodes possibles, les techniques nucléaires sont très séduisantes.

Ce n'est qu'en tirant pleinement parti de la science et de la technologie que l'humanité pourra résoudre le problème de la poussée démographique et des demandes qu'elle imposera sur nos ressources en diminution et assurer en même temps un niveau de vie meilleur à de grandes masses de population.

Au cours des ans, les Nations Unies ont donné une importance toujours croissante à leur rôle de promoteur de la coopération scientifique dans le monde entier. La science ne connaît pas de frontières et les savants eux-mêmes ont une conception essentiellement internationaliste et ont conscience de l'importance capitale de la coopération internationale. La science contribue par conséquent, et d'une manière inestimable, à faire tomber les barrières politiques entre les nations, en particulier celles qui s'opposent au libre échange des informations qui, nous le savons tous, est indispensable au progrès de la science. Les trois premières Conférences internationales sur l'utilisation de l'énergie atomique à des fins pacifiques, en 1955, 1958 et 1964, ont eu pour principal mérite de supprimer les restrictions qui avaient été artificiellement imposées à la communication scientifique. Elles ont donc joué un rôle vraiment utile tant sur le plan politique que sur le plan scientifique et économique.

Si l'on a atteint en grande partie ce principal objectif, la liberté dans la recherche de la connaissance, un objectif tout aussi important, l'accélération du transfert de la science et de la technologie aux pays en voie de développement, est encore loin de l'être. Un premier pas considérable a été fait à la Conférence des Nations Unies sur les applications de la science et de la technique au profit des pays sous-développés en 1963. Il n'y a pas lieu de rappeler ici les nombreux efforts déployés par l'Organisation des Nations Unies et ses institutions spécialisées pour promouvoir ce transfert des connaissances technologiques, mais il faut rappeler à la Conférence le rapport complet publié par les Nations Unies en 1969 sur la contribution de l'énergie nucléaire au progrès économique et scientifique des pays en voie de développement.

Il est également indispensable que la science et la technique soient mieux utilisées pour résoudre les problèmes qu'ont créés certaines de leurs applications. La Conférence que les Nations Unies organiseront en juin 1972 à Stockholm sera la première grande réunion internationale chargée d'étudier toutes les incidences de la technologie sur le milieu humain.

L'énergie nucléaire est désormais capable de contribuer de plus en plus au bien-être des pays en voie de développement; c'est donc à juste titre que cette quatrième Conférence, plus encore que celles qui l'ont précédée, doit intéresser les économistes, les planificateurs et les hommes politiques tout autant que les scientifiques. J'ai été heureux d'apprendre que nombre de mémoires qui seront présentés pendant cette Conférence mettront en lumière non seulement les bienfaits que l'on peut attendre de l'énergie atomique, mais aussi les effets secondaires dangereux qui peuvent en résulter. Ils tiendront compte des interactions de l'énergie atomique et d'autres domaines scientifiques connexes. Ils donneront également des renseignements sur les coûts et le financement des installations nucléaires, ce qui permettra à chaque pays de voir quels sont les avantages de l'énergie nucléaire qui lui seront le plus utiles et quand il pourra en tirer le meilleur profit.

Je sais par exemple qu'il y a encore bien des régions du monde où il ne serait pas à l'heure actuelle économiquement raisonnable ou pratique de se doter de centrales nucléaires, le plus souvent parce que la demande d'énergie y est encore trop faible pour justifier la construction de centrales nucléaires de dimensions rentables, ou parce qu'elles possèdent encore des ressources abondantes non exploitées d'énergie classique. Je ne doute pas qu'à la fin de la Conférence les délégations disposeront de données plus complètes pour décider si, et dans quelles circonstances, leurs gouvernements pourront lancer des programmes énergétiques nucléaires.

Au moment où commence cette Conférence, je voudrais profiter de l'occasion qui m'est offerte de dire toute la gratitude dont nous sommes redevables à l'égard des hommes de science qui ont présidé avec un si grand succès et une telle distinction les trois premières Conférences de Genève: M. Homi Bhabha qui, hélas, n'est plus parmi nous, M. Francis Perrin et M. Vassily Emelyanov, ancien président du Comité d'Etat pour l'énergie atomique de l'Union soviétique, qui, j'ai le plaisir de le relever, assiste à cette cérémonie d'ouverture.

Je tiens aussi à rendre particulièrement hommage à tous les membres éminents du Comité consultatif scientifique de l'Organisation des Nations Unies qui ont inlassablement consacré leur temps et le meilleur d'eux-mêmes à l'organisation de ces quatre Conférences de Genève. Monsieur Rabi, le maître d'œuvre de la première Conférence, sera parmi les orateurs qui prendront la parole ce matin. Je crois savoir que c'est M. Rabi et M. Lewis Strauss qui, en 1953, ont eu les premiers l'idée d'une conférence de ce genre. Ces conférences ont permis d'accroître la coopération scientifique d'une manière considérable et ont beaucoup stimulé les travaux de l'Agence internationale de l'énergie atomique. Une conséquence heureuse a été la collaboration de travail étroite de l'Organisation des Nations Unies et de l'Agence pour la préparation de ces réunions.

J'ai parlé des effets secondaires indésirables de la science et de la technologie. Dans aucun autre domaine cela n'est plus frappant qu'en matière de technologie nucléaire, puisque l'énergie contenue dans l'atome s'est manifestée pour la première fois sous la forme d'une arme. Les problèmes posés par l'ambivalence de la technologie nucléaire n'ont pas cessé de faire l'objet d'une intense activité à l'Organisation des Nations Unies et dans ses organes. Je suis heureux de constater que certains progrès ont été faits vers la solution de ces problèmes, par exemple par la conclusion du Traité de Moscou en 1963 et celle du Traité sur la non-prolifération en 1968. Je vois aussi un encouragement dans le succès obtenu par l'Agence internationale de l'énergie atomique dans l'élaboration de garanties à la fois efficaces et acceptables, auxquelles ont souscrit la quasi-unanimité des 50 nations qui ont participé à cette tâche. C'est donc à juste titre que la Conférence étudiera aussi les modalités techniques des garanties qui sont indissolublement liées à l'essor et à la diffusion de l'énergie nucléaire.

Les résultats obtenus ne signifient pas que tout est parfait et je regrette que les essais d'armes se poursuivent. J'espère sincèrement que l'on aboutira bientôt à une interdiction complète des essais atomiques à la Conférence du Comité du désarmement qui se réunit actuellement à Genève.

L'énergie nucléaire assortie de garanties appropriées et utilisée dans des conditions sûres peut apporter des bienfaits inouïs à l'humanité. La responsabilité de ses progrès, de l'application des garanties et de son utilisation en toute sécurité incombe dans une mesure considérable à ceux qui participent à la Conférence. Je suis convaincu que tous, les hommes de science comme les non-spécialistes, partiront d'ici avec une connaissance plus complète de ce que l'énergie nucléaire pacifique a permis jusqu'ici de réaliser et ce qu'elle pourra accomplir d'ici à la fin du 20ème siècle.

Je souhaite à la Conférence le plus grand succès possible.

ПОСЛАНИЕ У ТАНА, Генерального Секретаря Организации Объединенных Наций

Многие из тех, кто писал о применении науки в конце XIX века, рассматривали ее как источник решения вековых проблем человечества – бедности, голода и болезней. Они пришли к выводу, что наука освободит человека от предрассудков, суеверия и неграмотности. Наука позволит человеку решить эмпирически эти проблемы и, таким образом, создать более совершенное общество.

Сейчас мы являемся свидетелями начальной стадии процесса, который может быть назван научной революцией, эрой с почти неограниченными горизонтами. Однако мы должны также признать: оптимизм в отношении того, что наука может сделать для человека, недавно в некоторой степени уменьшился. Достижения науки открыли новые перспективы, но вместе с тем принесли некоторые непредвиденные и неприятные побочные эффекты, которые сейчас тщательно изучаются.

Влияние автомобиля на экономику, например, нельзя переоценить, но мы сейчас хорошо знаем о проблемах загрязнения, вызванных значительным увеличением использования автотранспорта в мире. Другой проблемой, с которой мы сталкиваемся, являются остатки инсектицидов; чтобы избежать вредных побочных эффектов, необходимо разработать новые нестойкие вещества с особыми свойствами. Среди возможных новых методов наиболее перспективными показали себя ядерные методы.

Только путем самого широкого использования преимуществ науки и техники человечество сможет решать проблемы роста населения и связанные с ним проблемы удовлетворения потребностей в наших истощающихся ресурсах и в то же время достичь для громадного количества людей высокого уровня жизни.

Со временем Организация Объединенных Наций стала играть более важную роль в содействии международному научному сотрудничеству. Наука не признает границ, а сами ученые являются, по существу, интернационалистами в своих взглядах и понимании большой важности международного сотрудничества. Наука, поэтому, является неоценимым средством ломки политических барьеров между народами, особенно в области свободного обмена информацией, которая, как мы все знаем, совершенно необходима для научного прогресса. Первые три Международные конференции по использованию атомной энергии в мирных целях, проходившие в 1955, 1958 и в 1964 годах, были весьма успешными в устранении искусственных ограничений на пути установления научных связей. Поэтому эти Конференции играли большую роль как в политическом, так и в научном и экономическом плане.

Если первая цель – достижение свободного обмена знаниями – была, в основном, осуществлена, то такая же важная задача ускорения передачи научных и технических знаний развивающимся странам еще далека от выполнения. Начало этому было положено на конференции Организации Объединенных Наций по применению науки и техники для нужд менее развитых районов мира, состоявшейся в 1963 году. Не стоит касаться деятельности Организации Объединенных Наций и ее учреждений, направленной на содействие прогрессу в области передачи технологии, однако на нынешней Конференции следует упомянуть о всеобъемлющем докладе, подготовленном Организацией Объединенных Наций в 1969 году, по вопросу о вкладе ядерной энергии в экономические и научные достижения развивающихся стран.

Следует также приложить больше усилий в области науки и техники, с тем чтобы решить проблемы, которые возникли в связи с развитием некоторых направлений. Конференция Организации Объединенных Наций, которая состоится в Стокгольме в июне 1972 года, будет первым большим международным совещанием, где будут рассмотрены все виды воздействия техники на окружающую человека среду.

В настоящее время ядерная энергия может внести большой вклад в дело улучшения благосостояния развивающихся стран и необходимо, чтобы эта Конференция, по сравнению с предшествующими, была организована с учетом интересов экономистов, плановиков, политических деятелей, а также самих ученых. Мне было приятно узнать, что во многих докладах, которые будут представлены на открывающейся здесь сегодня Конференции, будет дан обзор потенциальных благ, а также возможного побочного вредного влияния ядерной энергии. При этом будет учтена взаимосвязь между атомной энергией и другими соответствующими областями науки. В докладах будет представлена информация о стоимости и финансировании сооружения ядерных установок, которая поможет отдельным странам решить, какие выгоды можно извлечь от использования ядерной энергии и когда следует приступить к ее применению.

Я понимаю, например, что в мире существует много районов, где по экономическим или практическим соображениям еще невозможно приступить к строительству атомных электростанций. Как правило, это объясняется тем, что потребность в энергии все еще слишком мала, чтобы можно было строить атомные электростанции экономически выгодного размера, или тем, что еще имеются богатые неиспользованные ресурсы обычных источников энергии. Я уверен, что по завершении работы Конференции присутствующие на ней представители правительств смогут получить много данных, которые помогут им решить, когда и при каких условиях для их правительств будет целесообразно приступить к осуществлению программ в области ядерной энергетики.

В связи с началом работы Конференции, мне бы хотелось воспользоваться случаем, чтобы выразить нашу признательность ученым, которые председательствовали с таким успехом на первых трех Женевских Конференциях: д-ру Хоми Баба, которого больше нет с нами, д-ру Френсису Перрену, профессору Василию Емельянову, бывшему председателю Государственного Комитета по использованию атомной энергии СССР, который, и мне приятно отметить это, присутствует на церемонии ее открытия.

Я хотел бы также отдать дань уважения членам, как прошлым, так и настоящим, Научно-консультативного комитета Организации Объединенных Наций, которые бескорыстно жертвовали своим временем и отдали все свои силы для организации четырех "Женевских Конференций". Д-р Раби, инициатор созыва первой Конференции, будет одним из докладчиков на сегодняшнем утреннем заседании. Идея созыва такой конференции, как мне говорили, была высказана д-ром Раби и г-ном Льюисом Штраусом в 1953 году. Проведение Конференций способствовало расширению научного сотрудничества в этой области и значительной активизации деятельности Международного агентства по атомной энергии. Конференции способствовали более тесному сотрудничеству между Организацией Объединенных Наций и МАГАТЭ в проведении научно-технических совещаний.

Я упомянул о нежелаемых побочных эффектах науки и техники. Ни в одной из других областей это не проявилось так, как в ядерной технике, где потенциальная энергия атома была впервые продемонстрирована в виде оружия. Проблемы, возникающие в результате двойственности применения ядерной энергии, всегда являлись и являются объектом интенсивной работы Организации Объединенных Наций и ее отдельных учреждений. Весьма приятно, что был достигнут определенный прогресс в решении этих проблем, как например, заключение Московского договора 1963 года и Договора о нераспространении ядерного оружия 1968 года. Меня вдохновляет также успех МАГАТЭ в разработке эффективной и приемлемой системы гарантий, которая была единодушно одобрена 50-ю заинтересованными государствами, принявшими участие в ее подготовке. Поэтому необходимо, чтобы настоящая Конференция изучила технические аспекты гарантий, непосредственно связанные с развитием ядерной энергетики.

Эти достижения не означают, что у нас все в порядке, и я сожалею, что испытания ядерного оружия продолжаются. Я искренне надеюсь, что соглашение о полном запрещении испытаний ядерного оружия будет достигнуто в недалеком будущем на Комитете по разоружению, который в настоящее время работает в Женеве.

Ядерная энергия надлежащим образом поставленная под гарантии и применяемая при соблюдении норм безопасности, может принести человечеству огромную пользу. Ответственность за ее развитие, постановку под гарантии и безопасное применение в значительной степени будет возложена на тех, кто сейчас присутствует на этой Конференции. Я уверен, что все вы, специалисты, работающие в различных областях науки и техники, разъедетесь после этой Конференции с полным пониманием того, что достигнуто на сегодня в области мирного использования ядерной энергии и что, очевидно, будет достигнуто к концу двадцатого века.

Я желаю вашей Конференции всяческих успехов в работе.

MENSAJE DE U THANT,
Secretario General de las Naciones Unidas

Muchos de los autores que a finales del siglo XIX escribieron en torno a la ciencia y a sus aplicaciones juzgaron que iba a ser la panacea de los problemas que la humanidad tenía planteados desde tiempos inmemoriales: la necesidad, el hambre y la enfermedad. Llegaron a creer que la ciencia liberaría al hombre de la superstición, del mito y de la ignorancia, y que le permitiría abordar sus problemas de una forma empírica, creando así una sociedad más próspera y que ofrecería mayores oportunidades.

Hoy día, somos testigos de la fase inicial de lo que podríamos llamar «la revolución científica», una era cuyos horizontes difícilmente pueden vislumbrarse. Ahora bien, hemos de reconocer también que el optimismo que despierta lo que la ciencia puede hacer por el hombre se ha enfriado un tanto. Los beneficios que reporta han abierto nuevos panoramas, pero también han acarreado ciertas consecuencias secundarias, imprevistas y desagradables, cuya trascendencia se está sopesando minuciosamente en la actualidad.

No pueden ponderarse nunca lo bastante, por ejemplo, las repercusiones del automóvil sobre la economía, pero hoy en día nos damos cuenta de los problemas de contaminación que ha traído consigo la enorme difusión de los vehículos de motor en el mundo entero. Otro problema al que hay que hacer frente es el de los residuos de los insecticidas: para impedir que haya efectos secundarios nocivos, hay que encontrar nuevos agentes de acción no persistente y de efectos muy específicos. Entre los nuevos métodos posibles, las técnicas nucleares ofrecen alentadoras perspectivas.

Sólo si aprovecha al máximo las ventajas que ofrecen la ciencia y la tecnología, podrá enfrentarse la humanidad con los problemas de la explosión demográfica y con los gravámenes que ésta impone sobre los decrecientes recursos del mundo y conseguir al mismo tiempo un nivel de vida más elevado para grandes masas de la población.

A lo largo de los años, las Naciones Unidas han venido concediendo creciente importancia al papel que les corresponde en el fomento de la cooperación científica en el mundo entero. La ciencia no conoce fronteras y los propios científicos tienen un espíritu esencialmente internacional y conciencia de la vital importancia que entraña dicha cooperación internacional. Por lo tanto, la ciencia constituye un medio de incalculable valor para derribar las fronteras políticas entre las naciones, sobre todo las barreras que se oponen al libre intercambio de información, que, como todos sabemos, es esencial para el progreso de la ciencia. Las tres primeras conferencias internacionales sobre la utilización de la energía atómica con fines pacíficos celebradas en 1955, 1958 y 1964 lograron suprimir ciertas restricciones artificiales que se habían impuesto a la comunicación en el campo científico. Desempeñaron, por tanto, un importante papel, tanto político como científico y económico.

Si bien se ha alcanzado en gran parte el primer objetivo de la libertad en la búsqueda del conocimiento, está aún lejos de lograrse otra meta no menos importante, que es acelerar la transmisión de ciencia y de tecnología a los países en desarrollo. Se dio un paso inicial de gran importancia en la Conferencia de las Naciones Unidas sobre la aplicación de la ciencia y la tecnología en beneficio de las regiones menos desarrolladas, celebrada en 1963. No es éste el lugar oportuno para citar los numerosos esfuerzos que las Naciones Unidas y los organismos de su sistema han emprendido con miras a fomentar el proceso de difusión de la tecnología, pero procede recordar en esta Conferencia el amplio informe que las Naciones Unidas prepararon en 1969 sobre la aportación de la energía nuclear al progreso económico y científico de los países en desarrollo.

Es igualmente esencial intensificar los esfuerzos de la ciencia y la tecnología hacia la resolución de los problemas a que han dado lugar algunas de sus aplicaciones. La Conferencia que las Naciones Unidas celebrará en junio de 1972 en Estocolmo constituirá la primera reunión internacional de alto rango en la que se estudiarán de un modo global las repercusiones de la tecnología sobre el medio humano.

Ahora que la energía nuclear está en condiciones de aportar una creciente contribución al bienestar de los países en desarrollo, procede que esta Conferencia, más aún que las precedentes, trate de interesar tanto a los economistas, planificadores y a hombres de estado como a los propios científicos. He visto con satisfacción que un gran núcleo de las memorias que se presentarán en el curso de la Conferencia que hoy se inaugura aquí pondrán de relieve tanto los posibles beneficios como los efectos peligrosos secundarios potenciales. Tendrán presentes las relaciones mutuas entre la energía atómica y otros campos científicos afines. Facilitarán asimismo información sobre el costo y financiamiento de las instalaciones nucleares, que ha de servir de ayuda a las distintas naciones en el momento de decidir cuáles de los beneficios de la energía nuclear les han de ser más útiles y la fecha en que deben introducirse.

Entiendo, por ejemplo, que hay muchas regiones en el mundo en las que no sería todavía económico o viable construir centrales nucleoeléctricas, generalmente debido a que la demanda de energía es todavía demasiado pequeña para permitir la construcción de centrales nucleoeléctricas de dimensiones económicas o porque se dispone aún de ricos recursos de energía clásica todavía sin explotar. Tengo la seguridad de que al término de la presente Conferencia, los funcionarios gubernamentales que a ella asisten habrán podido reunir muchos de los datos que precisan para decidir en qué circunstancias sería oportuno que sus gobiernos pongan en marcha un programa de energía nucleoeléctrica.

Al comenzar esta Conferencia, aprovecho la oportunidad para hacer constar nuestra deuda de gratitud a los científicos que han presidido con tal acierto y distinción las tres primeras Conferencias de Ginebra: el Dr. Homi Bhabha que desgraciadamente ya no se encuentra entre nosotros, el Dr. Francis Perrin y el Prof. Vassily Emelyanov, ex-presidente del Comité Estatal de la Unión Soviética para la Energía Atómica quien – y es un placer para mí anunciarlo – asiste a esta ceremonia de apertura.

Deseo igualmente tributar un especial homenaje a los eminentes miembros, tanto actuales como antiguos, del Comité Científico Consultivo de las Naciones Unidas que no han regateado ni su tiempo ni sus mejores esfuerzos en la organización de estas cuatro «Conferencias de Ginebra». El Dr. Rabi, arquitecto principal de la primera Conferencia será uno de los oradores que harán uso de la palabra esta mañana. Según se me ha informado, la idea de una conferencia de este tipo partió en 1953 del Dr. Rabi y de Mr. Lewis Strauss. Estas Conferencias han dado lugar a una cooperación científica mucho mayor en esta esfera y han estimulado considerablemente la labor del Organismo Internacional de Energía Atómica. Uno se sus frutos beneficiosos ha sido la estrecha colaboración de trabajo entre las Naciones Unidas y el OIEA en la organización de las reuniones.

He mencionado ya los efectos secundarios perniciosos de la ciencia y la tecnología. En ninguna otra esfera puede verse este hecho con mayor claridad que en la tecnología nuclear, en la que la energía potencial del átomo se demostró por primera vez en forma de arma militar. Los problemas que se derivan de la ambivalencia de la tecnología nuclear no han cesado de ser objeto de intensos trabajos en las Naciones Unidas y en sus órganos. Es para mí una satisfacción que se hayan logrado algunos progresos en el control de estos problemas, por ejemplo, en virtud del Tratado de Moscú de 1963 y del Tratado sobre la no proliferación de 1968. Me siento también alentado por el éxito que ha logrado el OIEA en la elaboración de unas salvaguardias, eficaces y aceptables, que han sido refrendadas prácticamente por unanimidad por las 50 naciones interesadas que participaron en esta labor. Por consiguiente, procede también que esta Conferencia estudie los aspectos técnicos de las salvaguardias que están indisolublemente vinculados con el desarrollo y la difusión de la energía nucleoeléctrica.

Estas consecuciones no quieren decir que todas las perspectivas sean favorables, y lamento que prosigan las pruebas con armas. Sinceramente confío en que se llegará en un futuro próximo a una proscripción completa de estas pruebas en la Conferencia del Comité de Desarme que actualmente se está reuniendo en Ginebra.

La energía nuclear, debidamente salvaguardada y empleada en condiciones de seguridad, puede reportar beneficios sin precedente a la humanidad. En gran parte, las personas que asisten a esta Conferencia tienen la responsabilidad del progreso de dicha energía, de que se le apliquen salvaguardias y de que se emplee sin riesgos. Estoy seguro de que todos, tanto los científicos como los que no lo son, tendrán al término de esta Conferencia un conocimiento más completo de lo que se ha conseguido hasta la fecha en la esfera de la utilización de la energía nuclear con fines pacíficos y de lo que es probable que se logre hasta el final del siglo XX.

Deseo todo género de éxitos a esta Conferencia.

OPENING ADDRESS

Glenn T. SEABORG
President of the Conference

I embark on this office with great humility, some pride, and an overwhelming sense of hope and excitement for the future of the still new science on which we have come here to confer.

I come with humility because a conference of this magnitude cannot fail to call to mind the tremendous debt which we of the present owe to the towering intellects of the past whose accomplishments made possible the fantastic age of science in which we live. Man's acquisition of knowledge has been a continuous process and even from the vantage point of history we can identify only with difficulty the truly crucial discoveries and their authors. When we examine even the most dramatic and far-reaching contributions, we find that they are built on the foundations of previous thinkers, who often came remarkably close to the summit which was later gained.

Our field of nuclear energy is no exception. No history of its origins would omit the revolutionary contributions of Einstein, of Rutherford, of Bohr and, of course, of Fermi, Hahn, Meitner, and Strassmann, who unlocked the final doorway to the realization of practical energy from the nucleus of the atom.

I come with some pride because my own country has, I believe, done its share not only in developing the peaceful uses of nuclear energy, but – equally important – in fostering and applying the concept that these benefits should be available to all nations. I hope that I can be pardoned if I observe that this conference stands as a tribute to, among others, the late President Dwight D. Eisenhower, whose proposals before the United Nations General Assembly on 8 December 1953 initiated the Atoms for Peace program, and who later personally suggested the convening of the first Geneva Conference.

I come with hope and excitement because I believe we are still on the threshold of an era of great discovery and of consolidation and exploitation of past discoveries, an era which, by the end of this century, will bring from nuclear energy unimagined benefits that will directly improve the quality of life for the greater part of the six to seven billion people who will then inhabit the earth.

Inevitably, occupying this podium leads one to review the wisdom of those who served before as Presidents of these conferences. Only Homi Bhabha, in 1955, had the well-deserved honour but the far harder task, of speaking first. The choice of Dr. Homi Bhabha as President of the first Geneva Conference was an inspired one. Not only did it do honour to this outstanding man of science and government, but by drawing a president from the developing world it emphasized the universality of both the capabilities and the needs in the field of nuclear energy. Building on the magnificent foundation created by Dr. Bhabha, India has moved ahead to become the first of the developing countries to apply nuclear energy as a primary power source. Thus Dr. Bhabha correctly prophesied that nuclear energy was of importance not only to the industrialized nations of the world but to the developing nations as well. Indeed, his basic theme was that if the vast majority of the world's population now living in the developing nations is to achieve the energy-dependent standard of living already enjoyed by the industrialized countries, nuclear power must enjoy widespread application.

Bhabha also made the then sensational prediction that within two decades we would achieve the production of useful energy from fusion, thereby opening the way to the use of deuterium from the sea as a virtually limitless source of energy. With commendable scientific caution, Dr. Bhabha predicted only that, within this time, a method would be found for liberating fusion energy in a controlled manner. He did not forecast when this discovery would be forged into an economic and reliable commercial energy source. While time is running out for the achievement of the goal predicted by Dr. Bhabha, I will join him in the prophet's role and say that I do not rule out that a positive energy production from fusion might still be achieved by 1975, and almost certainly will be reached by 1980. If that comes to pass, Dr. Bhabha, whose life was tragically ended near this city while en route to an international atomic energy meeting, will be even more established as a man of great scientific foresight.

The President of the Second Geneva Conference was an equally distinguished nuclear pioneer from France - Francis Perrin. Faced with the knowledge that the hoped-for goal of economic nuclear power was more difficult than had been realized earlier, the Second Geneva Conference was an occasion of comparative pessimism. Professor Perrin correctly foresaw that at first nuclear power would be principally useful in the already highly industrialized countries. The phase that he predicted did indeed take place, but, as nuclear power is in operation or being installed in such nations as India, Pakistan, Korea, China, Argentina, and Brazil, we see this phase drawing to an end. By 1980, nuclear power plants are likely to be in operation in more than 15 countries currently considered as developing nations under United Nations criteria.

Professor Perrin stressed as one of the most important aspects of these conferences their function in removing the veils of secrecy from an important area of science, and opening up hitherto closed channels of communication. This was profoundly correct and was indeed a major achievement of the two earliest Geneva Conferences. The unclassified status of virtually all fields of importance to the peaceful uses of nuclear energy is now well established and taken for granted, but unfortunately the earlier classification for military purposes has in some instances been replaced by controls imposed in the name of commercial secrecy. As a nation whose well-being is based largely on the contributions of private enterprise, we do not doubt the importance of offering adequate rewards for private scientific initiative. The important and difficult point is to achieve the proper balance between widespread dissemination of information during the early phases of research and development on the one hand, and proper opportunity for the protection of detailed and advanced technology on the other hand. As a scientist who believes, as did Professor Perrin, that secrecy stultifies progress, I fear that the secrecy which is practiced in the name of commercial privacy can be as debilitating as that which was earlier practiced in the name of national security. If this Conference provides the same incentive for the publication of some information now considered proprietary as did earlier conferences for the publication of classified information, it will, indeed, serve a valuable purpose.

The Third Geneva Conference was a historic landmark. It clearly marked the beginning of the era of economic nuclear power. Indeed, it was possible to say at that conference, which I had the honor of attending as chairman of the United States delegation and for which I delivered the summary speech, that an "economic breakthrough" had been achieved in nuclear power technology. With more than 150 million kilowatts of nuclear power capacity now in operation, under construction, or on order in the world today, few, if any, can doubt the accuracy of that statement.

The President of the last Geneva Conference was my friend and colleague, Professor V.S. Emelyanov of the Soviet Union. In his excellent review of the status of nuclear science and technology, Professor Emelyanov wisely called attention to the importance of international co-operation and made special mention of the growing role and effectiveness of the International Atomic Energy Agency in fostering this co-operation. He also made the first reference to the exciting new prospects for the use of nuclear energy for the large-scale desalting of sea-water — an application which I believe we will see come into use well within our lifetime.

As I look back on the progress in nuclear science and technology, it seems to me that one fascinating fact stands out above all others. This field of science is perhaps the first, and certainly the largest, where progress did not "just happen". Great progress had been made in many other fields of science and technology before nuclear energy arrived on the scene. But in a general sense, progress in those fields came about as a result of the actions and interactions of many different and essentially independent programs and people. In the field of nuclear energy, for the first time, the pace of progress in a whole vast field of science was largely set as the result of the deliberate decisions and actions of governments and — at the outset — only a few of them. In keeping with this approach, even the international co-operation which brings us together here owes its existence to the deliberate decisions and actions of governments rather than to the more traditional channels of scientific co-operation.

I believe it has been an exciting and, on the whole, a highly successful experiment with vast ramifications outside its immediate boundaries. While human ingenuity remains the indispensable ingredient to scientific progress, our experience in nuclear energy has shown unmistakably that the pace and even the direction of development can be profoundly affected by the large-scale intervention of governmental policies and resources.

In an even more complete sense, this experience has been repeated in the field of space science. But I believe that nuclear energy remains not only the model, but the more magnificent example for the time being, since here we have seen the forced-draft development of a field of science and technology which has major and immediate practical and economic impact for a large proportion of the world's countries.

Perhaps the only historical model for what has taken place in nuclear energy in the last 25 years is an earlier age of discovery, when far-sighted governments of that day undertook the exploration not just of a new world of science, but of a new world across the seas. Perhaps, in the eyes of history, the consequences of our explorations in the new world of nuclear energy will match in significance those of that earlier age of discovery.

I have chosen to speak in very general terms of the background of our conferences and of the science which they treat. The real message of this

Conference, the story of seven years of progress since we last met in 1964, will necessarily and properly unfold from the Proceedings which will follow. But I will not entirely forego the opportunity to speak, as have my predecessors, of what has happened, and what we might expect to see happen in the years ahead.

The dramatic background for our Conference — one to which I have already pointed — is that nuclear power is no longer "around the corner", but here. The total investment in the 150 million kilowatts of power plants to which I referred will exceed $45 billion when they are completed in 1980 and, of course, by that time many more plants totalling many millions of additional kilowatts will be well along towards completion. The power which these plants will generate in 1980 will almost equal the whole generating capacity of the USA at the time of our last conference. And by the turn of the century, there seems little doubt that half of the US total of more than 1500 million kilowatts will be nuclear, with a similar pattern of growth taking place in other major regions of the world.

But despite this success — one which I believe deserves the overworked term of phenomenal — much remains to be done and problems still beset our burgeoning new industry. The great remaining task for nuclear power technology is to unlock the massive energy resources of the fertile isotopes — uranium-238 and thorium — by completing the development of an economic breeder reactor. This goal is now occupying the energies and resources of most of the world's major nuclear power development programs. I do not doubt that it will be achieved, but the costs to be met and the time required will be great. I believe that we will see the introduction of commercial fast-breeder reactors of the liquid-metal-cooled type in several countries in the mid-1980s. While several large-scale prototypes can and indeed must be built before then if this goal is to be achieved, these prototypes will not themselves be economically competitive.

For the most part, our current problems in nuclear power are centred on the issue of the environment, and because of that, they are in a certain sense ironic. No new field of science and technology — perhaps of all human endeavour — has applied such intensive voluntary restraints to ensure the safety of its activities as has nuclear energy. As a result, in country after country, nuclear activities have achieved safety records at the very top of all industrial activities. Sophisticated new procedures and equipment have been developed to ensure the containment of the radiation and materials involved in nuclear activities. Regulatory procedures of unprecedented stringency have been adopted by the leading nuclear nations to ensure the safety of their nuclear power activities.

Viewed objectively, nuclear power offers an unparalleled opportunity to reverse the trend towards greater and greater environmental pollution from conventional fuels and combustion products, with all their known and unknown hazards.

Despite this, strong and sometimes strident voices have been raised against the use of nuclear power on environmental grounds in a number of countries. As responsible guardians of the public trust in the safety of nuclear activities, we should not deny careful consideration to even the most improbable hypotheses relating to the hazards of nuclear power, and we have not done so. Indeed, to ensure the safety of our activities, we of the nuclear community pioneered the approach of taking seriously the highly improbable. Today's nuclear power plants involve the release of such small amounts of radiation that an individual located continuously at a nuclear plant boundary would receive less additional radiation exposure each year than that experienced by those of us who crossed the Atlantic to attend this conference. The patient explanation of facts such as these has borne fruit. Today I believe there is noticeably greater public understanding of the safety of nuclear power than at this time a year ago. And with public understanding, public acceptance will be the inevitable result. This Conference gives us another important means of reaching that goal.

Reviewing progress in the field of controlled fusion has been a hallmark of these Geneva Conferences ever since Dr. Bhabha's exciting prediction in 1955. Today, even though the goal of achieving net energy production from controlled fusion still eludes us, we know far more than ever about plasmas and their behaviour. As a result, as I have already said, I believe, Dr. Bhabha's prediction of net energy within two decades of 1955 will be missed, if at all, by only a small margin. But the translation of this result into a practical and economic source of commercial electric power is a potentially much more difficult and time-consuming job which I do not believe can be realized much before the end of this century.

In virtually every other area of our broad field, the progress since 1964 has been great. Radioisotopes, which have long since taken their place as a powerful tool of research, medicine and industry have increased their application considerably since 1964. But that tells only part of the story, for the dramatic aspect has been in the number of new applications. From human cardiac pacemakers to providing power for lunar experiments, radioisotopes are performing tasks that could not be duplicated in any other way.

I believe there is a good prospect that radioisotope-powered artificial hearts will be successfully developed and in experimental use within five years. In a more quiet way, radioisotopes are creating a revolution in medicine that many experts compare with the introduction of the X-ray in 1896. The medical scintillation camera permits the study of entire organs while actually functioning, with radiation exposures to the patient far less than those that would be required by the use of conventional X-rays.

Food preservation through irradiation on a widespread commercial basis is still one of the goals ahead of us, although some specialized applications are beginning to come into use. Here, as in some other areas, I suspect that our priorities have become disordered through a failure to balance risks against benefits. With tens of millions of the world's people still suffering from hunger and its more insidious partner, malnutrition, the ability of radiation to extend the storage time of food, and to reduce losses due to infestation and sprouting has not been given the role which it deserves. This is another area where I believe I can safely predict widespread application within a decade or two.

During this Conference, you will receive an up-to-date report on the peaceful uses of nuclear explosives. I would not seek to obscure the still controversial nature of this application of nuclear energy. There are people in many nations who believe sincerely that the exploitation of the peaceful benefits of nuclear explosives will somehow increase the pressures and opportunities for the acquisition of nuclear weapons — from which peaceful nuclear explosives are unfortunately indistinguishable. This attitude overlooks, however, the progress which is reflected in the Treaty on Non-Proliferation of Nuclear Weapons (NPT). Article V of this Treaty demonstrates not only the worldwide interest in peaceful nuclear explosives, but provides a logical solution to the conflict between widespread availability of these benefits and the need to avoid the spread of nuclear explosive devices themselves.

The adoption of this Treaty is in itself a major development that merits taking note of in this progress report. In 1964, Professor Emelyanov called attention to the then recently adopted treaty banning nuclear weapons tests in the atmosphere, outer space, and under water, and expressed the hope, shared by all, that further steps would be taken towards the solution of international problems by negotiation. The Non-Proliferation Treaty is another solid step in this progression.

It would be remiss not to identify in this summary of major progress since 1964 the development by the International Atomic Energy Agency of the new framework for the application of safeguards under the NPT. Both the results of this work, and the constructive spirit in which it was carried out show that positive accomplishments can be secured through international co-operation even in areas of great political and technical complexity. I am convinced that through this endeavour, the IAEA has greatly improved the prospects for a broad and effective implementation of the NPT.

What of the future? I have already ventured some predictions in pointing to the highlights of our recent progress, but there are many other exciting prospects in store for us before this century ends. I believe that through the use of nuclear propulsion the outer planets such as Jupiter will surely be examined instrumentally in this century, and that man is likely to visit Mars by the same means.

Giant earth-stationary satellites bearing compact nuclear reactors will broadcast television programs and other messages directly to home receivers.

Nuclear-powered tankers and other nuclear merchant ships will almost certainly ply the seas.

Peaceful nuclear explosives will be employed on a widespread scale to improve the recovery of underground natural resources, and possibly to modify topography in such ways as the building of harbours, canals, and reservoirs.

Our achievements will not be exclusively scientific and technological. I believe we will see international agreements to ensure the safe transport of radioactive materials and their safe disposal. Nuclear trade will become essentially conventional in nature, subject only to the requirement that its peaceful purpose be ensured by appropriate safeguard arrangements. International co-operation will continue to flourish, but will become less a concern of governments and more a direct activity of scientists and industry. On the frontier of nuclear science, larger accelerators will be built under international auspices.

I believe that all these will take place if we continue to act wisely in allocating to nuclear science and technology the resources which they deserve. The demands on the world's resources have never been greater. Many of the needs are urgent and, in some respects, more basic than the need for advanced technology. Even in the most affluent nations, poverty and hunger persist, and the gap which separates the industrialized from the developing nations is still disappointingly wide. But no civilization would ever reach greatness if the level of all its activities were held to a common denominator. Excellence in science and technology is as necessary to a successful society as is excellence in the arts, or any other field of human endeavour. In the final analysis, the alleviation of the human wants which have been with us for so long will depend on the degree to which a society can fashion and apply new technology to make our natural and human resources go further.

The solution to the problem of priorities must not be to stifle scientific initiative, but to encourage it even as we seek to meet the other urgent needs. Perhaps, here again, our Conference can play a role in increasing public and official understanding of the relevance of our goals to the needs of society.

It has become an honoured tradition of these conferences to pay tribute to distinguished nuclear scientists whose lives have ended since our previous meeting. This time our list is an especially sad one, since it includes the names of the President of the First Geneva Conference, Homi Bhabha, and of the great and beloved pioneer of nuclear energy, Otto Hahn. To honour their memory, to honour Sir John Cockcroft, Lise Meitner, and Igor Tamm, and all the other members of this unique international community who have departed since we last met, I propose that we rise for a moment of silence.

I now express the wish that our Conference proceed in the same tradition of scientific excellence and full and open discussion that has marked our previous meetings.

Translations into French, Russian and Spanish follow.

DISCOURS D'OUVERTURE

Glenn T. SEABORG
Président de la Conférence

C'est avec un sentiment de grande humilité mêlée d'un peu d'orgueil, une émotion et un espoir immenses pour l'avenir de la science encore nouvelle dont nous allons parler, que j'assume la présidence de cette Conférence.

J'éprouve un sentiment d'humilité parce qu'une conférence de cette ampleur ne peut pas manquer de me rappeler la dette énorme que nous avons envers les intelligences hors série dont les découvertes ont permis l'avènement de l'ère scientifique dans laquelle nous vivons maintenant. L'acquisition des connaissances par l'homme a été un processus continu et, même avec le recul de l'histoire, on ne peut identifier qu'avec difficulté les découvertes vraiment capitales et leurs auteurs. Même lorsque nous examinons les découvertes les plus fantastiques et les plus importantes quant à leurs conséquences, nous constatons qu'elles sont construites sur les fondements posés par les penseurs précédents qui étaient souvent arrivés très près du sommet qui fut ensuite atteint.

L'énergie nucléaire ne fait pas exception. Aucun historien de ses origines ne saurait omettre les apports révolutionnaires d'Einstein, de Rutherford, de Bohr et, bien entendu, de Fermi, Hahn, Meitner et Strassmann qui ont ouvert la dernière porte conduisant à la réalisation pratique de l'exploitation de l'énergie contenue dans le noyau de l'atome.

J'éprouve aussi un certain orgueil parce que mon pays a fourni, je le crois, sa part non seulement en développant les applications de l'énergie atomique à des fins pacifiques, mais aussi — et c'est également important — en défendant et en appliquant l'idée que ces avantages doivent être disponibles pour tous les pays. J'espère que l'on me pardonnera si je fais observer que la présente Conférence vient rendre hommage, entre autres, au regretté Président Eisenhower, dont les propositions faites devant l'Assemblée générale des Nations Unies le 8 décembre 1953 ont amorcé le programme connu sous le nom de l'«Atome pour la paix» et qui, plus tard, a proposé personnellement l'organisation de la première Conférence de Genève.

J'éprouve un sentiment d'espoir et une vive émotion parce que je pense que nous sommes encore au début d'une période de grandes découvertes nouvelles, et de consolidation et d'exploitation des découvertes du passé, une période qui, à la fin de ce siècle, apportera à l'humanité des bienfaits inespérés tirés de l'énergie nucléaire, qui amélioreront directement la qualité de la vie pour la plus grande partie de la population de six à sept milliards d'habitants qui sera alors celle de notre planète.

Lorsqu'on occupe cette tribune, on est inévitablement conduit à se souvenir de la sagesse de ceux qui ont présidé les trois précédentes Conférences. En 1955, M. Homi Bhabha a eu l'honneur bien mérité d'être le premier à assumer la présidence, ce qui était aussi une tâche très lourde. Le choix de M. Homi Bhabha à la tête de la première Conférence de Genève fut un choix heureux. Non seulement il rendait justice à ce grand savant et homme d'Etat, mais en se portant sur un ressortissant d'un pays en voie de développement il soulignait l'universalité des capacités et des besoins dans le domaine de l'énergie nucléaire. Sur les magnifiques fondements posés par M. Bhabha, l'Inde fut le premier pays en voie de développement utilisant l'énergie nucléaire comme source primaire d'électricité. Car M. Bhabha avait bien vu que l'énergie nucléaire était importante non seulement pour les pays industrialisés, mais aussi pour les pays en voie de développement. Et même, son idée maîtresse était que si la grande majorité de la population du monde qui habite actuellement les pays en voie de développement voulait atteindre le niveau de vie tributaire de l'énergie dont bénéficiaient déjà les pays industrialisés, l'énergie d'origine nucléaire devrait recevoir une application généralisée.

M. Bhabha avait aussi fait une prédiction sensationnelle, à savoir qu'en deux décennies nous réaliserions la production d'énergie utilisable à partir de la fusion, ouvrant ainsi la voie à l'utilisation du deutérium des mers qui constitue une source d'énergie virtuellement illimitée. M. Bhabha avait eu la sagesse de prédire seulement que, pendant cette période, on trouverait une méthode pour libérer l'énergie de fusion d'une manière contrôlée mais non pas que cette découverte pourrait être appliquée pour constituer une source d'énergie industrielle rentable et fiable. Pendant que le délai fixé par M. Bhabha n'est pas encore expiré, je veux me joindre à lui dans le rôle de prophète et dire que je n'exclus pas qu'une production positive d'énergie à partir de la fusion puisse être réalisée en

1975 et qu'elle le sera presque certainement en 1980. Dans ce cas, M. Bhabha, qui a trouvé une mort tragique non loin de cette ville alors qu'il se rendait à une grande réunion internationale consacrée à l'énergie atomique, verra sa réputation de grand prophète scientifique vraiment consacrée.

Le Président de la deuxième Conférence de Genève fut aussi un pionnier nucléaire, un Français, M. Francis Perrin. Sachant bien que l'objectif tant souhaité de l'énergie nucléo-électrique rentable serait plus difficile à atteindre que l'on ne l'avait cru tout d'abord, les participants à la deuxième Conférence de Genève se montraient relativement pessimistes. Le Professeur Perrin a eu le mérite de prévoir que tout d'abord l'énergie d'origine nucléaire serait principalement utile dans les pays déjà très industrialisés. Cette prédiction se réalisa effectivement; mais, comme des centrales nucléaires sont déjà en exploitation ou en cours d'installation dans des pays comme l'Inde, le Pakistan, la Corée, la Chine, l'Argentine et le Brésil, on voit que cette phase approche de son terme. En 1980, il est probable que des centrales nucléaires seront exploitées dans plus de 15 pays actuellement considérés comme en voie de développement d'après les critères de l'Organisation des Nations Unies.

Le Professeur Perrin a souligné que l'un des plus importants aspects de ces conférences est le fait qu'elles font disparaître les voiles du secret dans un domaine très important de la science, ouvrant ainsi des communications jusqu'alors fermées. C'est strictement exact et c'est même un des principaux mérites des deux premières Conférences de Genève. Il est maintenant acquis que virtuellement tous les domaines importants de l'utilisation pacifique de l'énergie atomique ont cessé de constituer des secrets militaires; mais, malheureusement, des contrôles imposés au nom du secret industriel sont venus les remplacer. Etant donné que le bien-être d'un pays est fondé en grande partie sur les contributions des entreprises privées, nous ne doutons pas de l'importance qu'il y a à rémunérer l'initiative scientifique privée. Ce qui est important mais difficile, c'est d'établir un équilibre approprié entre la dissémination généralisée de renseignements pendant les premières phases des travaux de recherche et de mise au point, et une protection convenable des techniques détaillées et perfectionnées. En tant qu'homme de science, je pense comme le Professeur Perrin que le secret stérilise le progrès et j'ai peur que les précautions prises au nom de la propriété industrielle ne soient aussi néfastes que celles qui existaient autrefois pour des raisons de sécurité nationale. Si la présente Conférence fournit le même stimulant à la publication de certains renseignements actuellement considérés comme du domaine de la propriété que les précédentes Conférences à la publication des renseignements «classés», elle aura atteint un objectif extrêmement important.

La troisième Conférence de Genève a marqué une date dans l'histoire : l'avènement de l'énergie d'origine nucléaire rentable. On a même pu dire à cette Conférence, à laquelle j'ai eu l'honneur de participer à la tête de la délégation des Etats-Unis et de prononcer le discours de synthèse, qu'une «percée économique» avait été effectuée en ce qui concerne la technologie nucléo-électrique. Avec plus de 150 millions de kilowatts pour les centrales nucléaires en exploitation, en construction ou sous commande dans le monde, on ne peut guère aujourd'hui douter de la véracité de cette déclaration.

Le Président de la troisième Conférence de Genève fut mon ami et collègue, le Professeur Emelyanov, envoyé par l'Union soviétique. Dans le remarquable tour d'horizon qu'il a effectué sur la science et la technologie nucléaires, M. Emelyanov a appelé l'attention sur l'importance de la coopération internationale, en mentionnant tout spécialement le rôle croissant et l'efficacité de l'Agence internationale de l'énergie atomique dans ce domaine. Il a également parlé pour la première fois des perspectives nouvelles et séduisantes offertes par l'utilisation de l'énergie nucléaire dans de grandes usines de dessalement de l'eau de mer, et je pense que notre génération pourra assister à cette réalisation.

Lorsque je jette un regard en arrière sur le développement de la science et de la technologie nucléaires, il me semble qu'un fait extrêmement intéressant éclipse tous les autres: ce domaine de la science est peut-être le premier et certainement le plus vaste où le progrès n'est pas arrivé «comme cela». De grands progrès ont été faits dans beaucoup d'autres domaines de la science et de la technique avant que l'énergie nucléaire entre en scène. Mais, d'une manière générale, ces progrès ont été le résultat des actions et des interactions de différents programmes et personnes essentiellement indépendants. En matière d'énergie nucléaire, pour la première fois, la marche du progrès dans tout un vaste domaine de la science a été en grande partie le résultat de décisions de gouvernements et – aux tout premiers débuts – seulement d'un petit nombre. Dans la même optique, même la coopération internationale qui nous réunit ici doit son existence aux décisions et aux actes délibérés de gouvernements plutôt qu'aux voies plus traditionnelles de la coopération scientifique.

Je crois que c'est une expérience passionnante et, dans l'ensemble, très fructueuse avec de vastes ramifications en dehors de ses frontières immédiates. Alors que l'ingéniosité de l'homme reste l'élément indispensable du progrès scientifique, notre expérience en matière d'énergie nucléaire a montré indubitablement que la rapidité et même la direction du développement peuvent être profondément affectées par des interventions importantes de directives et de ressources gouvernementales.

D'une manière encore plus complète, cette expérience s'est répétée dans le domaine de la science spatiale, mais je pense que l'énergie nucléaire reste non seulement le modèle mais aussi l'exemple le plus significatif à l'heure actuelle, car nous avons assisté au développement en force d'un domaine de la science et de la technique qui a une incidence pratique et économique considérable et immédiate pour une grande proportion des pays du monde.

Le seul précédent historique de ce qui s'est passé en matière d'énergie nucléaire depuis 25 ans est peut-être une ère de découvertes plus ancienne lorsque des gouvernements à larges vues entreprirent l'exploration non pas d'un nouveau monde de la science mais d'un nouveau monde au-delà des mers. Il est possible que, aux yeux de l'histoire, les conséquences de nos explorations dans le nouvel univers de l'énergie nucléaire aient la même importance que celles des grandes découvertes géographiques.

J'ai voulu parler en termes très généraux de la toile de fond de nos conférences et des sciences auxquelles elles sont consacrées. Le message véritable de cette réunion, l'histoire des sept années de progrès depuis notre dernière rencontre en 1964, se dégageront nécessairement et pertinemment des discussions qui vont suivre. Mais je ne veux pas entièrement laisser passer l'occasion de parler, comme l'ont fait mes prédécesseurs, de ce qui s'est passé et de ce que nous pouvons attendre des années qui viennent.

Comme je vous l'ai déjà dit, cette Conférence est marquée par le fait capital que l'énergie d'origine nucléaire n'est plus «à notre porte» mais qu'elle est atteinte. Le montant total des investissements pour les 150 millions de kilowatts nucléaires dont j'ai parlé dépassera 45 milliards de dollars lorsque les centrales seront terminées en 1980 et, naturellement, à ce moment, beaucoup d'autres centrales représentant plusieurs millions de kilowatts supplémentaires approcheront alors de leur achèvement. L'énergie que ces usines produiront en 1980 sera presque égale à la capacité totale de production d'électricité des Etats-Unis à la dernière Conférence de Genève. Et, vers l'an 2000, il ne fait guère de doute que la moitié de la capacité de production d'énergie électrique des Etats-Unis, qui dépassera 1, 5 milliard de kilowatts, sera nucléaire et que le rythme de développement sera le même dans les autres grandes régions du monde.

Mais, en dépit de ce succès qui mérite, je crois, l'épithète de phénoménal, il reste beaucoup à faire et notre nouvelle industrie proliférante doit résoudre encore des problèmes. La grande tâche qui incombe encore à la technologie nucléo-électrique est de dégager les ressources énergétiques massives enfermées dans les isotopes fertiles – uranium-238 et thorium – en achevant la mise au point d'un réacteur surgénérateur rentable. Cet objectif occupe actuellement les énergies et les ressources de la plupart des grands programmes de développement énergétique nucléaire. Je ne doute pas qu'il sera atteint, mais il faudra beaucoup de temps et des frais importants. Je pense que nous verrons l'introduction de réacteurs surgénérateurs rapides industriels refroidis par un métal liquéfié dans plusieurs pays vers 1980. Plusieurs prototypes de grandes dimensions peuvent être construits avant cette date et on devra même les construire si l'on veut atteindre le but fixé; mais ils ne seront pas eux-mêmes concurrentiels.

Nos problèmes actuels en matière d'énergie d'origine nucléaire sont centrés sur la question de l'environnement et il y a là une certaine ironie. Aucun domaine nouveau de la science et de la technique n'a connu de telles restrictions volontaires visant à assurer la sécurité. Dans tous les pays, les activités nucléaires ont obtenu des dossiers de sécurité qui les placent à la pointe de toutes les activités industrielles. On a mis au point des procédés et du matériel extrêmement complexes pour assurer le confinement de l'environnement et des matières. On a adopté des procédures normatives d'une rigueur sans précédent dans les principaux pays nucléaires pour assurer la sécurité.

Considérée objectivement, l'énergie d'origine nucléaire offre une occasion sans précédent de renverser la tendance à une pollution de l'environnement toujours plus grande par les combustibles classiques et les produits de combustion, avec tous les risques connus et inconnus que cela comporte.

Et malgré cela, des voix puissantes et parfois stridentes se sont élevées contre l'emploi de l'énergie nucléo-électrique, au nom de la protection du milieu, dans plusieurs pays. Comme nous sommes chargés de maintenir la confiance du public dans la sécurité des activités nucléaires, nous ne saurions refuser d'étudier avec soin même les plus improbables hypothèses relatives aux risques de l'énergie d'origine nucléaire. Et même, pour assurer la sécurité de nos activités, nous sommes les premiers, nous les membres de la communauté nucléaire, à avoir pris au sérieux des risques extrêmement improbables. Aujourd'hui, les centrales nucléaires impliquent le dégagement de quantités de rayonnements si petites que même un individu séjournant constamment au voisinage d'une centrale nucléaire recevra chaque année une dose de rayonnement supplémentaire moins importante que ceux qui ont traversé l'Atlantique pour assister à cette Conférence. L'explication patiente de faits comme celui-ci a porté des fruits. Aujourd'hui, je pense que le public comprend beaucoup mieux la sécurité de l'énergie nucléaire qu'il y a un an. Et si le public comprend, il doit inévitablement accepter l'atome. La présente Conférence nous offre un moyen d'atteindre ce but.

La tradition veut que l'on fasse le point des progrès de la fusion contrôlée aux Conférences de Genève, depuis la prédiction faite par M. Bhabha en 1955. Aujourd'hui, même si la production nette d'énergie par fusion contrôlée est un objectif qui continue à nous échapper, nous en savons beaucoup plus sur le plasma et son comportement. C'est pourquoi, comme je vous l'ai déjà dit, je crois que la prophétie de M. Bhabha concernant la production nette d'énergie avant 1975 ne sera pas contredite ou qu'elle ne le sera qu'à une étroite marge près. La traduction de ce résultat en une source pratique et économique d'énergie électrique industrielle risque d'être beaucoup plus difficile et de prendre beaucoup plus de temps, et je pense que l'on y parviendra avant la fin de ce siècle.

Dans presque tous les autres secteurs du large domaine qui nous occupe, les progrès réalisés depuis 1964 sont très importants. Les radioisotopes qui, depuis longtemps, ont pris leur place en tant qu'instrument puissant pour la recherche, la médecine et l'industrie, ont vu leurs applications se multiplier depuis 1964. Mais ce n'est pas tout, car un nombre sensationnel de nouvelles applications sont apparues. Depuis le régulateur cardiaque jusqu'aux sources d'énergie pour les expériences sur la lune, les radioisotopes accomplissent des tâches irremplaçables.

Je pense que l'on a bon espoir de mettre au point des cœurs artificiels actionnés par les radioisotopes et de les expérimenter d'ici à cinq ans. D'une manière générale, les radioisotopes provoquent une révolution en médecine que beaucoup de spécialistes comparent avec l'introduction de rayons X en 1896. Les compteurs à scintillation médicaux permettent d'étudier des organes entiers pendant leur fonctionnement, en imposant au malade une exposition aux rayonnements bien inférieure à celle qui serait nécessaire si l'on employait des rayons X classiques.

La conservation des denrées alimentaires par irradiation à l'échelle industrielle est encore un objectif que l'on s'efforce d'atteindre, bien que certaines applications particulières commencent à être utilisées. Là encore, je pense que les urgences ont été bouleversées parce qu'on n'a pas réussi à équilibrer les risques par rapport aux avantages. Lorsque 10 millions d'habitants du globe souffrent encore de la faim et d'un mal plus insidieux, la malnutrition, la possibilité d'augmenter grâce aux rayonnements la durée de conservation des aliments et de diminuer les pertes résultant de l'infestation et de la germination n'a pas obtenu tout le rôle qu'elle mérite. C'est là un autre secteur où je pense que l'on peut prévoir sans risque d'erreur une application généralisée dans les dix ou vingt ans qui viennent.

Pendant la Conférence, vous recevrez un rapport à jour sur les applications pacifiques des explosions nucléaires. Je ne chercherai pas à obscurcir la nature encore controversée de cette application de l'énergie nucléaire. Dans beaucoup de pays, des personnes pensent sincèrement que l'exploitation des avantages pacifiques des explosifs nucléaires augmentera quelque peu les pressions et la possibilité d'acquisition d'armes nucléaires — dont les explosifs nucléaires pacifiques sont malheureusement impossibles à distinguer. Cette attitude ne tient cependant pas compte des progrès qui se reflètent dans le Traité sur la non-prolifération des armes nucléaires. L'Article V de ce Traité montre non seulement l'intérêt mondial que suscitent les explosifs nucléaires mais fournit en outre une solution logique au conflit entre le désir de mettre ces avantages à la disposition de tous et le besoin d'éviter la prolifération des agents explosifs nucléaires eux-mêmes.

L'adoption de ce Traité est en elle-même une grande réalisation qui mérite que j'en parle dans ce tour d'horizon. En 1964, le Professeur Emelyanov a appelé l'attention sur le Traité récemment adopté interdisant les essais d'armes nucléaires dans l'atmosphère, dans l'espace extérieur et sous l'eau, et il a exprimé l'espoir, partagé par tous, que l'on prendrait d'autres mesures pour résoudre les problèmes internationaux par voie de négociation. Le Traité sur la non-prolifération est un autre pas considérable dans cette voie.

Dans ce résumé des principaux progrès réalisés depuis 1964, on ne saurait manquer de souligner le développement par l'Agence internationale de l'énergie atomique (AIEA) d'un nouveau cadre pour l'application des garanties au titre du TNP. Les résultats de ce travail et l'esprit constructif dans lequel il a été réalisé montrent que des résultats positifs peuvent être atteints grâce à la coopération internationale, même dans des secteurs d'une grande complexité politique et technique. Je suis convaincu qu'en entreprenant cette tâche, l'AIEA a considérablement amélioré les perspectives d'une exécution large et efficace du TNP.

Que dire de l'avenir? J'ai déjà risqué quelques prédictions en soulignant les points saillants des progrès que nous venons de réaliser; mais de nombreuses autres perspectives séduisantes vont s'ouvrir pour nous avant la fin de ce siècle. Je pense que grâce à la propulsion nucléaire des planètes extérieures comme Jupiter seront certainement étudiées à l'aide d'instruments avant l'an 2000 et que l'homme pourra par le même moyen arriver jusqu'à Mars.

Des satellites géants, stationnaires par rapport à la Terre et munis de petits réacteurs nucléaires, diffuseront des programmes de télévision et d'autres messages qui parviendront directement à leurs destinataires.

Des bateaux-citernes nucléaires et d'autres navires marchands à propulsion atomique sillonneront presque certainement les mers.

Des explosifs nucléaires pacifiques seront employés sur une vaste échelle pour faciliter la récupération de ressources naturelles souterraines et peut-être pour modifier la topographie en construisant des ports, des canaux et des réservoirs.

Nos réalisations ne seront pas uniquement scientifiques et technologiques. Je pense qu'il y aura des accords internationaux assurant le transport et l'évacuation en toute sécurité des matières radioactives. Le commerce nucléaire deviendra essentiellement conventionnel et sera soumis à la seule exigence que son objectif pacifique soit assuré par des accords de garanties appropriés. La coopération internationale continuera à se développer mais elle sera moins l'affaire des gouvernements et deviendra une activité plus directe des scientifiques et de l'industrie. A la frontière de la science nucléaire, de plus grands accélérateurs seront construits sous des auspices internationaux.

Je pense que tout cela se produira si nous continuons à allouer sagement à la science et à la technologie nucléaires les ressources qu'elles méritent. Les demandes imposées aux ressources mondiales n'ont jamais été plus grandes. Beaucoup des besoins sont urgents et, à certains égards, plus fondamentaux que le besoin d'une technologie perfectionnée. Même dans les pays les plus riches, la pauvreté et la faim persistent et l'écart qui sépare les pays industrialisés des pays en voie de développement est toujours terriblement large. Mais aucune civilisation ne deviendra jamais grande si le niveau de toutes ses activités est ramené à un dénominateur commun. L'excellence en matière de science et de technique est aussi nécessaire à une société prospère que l'excellence dans les arts et dans les autres domaines de l'effort humain. En dernière analyse, le soulagement des misères que l'humanité subit depuis si longtemps dépendra de la mesure dans laquelle la société pourra façonner et appliquer la nouvelle technologie pour promouvoir le progrès que permettent nos ressources naturelles et humaines.

La solution du problème des priorités ne doit pas étouffer l'initiative scientifique mais l'encourager, même si l'on cherche à satisfaire aussi les autres besoins urgents. Peut-être que, là aussi, la Conférence peut jouer un rôle en faisant mieux comprendre au public et aux dirigeants que nos objectifs correspondent bien aux besoins de la société.

La tradition exige que je rende hommage aux éminents savants nucléaires qui ont disparu depuis notre dernière réunion. Cette fois, la liste est particulièrement douloureuse parce qu'elle comprend les noms du Président de la première Conférence de Genève, Homi Bhabha, et de ce grand pionnier de l'énergie nucléaire que nous aimions tous, Otto Hahn. Pour honorer leur mémoire, pour honorer Sir John Cockcroft, Lise Meitner et Igor Tamm, et tous les autres membres de cette communauté internationale unique qui nous ont quittés depuis la dernière Conférence, je propose d'observer une minute de silence.

Il me reste à souhaiter que cette Conférence renoue avec la tradition de haute tenue scientifique et de discussions libres et ouvertes qui a marqué nos précédentes réunions.

ВЫСТУПЛЕНИЕ НА ОТКРЫТИИ КОНФЕРЕНЦИИ

Гленн Т.СИБОРГ
Председатель Конференции

Я приступаю к исполнению своих обязанностей с чувством высокой ответственности, с некоторой гордостью, надеждой и волнением за будущее все еще молодой науки, для обсуждения проблем которой мы здесь собрались.

Я приступаю к исполнению своих обязанностей с чувством высокой ответственности, потому что проведение конференции такого масштаба не может не напомнить нам о том огромном долге, в котором мы, современное поколение, находимся перед выдающимися интеллектами прошлого, чьи достижения привели к веку фантастической науки. Приобретение знаний человеком представляет собой постоянный процесс, и даже нам, имеющим возможность проследить всю историю развития науки, с трудом удается выделить поистине решающие открытия и установить их авторов. При рассмотрении даже самых существенных вкладов в науку мы убеждаемся, что в их основе лежат идеи наших предшественников-мыслителей, довольно часто приближавшихся к заветной цели, которая достигалась позже.

Область ядерной энергии не является исключением. История ее происхождения не может не учитывать революционных вкладов Эйнштейна, Розерфорда, Бора и, конечно, Ферми, Хана, Мейтнера и Штрассмана, которые положили начало практическому извлечению энергии из ядра атома.

Я приступаю к исполнению своих обязанностей с чувством некоторой гордости, поскольку моя страна внесла свой вклад не только в развитие использования ядерной энергии в мирных целях, но и в утверждение концепции, что блага от использования этого вида энергии должны быть доступны всем народам. Я надеюсь, что меня не осудят за напоминание о том, что проведением этой Конференции мы отдаем дань покойному президенту Дуайту Д.Эйзенхауэру, который 8 декабря 1953 года внес на рассмотрение Генеральной Ассамблеи Организации Объединенных Наций предложения, положившие начало осуществлению программы "Атомы для мира", и который позднее предложил созвать Первую Женевскую конференцию.

Я приступаю к исполнению своих обязанностей с надеждой и волнением, потому что я считаю, что мы все еще находимся на пороге эры великих открытий, дальнейшего развития и использования достижений прошлых лет, – на пороге эры, когда (к концу XX века) человек получит от использования ядерной энергии колоссальные выгоды. Эти выгоды непосредственно приведут к улучшению жизненного уровня большей части шести-семи-миллиардного населения, которое к тому времени будет проживать на земном шаре.

Находясь на этой почетной трибуне, невольно приходишь к мысли напомнить о мудрости тех, кто председательствовал на предыдущих Конференциях. В 1955 году такая честь была оказана д-ру Хоми Баба, но ему предстояло выполнить более сложную задачу – выступить первым. Выбор д-ра Хоми Баба председателем Первой Женевской конференции был весьма удачным. Ему была оказана честь не только как выдающемуся ученому и государственному деятелю. Назначение председателем Конференции представителя развивающегося мира подчеркивало универсальность возможностей и потребностей в области использования ядерной энергии. Благодаря большой научной и организаторской деятельности д-ра Баба, Индия выдвинулась на первое место среди развивающихся стран в области использования ядерной энергии как основного энергоисточника. Таким образом, д-р Баба совершенно правильно предсказал, что ядерная энергия имеет важное значение не только для индустриально развитых, но также и для развивающихся стран. Его основная концепция состояла в том, что развивающиеся страны, составляющие большую часть населения земного шара, для достижения жизненного уровня индустриально развитых стран, который определяется общим состоянием энергетики, должны более широко использовать ядерную энергию.

Баба сделал также сенсационное предсказание о том, что через два десятилетия мы добьемся производства полезной энергии за счет ядерного синтеза и тем самым откроем путь к извлечению дейтерия из морей и океанов для его использования в качестве практически неиссякаемого источника энергии. С присущей научной осторожностью д-р Баба предсказал, что в этот период времени будет найден только метод получения ядерной энергии за счет управляемого термоядерного синтеза. Он не уточнял, когда это открытие будет воплощено в экономически выгодный и надежный коммерческий источник энергии. Пока наука стремится к осуществлению целей, предсказанных д-ром Баба, я присоединюсь к нему в роли пророка и отмечу, что не исключаю возможности производства энергии за счет ядерного синтеза к 1975 году, и почти наверняка – к 1980 году. Если это предвидение сбудется, то д-р Баба, жизнь которого трагически оборвалась недалеко от этого города, когда он направлялся на одно из международных совещаний по использованию атомной энергии, приобретет репутацию человека большого научного предвидения.

Председателем Второй Женевской конференции был тоже выдающийся ученый в области использования ядерной энергии – Френсис Перрен (Франция). Пессимистический характер Второй Женевской конференции объяснялся тем, что получение экономически выгодной ядерной энергии оказалось делом более трудным, чем это предполагалось. Профессор Перрен правильно предсказал, что использование ядерной энергии будет экономически выгодно сначала в высокоразвитых в промышленном отношении странах. Следует отметить, что эта стадия развития не только достигнута, но уже подходит к концу, поскольку в настоящее время атомные электростанции находятся в эксплуатации или в стадии строительства в таких странах, как Индия, Пакистан, Корея, Китай, Аргентина и Бразилия. По всей вероятности, к 1980 году атомные электростанции будут находится в эксплуатации более чем в 15 странах, которые в настоящее время, согласно критериям Организации Объединенных Наций, относятся к разряду развивающихся.

Профессор Перрен считал одной из наиболее важных функций таких Конференций – устранение завесы секретности в этой важной области науки, а также изыскание новых возможностей для расширения контактов и связей. Это была совершенно правильная точка зрения, которая нашла отражение в итогах двух предыдущих Женевских конференций. В настоящее время практически во всех сферах деятельности, имеющих значение для использования ядерной энергии в мирных целях, установлен и применяется как должное статус несекретности, но, к сожалению, соблюдение секретности, введенное ранее в военных целях, было заменено в ряде случаев осуществлением контроля за секретами коммерческого характера. Моя страна, благосостояние которой основывается в значительной степени на деятельности частных предприятий, не сомневается в важности предоставления надлежащих вознаграждений за проявление частной научной инициативы. Важным и трудным делом является достижение необходимого равновесия между широким распространением информации на ранних стадиях исследований и разработок, с одной стороны, и соответствующее обеспечение секретности в отношении разработанной и усовершенствованной технологии, с другой стороны. Придерживаясь точки зрения профессора Перрена, что секретность сводит прогресс на нет, я опасаюсь, что соблюдение секретности во имя сохранения коммерческой тайны может иметь такой же отрицательный эффект, как это имело место при соблюдении секретности во имя обеспечения национальной безопасности. Данная Конференция действительно окажет полезную услугу, если она в такой же степени будет стимулировать публикацию ряда информационных материалов, которые в настоящее время предназначены лишь для внутреннего пользования, как это было сделано на предыдущих конференциях в отношении опубликования секретной информации.

Третья Женевская конференция явилась исторической вехой на пути развития атомной науки и техники. Она ознаменовала начало эры экономичного использования ядерной энергии. В самом деле, на той Конференции, где я имел честь присутствовать в качестве руководителя делегации Соединенных Штатов Америки и выступал с заключительным обзором, можно было заявить, что в ядерно-энергетической технологии произошел "экономический сдвиг". Сейчас, когда в мире введены в эксплуатацию, находятся в стадии строительства или приняты заказы на сооружение атомных электростанций общей мощностью более 150 млн.кВт, мало найдется таких скептиков, – если они вообще найдутся, – которые сомневались бы в справедливости этого заявления.

Председателем Третьей Женевской конференции был мой друг и коллега профессор В.С.Емельянов из Советского Союза. В своем превосходном обзоре о состоянии развития ядерной науки и техники профессор Емельянов справедливо обратил внимание на значение международного сотрудничества, а также особо отметил возрастающую роль и эффективную деятельность Международного агентства по атомной энергии в деле укрепления этого сотрудничества. Он также был первым, кто указал на величественные перспективы опреснения морской воды с помощью ядерных методов в более широких масштабах, применение которых прочно войдет в наш быт.

Когда я окидываю взглядом достижения в области ядерной науки и техники, один факт представляется мне наиболее примечательным. Эта область науки является, вероятно, первой и, безусловно, самой обширной, где прогресс не "произошел внезапно". Во многих других областях науки и техники прогресс был достигнут до того, как появилась ядерная энергия. Однако в целом это явилось результатом действий и взаимодействий многих различных и, по существу, независимых друг от друга людей, а также реализации научных программ. В области ядерной энергии впервые прогресс в широком научном плане был в значительной степени обусловлен целенаправленными решениями и действиями правительств (причем вначале лишь правительств немногих стран). Благодаря этому даже расширение международного сотрудничества, которое нас объединяет, объясняется скорее целенаправленными решениями и действиями правительств, чем осуществлением научного сотрудничества по традиационным каналам.

Я считаю это поразительным и, в целом, исключительно успешным экспериментом, выходящим далеко за рамки одной этой области. В то время как человеческий разум является неотъемлемой составной частью научного прогресса, наш опыт в области ядерной энергии наглядно показывает, что темпы и даже направление развития могут определяться политикой и возможностями правительств.

Этот опыт нашел также воплощение (даже в более полном смысле) в области космической науки. Но я думаю, что ядерная наука является все же не только образцовым, но и замечательным примером, поскольку здесь мы наблюдаем планомерное развитие науки и техники, которое оказывает основное и непосредственное практическое и экономическое влияние на большинство стран мира.

Возможно, единственным историческим примером того, что произошло в области ядерной энергии за последние 25 лет, являются открытия более раннего периода, когда дальновидные правительства способствовали не только развитию нового мира науки, но и сотрудничеству с другими странами мира. Возможно, в историческом плане результаты наших исследований в такой новой области как ядерная энергия по своей значимости будут соответствовать ранее сделанным открытиям.

Я предпочел говорить в самом общем плане о предпосылках созыва наших Конференций и о той области науки, проблемы которой выносятся на их обсуждение. Миссия данной Конференции — которую отделяет семилетний период развития от предыдущей Конференции 1964 года — найдет должное отражение в ее трудах. Однако я не буду лишать себя возможности отметить, как и мои предшественники, то, чего мы уже достигли и на что мы можем рассчитывать в будущем.

Знаменательным для нашей Конференции, как я уже отмечал является то, что о ядерной энергетике не приходится больше говорить как о "чем-то близком", поскольку она уже прочно вошла в нашу жизнь. Общая сумма капиталовложений в атомные электростанции мощностью 150 млн. киловатт, о которых я упоминал, превысит 45 млрд.долл. к моменту завершения их строительства в 1980 году. Конечно, к этому времени в стадии завершения будет находится большое число дополнительных электростанций, общая мощность которых составит миллионы киловатт. Количество электроэнергии, производимое этими электростанциями в 1980 году, будет равно производству всей электроэнергии Соединенных Штатов Америки ко времени предыдущей Конференции. По всей вероятности, к концу этого века половина всего количества производимой электроэнергии в Соединенных Штатах Америки, которая составляет 1500 млн.киловатт, будет вырабатываться атомными электростанциями, причем аналогичные темпы развития наблюдаются и в других основных районах мира.

Однако несмотря на достигнутые успехи, которые как я считаю, по праву часто называют феноменальными, нам предстоит еще немало сделать и перед растущей новой отраслью промышленности стоит множество нерешенных проблем. Важной задачей в области технологии использования ядерной энергии является открытие огромных энергетических возможностей воспроизводящих изотопов — урана-238 и тория — путем завершения разработки экономичного реактора-размножителя на быстрых нейтронах. В различных странах мира большинство программ в области использования атомной энергии предусматривает проведение научных исследований в этом направлении. Я не сомневаюсь в осуществимости этой цели, но это потребует больших расходов и много времени. Я полагаю, что в середине 80-х годов в ряде стран мы станем свидетелями внедрения промышленных быстрых реакторов-размножителей с жидкометаллическими теплоносителями. Однако до использования таких реакторов на промышленной основе необходимо построить несколько их крупных прототипов, которые сами по себе не будут экономически конкурентоспособными.

Наши текущие проблемы в области ядерной энергетики сосредоточены, главным образом, на проблеме загрязнения окружающей нас среды.

и поэтому они являются в некотором смысле ироническими. Ни в одной другой новой области науки и техники — возможно из всех видов человеческой деятельности — не предпринимались такие интенсивные меры по обеспечению техники безопасности, как в области использования ядерной энергии. В результате, некоторые страны достигли рекордных показателей по технике безопасности в ядерной промышленности по сравнению со всеми другими отраслями. Были разработаны новые процедуры и виды оборудования в целях предотвращения распространения радиации, а также материалов, используемых в ядерной промышленности. Ведущими ядерными державами были утверждены беспрецедентные по своей строгости правовые положения для обеспечения техники безопасности в области использования ядерной энергии.

Объективно говоря, ядерная энергетика дает невиданную возможность коренным образом изменить тенденцию ко все возрастающему загрязнению окружающей нас среды обычными видами топлива и продуктами сгорания, со всеми их известными и неизвестными опасными последствиями.

Несмотря на это, в ряде стран раздаются сильные, а порой и резкие голоса против использования ядерной энергии в связи с ее якобы вредным воздействием на окружающую нас среду. Отвечая за обеспечение безопасной деятельности в ядерной области, мы не должны отказываться от тщательного рассмотрения даже самых невероятных гипотез, относящихся к опасным последствиям ядерной энергетики. Мы, ученые-ядерщики, первыми серьезно подошли к рассмотрению вопросов по обеспечению безопасной деятельности в нашей области, которые казались практически не осуществимы. Выход радиации на современных атомных электростанциях столь незначителен, что доза дополнительного облучения, ежегодно получаемая человеком, постоянно находящимся в зоне их расположения, является меньше той, которую получили участники нынешней Конференции, пересекшие Атлантический океан. Настойчивое объяснение таких обстоятельств дало свои благотворные результаты. Я считаю, что в настоящее время по сравнению с прошлым годом, со стороны общественности заметно возрасло понимание безопасности внедрения ядерной энергетики. А за этим неизбежно последует и общественное признание. На данной Конференции мы имеем еще одну хорошую возможность ускорить достижение этой цели.

Со времени волнующих предсказаний, сделанных доктором Баба в 1955 году, обзор успехов, достигнутых в области управляемого термоядерного синтеза, явился одним из основных критериев Женевских конференций. Сегодня, даже несмотря на то, что нам все еще не удается получить полезную энергию от управляемого термоядерного синтеза, мы значительно пополнили свои знания о плазме и ее поведении. Поэтому, как я уже сказал, я верю, что предсказания, сделанные доктором Баба относительно возможности получения полезной энергии из этого источника в ближайшие два десятилетия, сбудутся своевременно, а если и с опозданием, то весьма незначительным. Экономичное использование этого источника электроэнергии на промышленной основе возможно является более трудной задачей,и я не думаю, что мы добъемся этого раньше конца нынешнего столетия.

В период после 1964 года практически во всех остальных областях нашей широкой сферы деятельности были достигнуты большие успехи. Радиоизотопы, которые давно уже стали мощным средством проведения научных исследований, в этот период времени получили наиболее широкое применение в медицине и промышленности. Весьма внушительные успехи были также достигнуты в целом ряде новых областей, связанных с использованием изотопных методов. От применения в качестве стимуляторов сердечной деятельности человека, до использования как источника энергии при проведении экспериментов на Луне, радиоизотопы выполняют сейчас задачи, которые невозможно осуществить любым другим методом.

Я верю в перспективность того, что в ближайшие пять лет в экспериментальной медицине будут успешно разработаны и начнут применяться искусственные сердца, работающие на энергии радиоизотопов. Применение радиоизотопных методов в медицине произвело подлинную революцию, которую многие эксперты сравнивают с первым использованием рентгеновских лучей в 1896 году. Медицинская сцинтилляционная камера дает возможность изучить все органы человека в процессе их функциональной деятельности, причем пациент в гораздо меньшей степени подвергается облучению, чем при применении обычных рентгеновских лучей.

Сохранение пищевых продуктов с помощью облучения на широкой коммерческой основе все еще является одной из стоящих перед нами задач, хотя в отдельных областях промышленности этот метод уже нашел широкое применение. Мне кажется, что в этой и в некоторых других областях несколько нарушился принцип очередности, поскольку риск, на который мы идем, не всегда соответствует получаемым выгодам. Однако сегодня, когда в мире десятки миллионов людей все еще страдают от голода и недостатка питания, мы уделяем мало внимания возможности использования радиации в целях увеличения срока хранения пищевых продуктов и сокращения их потерь вследствие порчи и прорастания. Я могу смело предсказать, что через одно-два десятилетия в этой области изотопы также найдут широкое применение.

На данной Конференции будет представлен доклад, подготовленный с учетом всех последних достижений в области использования ядерных взрывов в мирных целях. Я не хочу уточнять и без того противоречивый характер этого вида применения ядерной энергии. Во многих странах есть люди, которые считают, что использование ядерных взрывчатых веществ в мирных целях в некоторой степени будет способствовать расширению возможностей в производстве ядерного оружия. К сожалению, ядерные взрывчатые вещества, используемые в мирных целях, ничем не отличаются от используемых в военных целях. Однако эти люди забывают о тех достижениях, которые нашли свое отражение в Договоре о нераспространении ядерного оружия. В Статье V этого Договора говорится не только об интересе, проявляемом во всем мире к использованию ядерных взрывчатых веществ в мирных целях, но также дается логическое решение противоречий между существующей возможностью получить эти блага и необходимостью избежать распространения самих ядерных взрывчатых устройств.

Подписание этого Договора само по себе является важным событием, которое заслуживает упоминания в указанном докладе. В 1964 году профессор Емельянов обратил внимание на только что вступивший в силу Договор о запрещении испытаний ядерного оружия в атмосфере, космосе и под водой и выразил всеобщую надежду, что будут предприняты дальнейшие шаги для решения международных проблем путем переговоров. Заключение Договора о нераспространении ядерного оружия является еще одним важным шагом на пути к достижению этой цели.

В этом кратком изложении наших основных успехов за период после 1964 года было бы упущением не отметить разработку Международным агентством по атомной энергии новой системы применения гарантий в соответствии с Договором о нераспространении ядерного оружия. Результаты этой работы и ее конструктивный дух говорят о том, что даже при решении сложных вопросов политического и технического характера можно достичь значительных успехов посредством международного сотрудничества. Я уверен, что именно поэтому МАГАТЭ значительно улучшило перспективы широкого и эффективного претворения в жизнь положений Договора о нераспространении ядерного оружия.

Что можно сказать о будущем? Я уже позволил себе сделать некоторые прогнозы в свете наших основных достижений, но до конца этого столетия мы еще имеем много других заманчивых перспектив. Я уверен, что используя ядерные двигатели, мы уже в этом столетии с помощью автоматических аппаратов непременно исследуем такие планеты, как Юпитер, и что человеку с помощью этих средств удастся побывать на Марсе.

Гигантские стационарные спутники земли с компактными ядерными реакторами будут транслировать телевизионные программы и другие передачи непосредственно в дома потребителей.

Можно с полной уверенностью сказать, что танкеры и другие торговые суда, работающие на ядерной энергии, в скором времени будут бороздить моря и океаны.

Мирные ядерные взрывы будут широко использоваться для скорейшего обнаружения месторождений полезных ископаемых, а также, возможно, для изменения топографии, – например, путем строительства гаваней, каналов и резервуаров.

Наши достижения не будут носить чисто научный и технический характер. Я уверен, что будут заключены международные соглашения по обеспечению безопасной перевозки радиоактивных материалов и их захоронения. Торговля ядерными материалами приобретет обычный характер только при условии, что ее мирное назначение будет подкреплено соответствующими соглашениями о гарантиях. Международное сотрудничество будет продолжать совершенствоваться и в меньшей степени станет делом правительств, все больше проявляясь в непосредственной деятельности ученых и промышленных кругов. В наш ядерный век будут построены под международной эгидой еще более мощные ускорители.

Я уверен, что все это осуществимо, если мы будем продолжать действовать благоразумно и ассигновать соответствующие средства, необходимые для развития атомной науки и техники. Спрос на мировые ресурсы сейчас как никогда велик. Весьма неотложным и в некотором смысле более важным делом является удовлетворение человеческих потребностей, чем потребностей в развитии техники. Даже в самых процветающих странах продолжает существовать бедность и голод, а экономический разрыв между индустриально развитыми и развивающимися странами все еще несоизмеримо велик. Однако ни одна цивилизация не сможет достичь своего величия, если уровень всей ее деятельности сводится к одному общему знаменателю. Совершенство в науке и технике так же необходимо для успешно развивающегося общества, как и совершенство в искусстве и других областях человеческой деятельности. В конечном итоге, решение этой проблемы будет зависеть от того, насколько общество сможет разработать и применить новую технику в целях дальнейшего развития наших природных и людских ресурсов.

Решение проблемы первоочередности должно заключаться не в подавлении научной инициативы, а в ее поощрении, даже когда мы стараемся удовлетворить другие неотложные потребности общества. Возможно, что наша Конференция также может сыграть свою роль в предоставлении возможности общественным и официальным кругам еще лучше осознать соответствие наших целей общественным интересам.

На этих конференциях стало почетной традицией чтить память видных ученых в области использования ядерной энергии, чья жизнь оборвалась со времени нашей последней Конференции. На этот раз список особенно печален, поскольку он включает имена председателя первой Женевской конференции Хоми Баба, известного и любимого всеми пионера в области ядерной энергии Отто Хана. Я предлагаю встать и почтить минутой молчания память сэра Джона Кокрофта, Лизе Мейтнер и Игоря Тамма, а также всех других ученых с мировым именем, которых больше нет с нами.

Позвольте мне выразить пожелание, чтобы наша Конференция по традиции проходила на высоком научном уровне, чтобы на ней велись такие же широкие и откровенные дискуссии, которыми были ознаменованы наши предыдущие встречи.

DISCURSO DE APERTURA

Glenn T. SEABORG
Presidente de la Conferencia

Asumo este puesto con el que me ha distinguido el Secretario General con gran humildad, un cierto orgullo y una abrumadora sensación de esperanza y de entusiasmo ante el futuro de la ciencia, nueva todavía, sobre la que vamos a tratar aquí.

Me presento con humildad, porque una conferencia de esta envergadura no puede dejar de recordarnos la inmensa deuda de gratitud que los hombres de hoy tenemos con los genios del pasado, cuya obra ha hecho posible la fantástica era de la ciencia en que vivimos. La adquisición de conocimientos por parte del hombre ha sido un proceso continuo e incluso desde la posición de ventaja de la historia sólo podemos identificar con dificultad los descubrimientos verdaderamente cruciales y a sus autores. Cuando examinamos incluso las aportaciones más espectaculares y más ricas en frutos, nos encontramos con que se basan sobre los cimientos asentados por pensadores anteriores, que muchas veces llegaron notablemente cerca de la cumbre más tarde alcanzada.

Nuestro campo de la energía nuclear no es ninguna excepción. En ninguna historia de sus orígenes se podrían omitir las revolucionarias aportaciones de Einstein, de Rutherford, de Bohr y, por supuesto, de

Fermi, Hahn, Meitner y Strassmann, que abrieron la última puerta hacia la obtención práctica de la energía encerrada en el núcleo del átomo.

Me presento con un cierto orgullo porque, a mi entender, mi propia patria ha cumplido la parte que le corresponde no sólo en el desarrollo de la utilización de la energía nuclear con fines pacíficos, sino también – lo que es igualmente importante – en el fomento y aplicación del concepto de que estos beneficios deben ponerse al alcance de todas las naciones. Espero que se me perdone si hago observar que esta Conferencia supone un homenaje, entre otras personas, al fallecido Presidente Dwight D. Eisenhower, cuyas propuestas ante la Asamblea General de las Naciones Unidas el 8 de diciembre de 1953 pusieron en marcha el programa de Atomos para la Paz y quien más tarde sugirió personalmente la convocatoria de la primera Conferencia de Ginebra.

Me presento con esperanza y entusiasmo, porque creo que estamos todavía en el umbral de una era de grandes descubrimientos y de consolidación y aprovechamiento de los descubrimientos efectuados en el pasado, era que, a finales del presente siglo, obtendrá de la energía nuclear beneficios inimaginables que contribuirán directamente a elevar el nivel de vida de la mayor parte de los seis a siete millares de millones de hombres que habitarán entonces la tierra.

Al ocupar este estrado, es inevitable recordar la sabiduría de aquellos hombres que han ostentado anteriormente el puesto de Presidentes de estas conferencias. Sólo Homi Bhabha, en 1955, tuvo el honor, bien merecido, pero con mucho la tarea más ardua, de hacer uso de la palabra en primer lugar. La elección del Dr. Homi Bhabha como Presidente de la primera Conferencia de Ginebra fue muy acertada. Con ella no solamente se rindió honor a este sobresaliente hombre de ciencia y de gobierno, sino que al nombrar un presidente del mundo en desarrollo, se subrayó el carácter universalista de las posibilidades y de las necesidades en el campo de la energía nuclear. Construyendo sobre los sólidos cimientos creados por el Dr. Bhabha, la India ha progresado hasta convertirse en el primero de los países en desarrollo que ha aplicado la energía nuclear como fuente primaria de energía eléctrica. Así, el Dr. Bhabha profetizó certeramente que la energía nuclear no sólo era de importancia para las naciones industrializadas del mundo, sino también para las naciones en desarrollo. De hecho, su tema básico fue el de que la gran mayoría de la población mundial que en la actualidad vive en los países en desarrollo debe alcanzar el nivel de vida, función de la energía, del que ya gozan los países industrializados mediante una amplia aplicación de la energía nucleoeléctrica.

Bhabha formuló también la predicción – sensacional en aquella fecha – de que, en el plazo de dos décadas, conseguiríamos la producción de energía útil a partir de la fusión nuclear, abriendo con ello el camino al empleo del deuterio del mar como fuente prácticamente ilimitada de energía. Con encomiable prudencia científica, el Dr. Bhabha predijo sólo que, dentro del citado plazo, se encontraría un método para liberar la energía de fusión de forma controlada. No anticipó cuándo se convertiría este descubrimiento en una fuente de energía comercial económica y de garantía. Mientras transcurre el tiempo hacia la consecución de la meta profetizada por el Dr. Bhabha, asumiré también el papel de adivino y diré que no descarto el hecho de que pueda conseguirse todavía en 1975 una producción positiva de energía de fusión y que casi con certeza se logrará hacia 1980. Si ello se convierte en realidad, el Dr. Bhabha, cuya vida terminó tan trágicamente cerca de esta ciudad mientras se hallaba en camino a una reunión internacional sobre energía atómica, quedará aún más consagrado como hombre de gran intuición científica.

El Presidente de la segunda Conferencia de Ginebra fue también un distinguido precursor nuclear de Francia: Francis Perrin. Al tener que hacer frente a la realidad de que la esperada meta de conseguir energía nucleoeléctrica en condiciones económicas era más difícil de alcanzar que lo anteriormente previsto, la segunda Conferencia de Ginebra se caracterizó por un relativo pesimismo. El Profesor Perrin previó certeramente que, en un principio, la energía nucleoeléctrica sería principalmente de utilidad en los países ya muy industrializados. La fase por él predicha llegó de hecho, pero, con la energía nucleoeléctrica ya implantada o en trance de serlo en naciones como la India, el Paquistán, Corea, China, Argentina y Brasil, vemos que tal fase se aproxima a su fin. Para 1980, es probable que estén en explotación centrales nucleares en más de 15 países actualmente calificados de naciones en desarrollo de acuerdo con los criterios de las Naciones Unidas.

El Profesor Perrin subrayó como uno de los aspectos más importantes de estas conferencias la función que representan levantando los velos del secreto en un importante campo de la ciencia, abriendo así canales de comunicación cerrados hasta la fecha. Ello es totalmente cierto y, de hecho, ha sido una de las consecuciones más importantes de las dos primeras Conferencias de Ginebra. La calidad de no secretos de casi todos los campos de importancia en la utilización de la energía nuclear con fines pacíficos está hoy en día bien consagrada y se da por supuesta, pero desgraciadamente, el anterior secreto relacionado con los fines militares ha quedado sustituido en algunos casos por otros controles impuestos en nombre del secreto comercial. Como nación cuyo bienestar se basa en gran parte en las aportaciones de la empresa privada, no dudamos de la importancia de ofrecer la adecuada compensación a la iniciativa científica privada. El punto importante y difícil es conseguir el equilibrio adecuado entre una amplia difusión de la información durante las fases iniciales de investigación y desarrollo, por una parte, y la debida oportunidad para proteger una tecnología detallada y avanzada, por otra. Como científico persuadido, al igual que el Profesor Perrin, de que el secreto anquilosa el progreso, me temo que el secreto que se guarda en nombre de los derechos comerciales privados resulte tan pernicioso como el anteriormente practicado en nombre de la seguridad nacional. Si la presente Conferencia llega a ofrecer el mismo incentivo para la publicación de ciertos datos que hoy son considerados como de propiedad privada, como lo hicieron las conferencias anteriores respecto de la publicación de información secreta, habrá conseguido un valioso fin.

La tercera Conferencia de Ginebra marcó un hito histórico. Vino a marcar claramente el comienzo de la era de la energía nucleoeléctrica económica. En efecto, fue posible afirmar en esa conferencia, a la que tuve el honor de asistir como presidente de la delegación de los Estados Unidos y en la que pronuncié el discurso de recapitulación, que se había conseguido romper la «barrera económica» en la tecnología de la energía nucleoeléctrica. Actualmente, con más de 150 millones de kilovatios de capacidad nuclear en explotación, en construcción o en fase de pedido en el mundo, serán pocos, si hay alguno, los que duden de la certeza de esta afirmación.

El Presidente de la última Conferencia de Ginebra fue mi amigo personal y colega, el Profesor V.S. Emelyanov, de la Unión Soviética. En la excelente revista que pasó al estado de la ciencia y de la tecnología nucleares, el Profesor Emelyanov recalcó sabiamente la importancia de la cooperación internacional e hizo mención especial de las crecientes funciones y eficacia del Organismo Internacional de Energía Atómica en el fomento de esta cooperación. Aludió también por primera vez a las prometedoras perspectivas de la utilización de la energía nuclear para la desalación en gran escala del agua del mar, aplicación que yo creo que veremos llegar a la práctica en el curso de nuestra vida.

Si miro retrospectivamente hacia los progresos realizados por la ciencia y la tecnología nucleares, me parece que hay un hecho fascinante que destaca por encima de todos los demás. Este campo de la ciencia es quizá el primero, y ciertamente el mayor, en el que los progresos no se han limitado a «suceder». Se habían efectuado grandes avances en muchos otros campos de la ciencia y de la tecnología antes de que entrara en escena la energía nuclear. Pero, hablando en términos generales, los avances en esos campos se produjeron como resultado de las acciones e interacciones de numerosos programas y personas diferentes y esencialmente independientes. En la esfera de la energía nuclear, por primera vez, el ritmo de progreso en todo un vasto campo de la ciencia ha quedado determinado en gran parte como consecuencia de las decisiones y actos deliberados de los gobiernos y – al comienzo – de tan sólo unos pocos de ellos. En consonancia con este punto de vista, incluso la cooperación internacional que nos reúne aquí debe su existencia a las decisiones y actos conscientes de los gobiernos, más que a los canales tradicionales de la cooperación científica.

Creo que ha sido un experimento fascinante y, en conjunto, de gran éxito, con vastas ramificaciones que se salen de sus fronteras inmediatas. Aunque el ingenio humano sigue siendo el ingrediente indispensable para el progreso científico, la experiencia que hemos adquirido en la esfera de la energía nuclear ha venido a demostrar de forma inequívoca que el ritmo y hasta la dirección del desarrollo pueden quedar profundamente afectados por la intervención en gran escala de las políticas seguidas por los gobiernos y por los recursos a disposición de éstos.

En un sentido aún más general, esta experiencia se ha repetido en el campo de la ciencia espacial. Pero yo creo que la energía nuclear no solamente sigue siendo el modelo, sino el ejemplo más característico por el momento, ya que en este caso hemos visto el desarrollo forzado de un campo de la ciencia y de la tecnología que tiene unas repercusiones prácticas y económicas, de gran importancia e inmediatas, para una gran proporción de los países del mundo.

Quizá el único antecedente histórico de lo que ha sucedido con la energía nuclear en los últimos 25 años sea una época anterior de descubrimientos en la que gobiernos de gran visión de aquel momento emprendieron la exploración, no precisamente de un nuevo mundo de la ciencia, sino de un nuevo mundo a través de los mares. Tal vez a los ojos de la historia las consecuencias de nuestras exploraciones en el nuevo mundo de la energía nuclear equiparen en importancia a las de aquella pasada época de descubrimientos.

He optado por hablar en términos muy generales de los antecedentes de nuestras conferencias y de la ciencia de que en ellas se trata. Es forzoso y natural que el mensaje real de esta Conferencia, la historia de siete años de avance desde que nos reunimos por última vez en 1964, se desprenda de las deliberaciones que se van a desarrollar a continuación. Pero no dejaré pasar totalmente por alto la oportunidad de hablar, como han hechos mis predecesores, de lo que ha sucedido y de lo que podemos esperar que ocurra en los años por venir.

El espectacular telón de fondo de nuestra Conferencia – al que ya he aludido – es que la energía nucleoeléctrica ya no está «a la vuelta de la esquina», sino que ya la tenemos aquí. La inversión total en las centrales nucleares con una capacidad de 150 millones de kilovatios a que me he referido superará los 45 000 millones de dólares cuando se encuentren terminadas en 1980 y, por supuesto, para esa fecha habrá otras muchas centrales próximas a su terminación, con una capacidad total de muchos millones de kilovatios adicionales. La potencia que generarán tales centrales en 1980 será casi igual a la capacidad total de generación de los Estados Unidos en la fecha en que se celebró nuestra última conferencia; y a finales de siglo, puede casi asegurarse que la mitad de los 1500 millones de kilovatios que se generarán en total en los Estados Unidos será de origen nuclear, siguiendo un esquema de crecimiento semejante otras regiones importantes del mundo.

Sin embargo, pese a este éxito – que creo merece el desgastado calificativo de fenomenal –, queda mucho por hacer y todavía hay problemas que acosan a nuestra floreciente nueva industria. La gran tarea que queda por resolver en la tecnología de la energía nucleoeléctrica es la de liberar los enormes recursos energéticos contenidos en los isótopos fértiles uranio-238 y torio, completando el desarrollo de un reactor reproductor económico. Esta meta consume en la actualidad las energías y recursos de la mayoría de los programas importantes de desarrollo de la energía nucleoeléctrica del mundo. No dudo que se conseguirá, pero los costos a que habrá que hacer frente y el tiempo necesario serán grandes. Creo que veremos la implantación de reactores reproductores rápidos comerciales del tipo refrigerado por metal líquido en varios países a mediados de la década de los años ochenta. Si bien antes de conseguir ese objetivo se podrán construir prototipos a gran escala – y de hecho deberían construirse –, tales prototipos no podrán por sí mismos competir económicamente.

En su mayor parte, los problemas que actualmente tenemos planteados en el campo de la energía nucleoeléctrica se centran en torno a la cuestión del medio ambiente y, precisamente por ello, resultan en cierto modo irónicos. En ningún nuevo campo de la ciencia y de la tecnología – quizá en ninguna empresa humana – se han aplicado voluntariamente restricciones tan intensas por garantizar la seguridad de sus actividades como en el campo de la energía nuclear. Como fruto de ello, en un país tras otro, se han logrado en las actividades nucleares records de seguridad que están a la cabeza de todas las actividades industriales. Se han desarrollado nuevos procedimientos y aparatos de compleja índole a fin de garantizar la contención de las radiaciones y de los materiales que intervienen en las actividades nucleares. Las naciones más destacadas en la esfera nuclear han adoptado reglamentos de un rigor sin precedente para cerciorarse de la ausencia de riesgos en sus actividades relacionadas con la energía nucleoeléctrica.

Objetivamente considerada, la energía nucleoeléctrica brinda una oportunidad sin rival para invertir la tendencia hacia una contaminación cada vez mayor del medio ambiente, producida por los combustibles tradicionales y por los productos de combustión, con todos los riesgos conocidos y desconocidos que entrañan.

Pese a ello, en una serie de países se han elevado fuertes voces — a veces estridentes — en contra de la utilización de la energía nucleoeléctrica basándose en razones relacionadas con el medio ambiente. Como custodios responsables de la confianza pública en la seguridad de las actividades nucleares, no debemos rehusar atenta consideración ni siquiera a los casos hipotéticos más improbables en relación con los riesgos de la energía nucleoeléctrica, y nunca lo hemos hecho. En realidad, para cerciorarnos de que estamos desarrollando nuestras actividades sin riesgos, los miembros de la comunidad nuclear hemos propugnado la política de tomar muy en serio los casos más improbables. En la actualidad las centrales nucleares dan lugar a la liberación de unas dosis de radiación tan pequeñas que un individuo que permaneciese de un modo continuo en los límites de una central nuclear estaría expuesto a una dosis adicional de radiaciones cada año inferior a la que recibimos aquellos de nosotros que hemos atravesado el Atlántico para asistir a esta Conferencia. La paciente explicación de hechos como estos ha producido sus frutos. Hoy día, creo que existe una comprensión pública notablemente mayor de la seguridad que ofrece la energía nucleoeléctrica que hace un año en esta misma fecha, y, con la comprensión del público, la consecuencia inevitable será la aceptación por parte de éste. La presente Conferencia nos proporciona un nuevo e importante medio para alcanzar esa meta.

Pasar revista a los progresos realizados en la esfera de la fusión controlada ha sido siempre una característica propia de estas Conferencias de Ginebra desde que el Dr. Bhabha expresó su fascinante predicción en 1955. En la actualidad, aunque aún se nos escapa la meta de conseguir la producción neta de energía a partir de la fusión controlada, sabemos mucho más que nunca acerca de los plasmas y de su comportamiento. Por lo tanto, como ya he dicho creo que la predicción del Dr. Bhabha de que se obtendría energía neta en el plazo de dos décadas a partir de 1955 fallará, en todo caso, sólo por un pequeño margen. Sin embargo, la transformación de este resultado en una fuente comercial, práctica y económica, de energía eléctrica es, en potencia, mucho más difícil y exigirá mucho más tiempo y no creo que pueda plasmarse en realidad mucho antes de finales del presente siglo.

En casi todos los restantes sectores del vasto campo de nuestra especialidad se han producido grandes progresos desde 1964. La aplicación de los radioisótopos, que hace ya mucho desde entonces que han asumido su puesto como poderoso instrumento de investigación, en medicina y en la industria, se ha multiplicado muchas veces desde 1964. Pero esto es sólo parte de la historia, porque las innovaciones más espectaculares se han producido en el número de nuevas aplicaciones. Desde los estimuladores del ritmo cardíaco humano a la provisión de energía para los experimentos lunares, los radioisótopos están desempeñando funciones que no se podrían haber realizado de ninguna otra manera.

Creo que existen buenas perspectivas de que se puedan desarrollar con éxito y entren en aplicación experimental en el plazo de cinco años los corazones artificiales accionados por radioisótopos. Más silenciosamente, los radioisótopos están creando una revolución en medicina que muchos expertos comparan con la introducción de los rayos X en 1896. La cámara médica de centelleo permite estudiar órganos enteros mientras funcionan, quedando expuesto el paciente a dosis de radiación mucho menores que las que exige el empleo de los rayos X tradicionales.

La conservación de alimentos por irradiación sobre una amplia base comercial es todavía una de las metas que tenemos por delante de nosotros, aunque están empezando a utilizarse algunas aplicaciones especializadas. En este caso, como en algunos otros, sospecho que se ha introducido un cierto desorden en el grado de prioridades por dejar de sopesar los riesgos frente a los beneficios. Cuando decenas de millones de habitantes de la tierra siguen sufriendo hambre y padeciendo de su acompañante más insidioso la malnutrición, la posibilidad de prolongar el período de almacenamiento de los productos alimenticios por irradiación y de reducir las pérdidas debidas a la infestación y a la formación de brotes no ha recibido la importancia que merece. Es éste otro sector en el que creo poder predecir, sin riesgo de error, que se producirá una amplia difusión dentro de una década o dos.

En el transcurso de esta Conferencia, se distribuirá un informe puesto al día sobre la utilización de los explosivos nucleares con fines pacíficos. No voy a tratar de complicar más aún la naturaleza todavía abierta a controversias de esta aplicación de la energía nuclear. En muchas naciones hay personas que creen con toda sinceridad que el aprovechamiento de los beneficios pacíficos de los explosivos nucleares dará lugar de alguna manera a un aumento de las presiones y de las oportunidades para adquirir armas nucleares, de las cuales no se pueden desgraciadamente distinguir los explosivos nucleares de carácter pacífico. Sin embargo, los que sostienen esta postura pasan por alto los progresos que se reflejan en el Tratado sobre la no proliferación de las armas nucleares. El artículo V de dicho Tratado demuestra no solamente un interés mundial por los explosivos nucleares de carácter pacífico, sino que aporta una solución lógica al conflicto que se plantea entre la amplia disponibilidad de estos beneficios y la necesidad de evitar la proliferación de los dispositivos explosivos nucleares propiamente dichos.

La adopción de este Tratado es de por sí un importante acontecimiento que bien merece ser mencionado en el presente informe sobre los progresos realizados. En 1964, el Profesor Emelyanov llamó la atención sobre el tratado, entonces recientemente adoptado, en virtud del cual se proscribían las pruebas con armas nucleares en la atmósfera, en el espacio ultraterrestre y bajo las aguas, y dio expresión a su esperanza, compartida por todos, de que se adoptarían nuevos pasos hacia la resolución de los problemas internacionales por vía de negociación. El tratado sobre la no proliferación constituye otro importante paso en este camino.

Sería negligencia no mencionar en el presente resumen de los principales progresos realizados desde 1964 el desarrollo por parte del Organismo Internacional de Energía Atómica de un nuevo marco para la aplicación de salvaguardias en virtud del Tratado sobre la no proliferación. Tanto los resultados logrados en estas tareas como el espíritu constructivo en que se han desarrollado ponen de relieve que se pueden alcanzar consecuciones positivas por conducto de la cooperación internacional, incluso en materias de gran complejidad política y técnica. Estoy persuadido de que con esta empresa el OIEA ha hecho aumentar grandemente las perspectivas de un amplio y eficaz cumplimiento del Tratado sobre la no proliferación.

¿Qué podemos decir sobre el futuro? He aventurado ya algunas predicciones al aludir a los puntos más destacados de los progresos efectuados recientemente, pero nos aguardan otras muchas interesantes perspectivas antes de que finalice el presente siglo. Creo que mediante el empleo de la propulsión nuclear se podrán examinar con instrumentos dentro del presente siglo los planetas extraterrestres tales como Júpiter y que es probable que el hombre visite Marte por el mismo medio.

Satélites gigantes estacionarios de la Tierra, con reactores nucleares de reducidas dimensiones a bordo, transmitirán programas de televisión y otros tipos de mensajes directamente a los receptores domésticos.

Casi con toda certeza, surcarán los mares petroleros de propulsión nuclear y otros buques mercantes accionados por el mismo sistema.

Los explosivos nucleares de carácter pacífico se emplearán en amplia escala para aumentar el rendimiento de los recursos naturales subterráneos y, posiblemente, para modificar la topografía, por ejemplo, mediante la construcción de puertos, canales y embalses.

Pero nuestros logros no serán exclusivamente de carácter científico y tecnológico. Creo que seremos testigos de acuerdos internacionales que garanticen el transporte y evacuación de los materiales radiactivos sin ningún género de riesgos. El comercio en la esfera de lo nuclear adquirirá carta de naturaleza, sujeto exclusivamente al requisito de que sus fines pacíficos queden garantizados por los oportunos arreglos de salvaguardia. Seguirá prosperando la cooperación internacional, pero dependerá menos de los gobiernos y pasará a ser una actividad más directa de los científicos y de la industria. En la frontera de la ciencia nuclear, se construirán aceleradores de mayores dimensiones bajo auspicios internacionales.

Creo que todos estos acontecimientos se convertirán en realidad si seguimos actuando con prudencia y tino al asignar a la ciencia y tecnología nucleares los recursos que merecen. Nunca han sido mayores las demandas ejercidas sobre los recursos del mundo. Muchas necesidades son de carácter urgente y, en algunos aspectos, más fundamentales que la necesidad de una tecnología de tipo avanzado. Hasta en las naciones más prósperas subsisten la pobreza y el hambre y el abismo que separa a las naciones industrializadas de aquellas en desarrollo es todavía decepcionalmente amplio. Sin embargo, ninguna civilización alcanzaría nunca la grandeza si se sometieran a un común denominador todas sus actividades. Para una sociedad floreciente es tan necesario sobresalir en la ciencia y en la tecnología como en las artes o en cualquier otro campo de actividad humano. En último extremo, para colmar las necesidades humanas que llevamos tan largo tiempo arrastrando hay que tener en cuenta el grado en que una sociedad es capaz de concebir y aplicar una nueva tecnología que haga prosperar nuestros recursos naturales y humanos,

La solución del problema de las prioridades no debe sofocar la iniciativa científica, sino alentarla, incluso cuando tratemos de satisfacer las demás necesidades urgentes. Quizá también en este aspecto pueda desempeñar una función nuestra Conferencia, aumentado la comprensión oficial y del público de la forma en que están relacionadas nuestras metas con las necesidades de la sociedad.

Se ha convertido en honorable tradición de estas conferencias tributar un homenaje a los científicos nucleares de prestigio fallecidos desde la reunión anterior. Esta vez, la lista es particularmente triste, ya que comprende los nombres del Presidente de la primera Conferencia de Ginebra, Homi Bhabha, y del grande y querido precursor de la energía nuclear, Otto Hahn. Para honrar su memoria, para honrar a Sir John Cockcroft, a Lise Meitner y a Igor Tamm, y a todos los demás miembros de esta comunidad internacional de características singulares que nos han abandonado desde que nos reunimos por última vez, propongo que nos pongamos en pie para guardar un momento de silencio.

Sólo me resta expresar el deseo de que esta Conferencia desarrolle sus tareas siguiendo la misma tradición de calidad científica y de franqueza y profundidad de diálogo que ha caracterizado nuestras anteriores reuniones.

OPENING ADDRESS

Sigvard EKLUND
Director General
of the International Atomic Energy Agency

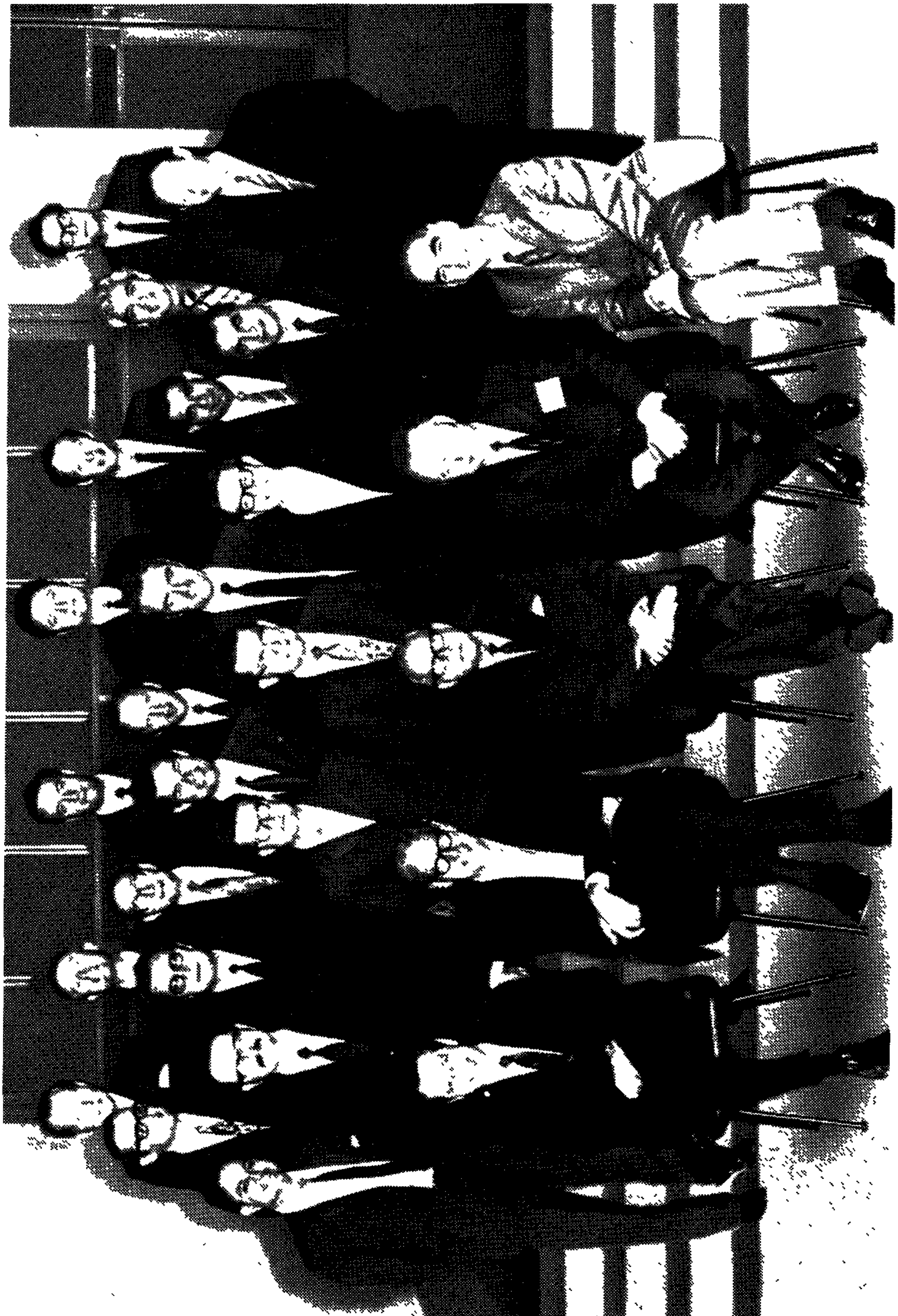
The first three "Geneva Conferences", held in 1955, 1958 and 1964, were devoted to exchange of information and to a careful analysis of the prospects which appeared to be opening up as a result of the harnessing of atomic energy for peaceful purposes. Many of you will certainly recall how the ups and downs of nuclear science and technology were reflected at those meetings. By the time of the Third Conference, experience – genuine experience – had been accumulated to enable us to appraise the competitive position of nuclear power with some confidence. Development of new reactor concepts was a theme which elicited a great deal of discussion.

Today, we have reached the stage where nuclear power can in some areas compete with conventional means of generating electricity; more than that, it is accounting for an ever-increasing proportion of installed capacity: at present the figure is 2%; but by 1980 it is expected to reach 13% and by the turn of the century, some 50%. Responsibility for the development and construction of reactors has, to a great extent, been taken over by industry. The large-scale introduction of nuclear power has become a matter of importance to economists, planners and government officials. Most of the problems of present-day reactors are now understood, at least in theory, and in some cases even solved.

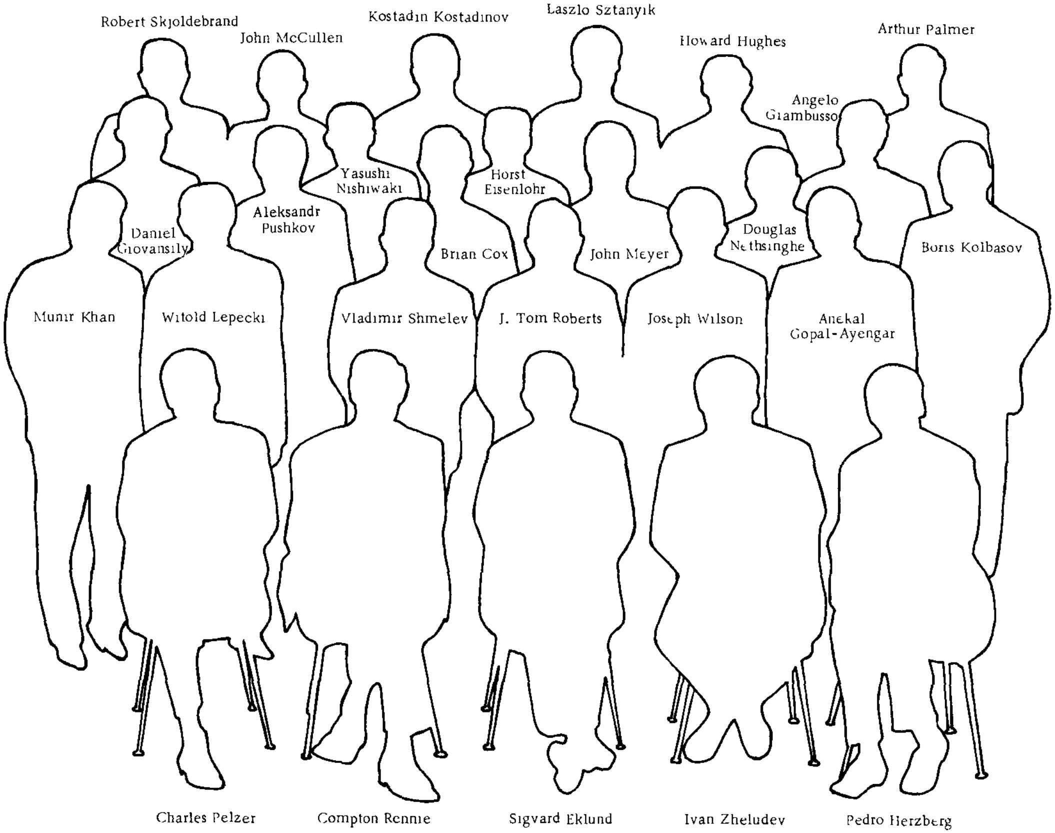
We are now faced with the practical problems of operating these plants, integrating the nuclear industry into national economies in an orderly fashion, securing adequate supplies of nuclear fuel, removing any barriers to international trade in nuclear materials and demonstrating to the consumer that the use of nuclear power will have no significant detrimental effects on the environment.

This trend towards the commercialization of nuclear power was recognized by the United Nations General Assembly when it declared that the present Conference should be convened, and requested that an agenda be drafted which would be "of interest to public officials, economists and planners as well as technologists". As you may imagine, the Secretary-General, with the assistance of the United Nations Scientific Advisory Committee and in co-operation with the IAEA, had no easy task in fulfilling that mandate.

We hope that the planning specialists and government officials, in particular those coming from developing countries, will find some guidance at this Conference, the scope of which in certain respects is larger than that of the previous ones. At the same time, we trust that the scientists and nuclear technologists will also find sessions which are particularly stimulating to them. We are sure that the Conference will provide an occasion for different groups to reach a better understanding of each other's problems and goals.



Mr. Sigvard Eklund and the Scientific Secretariat of the Conference



I think we can all agree that nuclear power has now come of age. Those of you who attended the World Energy Conference in Bucharest this June will recall the interesting sessions where nuclear power was discussed as an important supplement to our conventional energy sources. One may ask oneself why a special international conference on nuclear energy is needed at all, in the light of what I have just said. Nuclear power, however, because of the nature of the fuel used to produce it, has special international implications that set it apart from conventional means of generating electricity.

Firstly, the present generation of reactors represents only a transitory stage; international collaboration will facilitate reaching the next stages in the nuclear power industry – the commercial use of fast breeder reactors and, ultimately, the fusion reactor.

The strategic importance of nuclear materials which may be used either for peaceful or military purposes makes it vital to take international steps towards their regulation and control. Finally, because of their radiotoxicity and safety implications, nuclear fuels, especially when irradiated, have to be handled as potentially hazardous substances and these factors acquire a special importance when they are transported across national frontiers. The trade in nuclear materials is constantly growing and this growth is a necessary factor in the further development of the industry.

The growth of nuclear power depends on the supply of uranium. The European Nuclear Energy Agency and IAEA jointly conduct periodic surveys of world uranium and thorium reserves and have concluded that considerably more uranium must be found in the 1980s to meet the growing demand. If one considers that 85% of the deposits reported to exist in the Western World are located in only five countries, one may reasonably assume that large unexploited resources exist elsewhere, particularly in the developing countries. However, even the most intense exploitation of the world's uranium resources in conventional-type deposits might not be adequate to meet the long-term requirements of nuclear power, unless the fast breeder reactor comes into commercial use.

Another question that has come to the fore recently is that of uranium enrichment, at present mainly carried out by the United States of America and the Union of Soviet Socialist Republics. The increased use of nuclear power will create a need for additional enrichment capacity.

France has suggested a European enrichment plant, based on the French gaseous diffusion method. The Federal Republic of Germany, the Netherlands and the United Kingdom are collaborating in the development and exploitation of the gas centrifuge process, and South Africa has announced the development of a new enrichment method. The United States of America has recently declared its readiness to engage in exploratory multilateral discussions with other nations which have expressed an interest in constructing uranium enrichment facilities based on the United States gaseous diffusion technology. In addition to the discussions in the formal sessions on uranium enrichment, I am sure that the corridors of the Palais des Nations and the restaurants of Geneva will provide the venue for many personal contacts on this important subject during the Conference. The IAEA is also following these developments with interest, both because of the Agency's statutory function as a supplier of fuel and because of their future significance for international safeguards.

Another matter of great current interest – and one which has caused headaches in nuclear circles in several countries recently – is the public concern about the effect of nuclear power production on the environment. This concern has even reached the point where it has slowed down, if not impeded, the development of nuclear power in some countries. It is indeed paradoxical, and most unfortunate, that an industry, the nuclear industry, which has, from the beginning, taken such care to ensure that it will not harm the environment, and which can boast of a near perfect safety record, should have become the target of well-intentioned, but not always well-informed "environmentalists". As a matter of fact, if we do not consider hydro-power, which leads to special environmental problems, nuclear power is the cleanest means of producing electricity.

A major educational task lies before the atomic energy commissions, the nuclear industry, and the international organizations concerned. I do think there is a great need, in the whole controversy about the environment, to put things into the right perspective. This should not imply that there is no place for legitimate concern for the environment in the production of electricity by nuclear power; one has only to consider the improvements that can still be made with respect to thermal discharges. Also, although only very small amounts of radioactivity are released to the environment, containment is required for the much larger quantities that are not released, sometimes for periods of several centuries. With the projected growth of the industry, it will be essential that the excellent controls which have been exercised in the past continue to be applied, and even further developed, in the future. I trust this Conference will positively contribute to solving some of these problems.

The Secretary General has already mentioned the Treaty on the Non-Proliferation of Nuclear Weapons (NPT) which came into force on 5 March 1970. According to the Treaty, States not possessing nuclear weapons give up the option to develop, manufacture or receive them from any other country. States possessing nuclear weapons pledge themselves not to transfer nuclear weapons or explosive devices or to assist in their manufacture. The Agency was designated as the control organ of the Treaty, whereby non-nuclear-weapon States agree to accept Agency safeguards in order to verify the fulfilment of their obligations under the Treaty. The Agency is now in the process of negotiating safeguards agreements with non-nuclear-weapon States Parties to the Treaty. The Treaty has been signed by 98 non-nuclear-weapon States, 65 of which have ratified so far.

The Non-Proliferation Treaty, if properly implemented, should have as great an impact on the peaceful developments of nuclear energy as on the control of nuclear weapons. It is a source of satisfaction that the nuclear-weapon-States, pursuant to Article V of the Treaty which deals with peaceful nuclear explosions, have released a substantial amount of information on the status of this technology and its potentialities through the IAEA; this topic will be further discussed at a special session of this Conference. Article IV of the Treaty requires all Parties to facilitate and participate in the fullest possible exchange of equipment, materials and scientific and technological information for the peaceful uses of atomic energy with due consideration for the needs of the developing areas of the world. But NPT alone – even if fully implemented – would not solve the dilemma created by the military potential of the atom. I fully agree with the Secretary-General in his appeal for a complete test ban, which should open the way for further nuclear disarmament measures.

Nuclear technology is faced with an information explosion which can be coped with only by calling upon another technology embodied in the computer. The IAEA recently set up an International Nuclear Information System (INIS): a de-centralized, computer-based system which encompasses most of the world's nuclear literature in selected fields. A broadening of the subject scope is envisaged as the System develops. One of the System's products, a bibliographical list called the INIS Atomindex, is photo-typeset using the Agency-produced computer tape. The list of Conference papers which you have before you was produced in this way.

Out of the 72 countries participating in this Conference, some 50 will be presenting papers, as compared with 38 at the Third Conference in 1964. This is an indication of the growing interest of the developing countries in nuclear energy. For reasons that will become clear during the discussions, nuclear power is still confined to a small though steadily increasing group of developing countries. I hope the Conference will give us new pointers as to how we can accelerate the growth of nuclear power in the developing world. As you may have seen from the program, a panel on the introduction of nuclear power into the developing countries will take place during the Conference. This panel can be considered as part of the Agency's intensified efforts in this regard and will be followed up by more formal meetings during the autumn.

At the first United Nations Conference on the Peaceful Uses of Atomic Energy, in 1955, I attended the opening session from the gallery seated at the side of Dr. Glenn Seaborg, a privilege given to us as we were both to chair sessions at the Conference. I mention this at this solemn occasion when I have the privilege of seeing Dr. Seaborg next to me again, this time in his capacity as President of the Conference. For more than a decade Dr. Seaborg has served his country as chairman of the United States Atomic Energy Commission. When he now leaves that post, where his scientific approach and outstanding personality have had an impact on almost the whole world, I want to use this opportunity to thank him most wholeheartedly for his generous personal contribution in promoting the use of nuclear energy in order to bridge gaps between people, institutions and countries. All best wishes follow him for success in his future activities.

Translations into French, Russian and Spanish follow.

DISCOURS D'OUVERTURE

Sigvard EKLUND
Directeur général
de l'Agence internationale de l'énergie atomique

Les trois premières Conférences de Genève, organisées en 1955, 1958 et 1964, étaient consacrées à des échanges de documentation et à l'analyse approfondie des perspectives qui semblaient s'ouvrir à la suite de la domestication de l'énergie atomique à des fins pacifiques. Beaucoup d'entre vous se rappellent certainement comment les hauts et les bas de la science et de la technologie nucléaires se sont reflétés dans ces réunions. Au moment de la troisième Conférence, les leçons de l'expérience - une expérience vraiment digne de ce nom - s'étaient accumulées et permirent d'apprécier avec une certaine confiance la compétitivité de l'énergie d'origine nucléaire. La mise au point de nouvelles filières de réacteurs fut un thème qui suscita beaucoup de discussions.

Aujourd'hui, nous avons atteint le stade où, dans certaines régions, l'énergie nucléo-électrique peut concurrencer les moyens classiques de production d'électricité; en outre, elle représente une proportion toujours croissante de la capacité installée: 2% actuellement, probablement 13% en 1980 et environ 50% vers l'an 2000. La responsabilité de la mise au point et de la construction des réacteurs a, dans une grande mesure, été prise en charge par l'industrie. L'introduction en grand de l'énergie d'origine nucléaire est devenue une question importante pour les économistes, les planificateurs et les fonctionnaires. La plupart des problèmes posés par les réacteurs actuels sont maintenant bien compris, du moins en théorie, et dans certains cas ils sont même résolus.

Les problèmes pratiques qui se présentent maintenant à nous portent sur l'exploitation de ces centrales, l'intégration harmonieuse de l'industrie nucléaire dans les économies nationales, la recherche d'approvisionnements convenables de combustible nucléaire, la levée des barrières qui font obstacle au commerce international des matières nucléaires, la démonstration au consommateur de l'absence d'effets néfastes significatifs de cette industrie sur l'environnement.

L'Assemblée générale des Nations Unies a reconnu cette tendance lorsqu'elle a souhaité que l'on organise cette Conférence et que son ordre du jour «intéresse les fonctionnaires, les économistes et les planificateurs tout comme les technologues». Comme vous vous en doutez, la tâche du Secrétaire général pour s'acquitter de ce mandat, avec le concours du Comité consultatif scientifique de l'ONU et de l'AIEA, n'a pas été facile.

Nous espérons que les planificateurs et les fonctionnaires, en particulier ceux des pays en voie de développement, trouveront des enseignements à cette Conférence dont la portée est à certains égards plus vaste que celle des précédentes. En même temps, je suis sûr que les scientifiques et les technologues nucléaires trouveront nos travaux particulièrement intéressants. Nul doute que la Conférence fournisse à différents groupes l'occasion de mieux comprendre les problèmes et les objectifs de leurs partenaires.

Je pense que nous sommes tous d'accord pour dire que l'énergie nucléo-électrique a atteint sa majorité. Ceux d'entre vous qui ont assisté à la

Conférence mondiale de l'énergie, en juin dernier à Bucarest, se souviennent des séances intéressantes où l'on a étudié l'énergie d'origine nucléaire en tant que complément important des sources d'énergie classiques. On pourrait se demander pourquoi une conférence spécialement consacrée à l'énergie nucléaire est nécessaire après ce que je viens de dire. Mais cette forme d'énergie, à cause de la nature du combustible qu'elle utilise, a des incidences internationales particulières, bien distinctes de celles de l'énergie électrique classique.

Et d'abord, la génération de réacteurs actuelle ne représente qu'un stade transitoire; la collaboration internationale permettra d'atteindre plus facilement les prochaines étapes de l'industrie nucléo-électrique, à savoir l'industrialisation des réacteurs surgénérateurs rapides et, finalement, le réacteur à fusion.

D'autre part, l'importance stratégique des matières nucléaires qui peuvent être utilisées à des fins pacifiques ou militaires exige que l'on prenne des mesures internationales pour les réglementer et les contrôler. Enfin, à cause de leur radiotoxicité et des problèmes de sécurité qu'ils posent, les combustibles nucléaires, surtout lorsqu'ils sont irradiés, doivent être manipulés comme des substances dangereuses et cela devient tout particulièrement important lorsqu'ils sont transportés au-delà des frontières nationales. Le commerce des matières nucléaires ne cesse de connaître un développement qui est d'ailleurs nécessaire à l'essor de l'industrie atomique.

Le développement de l'énergie d'origine nucléaire dépend des approvisionnements d'uranium. L'Agence européenne pour l'énergie nucléaire et l'AIEA procèdent conjointement à des enquêtes périodiques sur les réserves mondiales d'uranium et de thorium, et elles ont constaté qu'il faudrait trouver beaucoup plus d'uranium dans quelque dix ans pour satisfaire la demande mondiale toujours en hausse. Si l'on considère que 85% des gisements signalés dans le monde occidental sont situés dans seulement cinq pays, on peut raisonnablement supposer que de vastes ressources inexploitées existent ailleurs, en particulier dans les pays en voie de développement. Mais même l'exploitation la plus intense de toutes les ressources mondiales d'uranium contenues dans des gisements de type classique risque de ne pas être suffisante pour satisfaire les besoins à long terme de l'énergie nucléo-électrique, à moins que le réacteur surgénérateur rapide ne soit industrialisé.

Une autre question qui est venue au premier plan est celle de l'enrichissement de l'uranium, actuellement effectué par les Etats-Unis d'Amérique et l'Union des Républiques socialistes soviétiques. L'utilisation accrue de l'énergie d'origine nucléaire créera un besoin de capacité d'enrichissement supplémentaire.

La France a suggéré la construction d'une usine d'enrichissement européenne, appliquant la méthode française par diffusion gazeuse. La République fédérale d'Allemagne, les Pays-Bas et le Royaume-Uni collaborent à la réalisation et à l'exploitation du procédé de centrifugation en phase gazeuse, et l'Afrique du Sud a annoncé la mise au point d'une nouvelle méthode d'enrichissement. Les Etats-Unis d'Amérique se sont déclarés prêts à engager des discussions multilatérales préparatoires avec les pays qui ont manifesté de l'intérêt pour la construction d'installations d'enrichissement fondées sur la technologie américaine de diffusion gazeuse. En plus des discussions officielles sur l'enrichissement de l'uranium, je suis sûr que les couloirs du Palais des Nations et les restaurants de Genève seront le théâtre de contacts personnels sur cet important sujet pendant la Conférence. L'AIEA, elle aussi, suit ces développements avec intérêt, d'abord parce que l'Agence est, de par son Statut, fournisseur de combustible, et ensuite à cause de leur importance future pour les garanties internationales.

Une autre question qui suscite actuellement un vif intérêt - et qui commence à donner des migraines dans les milieux nucléaires de plusieurs pays - est l'appréhension du public pour les conséquences de la production nucléo-électrique sur l'environnement. Ces craintes ont même fini par ralentir, sinon entraver, le développement de l'énergie d'origine nucléaire dans certains pays. Certes, il est paradoxal et très malencontreux qu'une industrie comme l'énergie atomique, qui dès le début a pris tant de soin pour ne pas nuire à l'environnement et peut se glorifier d'un dossier de sécurité presque parfait, soit en butte aux attaques de défenseurs du milieu humain pleins de bonnes intentions mais souvent mal informés. En fait, mise à part la centrale hydro-électrique qui pose des problèmes particuliers pour l'environnement, la centrale nucléaire est l'usine de production d'électricité la plus «propre».

Une vaste action d'éducation du public incombe aux commissions de l'énergie atomique, à l'industrie nucléaire et aux organisations internationales compétentes. Je pense qu'il y a grand besoin, dans toute la controverse sur l'environnement, de remettre les faits dans leur véritable perspective. Cela ne signifie pas qu'il n'y ait pas de place pour des inquiétudes légitimes pour le milieu dans la production d'électricité nucléaire; il suffit de considérer les perfectionnements que l'on peut encore apporter aux décharges thermiques. En outre, bien que seules de très petites quantités de radioactivité soient évacuées dans l'environnement, un confinement est nécessaire pour les quantités beaucoup plus grandes qui ne sont pas rejetées, et parfois pendant plusieurs siècles. Avec le développement prévu de cette industrie, il sera indispensable que le contrôle très strict qui a été exercé dans le passé soit maintenu et qu'il soit même ultérieurement amplifié. Je suis certain que cette Conférence contribuera à résoudre certains de ces problèmes.

Le Secrétaire général a déjà évoqué le Traité sur la non-prolifération des armes nucléaires (TNP) qui est entré en vigueur le 5 mars 1970. Aux termes de ce Traité, les Etats qui ne possèdent pas d'armes nucléaires renoncent à en mettre au point, à en construire ou à en recevoir d'aucun pays. Les Etats qui en possèdent s'engagent eux-mêmes à ne pas transférer des armes ou des engins explosifs nucléaires et à ne pas participer à leur fabrication. L'Agence a été désignée par le Traité comme organe de contrôle: les Etats non dotés d'armes nucléaires s'engagent à accepter les garanties de l'Agence pour vérifier qu'ils s'acquittent des obligations qui leur incombent en vertu du Traité. L'Agence a entamé la négociation d'accords de garanties avec des Etats non dotés d'armes nucléaires parties au Traité, lequel a été signé par 98 Etats non dotés d'armes nucléaires et ratifié jusqu'ici par 65 d'entre eux.

Le Traité sur la non-prolifération, s'il est convenablement exécuté, devrait avoir une incidence aussi grande sur le développement de l'énergie atomique à des fins pacifiques que sur le contrôle des armes nucléaires. C'est une source de satisfaction de constater que les Etats dotés d'armes nucléaires, conformément à l'article V du Traité qui concerne les explosions nucléaires pacifiques, ont communiqué à l'AIEA une masse considérable de documentation sur la situation de cette technologie et ses possibilités; ce sujet fera l'objet d'une séance spéciale de la Conférence. L'article V du Traité invite toutes les parties à faciliter l'échange le plus large possible de matériel, de matières et de documentation scientifique et technique sur l'application de l'énergie atomique à des fins pacifiques, et d'y participer, en tenant dûment compte des besoins des pays en voie de développement. Mais le TNP seul - même s'il est pleinement exécuté - ne résoudra pas le dilemme créé par le potentiel militaire contenu dans l'atome. Je me joins sans réserves à l'appel lancé par le Secrétaire général pour une interdiction totale des essais, qui devrait ouvrir la voie à d'autres mesures de désarmement nucléaire.

La technologie nucléaire connaît actuellement une prolifération explosive de sa documentation et doit recourir à l'aide d'une autre technologie, celle des ordinateurs. L'AIEA a mis au point un Système international de documentation nucléaire (INIS), décentralisé et mécanisé, qui embrasse la plus grande partie de la littérature nucléaire mondiale sur certains sujets. On envisage d'élargir la liste des sujets à mesure que le Système se développera. L'un des produits d'INIS, une liste bibliographique portant le nom d'Atomindex est imprimée photographiquement à partir de la bande d'ordinateur produite par l'Agence. La liste des mémoires de la Conférence qui vous a été remise a été obtenue de cette manière.

Sur les 72 pays qui participent à la Conférence, quelque 50 présenteront des communications (contre 38 à la troisième Conférence). Cela montre l'intérêt croissant des pays en voie de développement pour l'énergie nucléaire. Pour des raisons qui apparaîtront clairement pendant les discussions, l'énergie d'origine nucléaire est encore l'apanage d'un petit nombre, en augmentation constante, de pays en voie de développement. J'espère que cette Conférence nous donnera des indications sur la manière d'accélérer le développement de cette forme d'énergie dans le tiers monde. Comme l'indique le programme, un groupe d'étude de l'équipement nucléo-électrique des pays en voie de développement se réunira pendant la Conférence. On peut le considérer comme un exemple des efforts intensifs déployés par l'Agence à cet égard et il sera suivi par des réunions plus formelles cet automne.

En 1955, j'ai assisté à la séance d'ouverture de la première Conférence des Nations Unies sur l'utilisation de l'énergie atomique à des fins pacifiques depuis la tribune, à côté de M. Glenn Seaborg, à qui on avait accordé comme à moi ce privilège en qualité de président de séance. J'ai encore aujourd'hui le plaisir de voir M. Seaborg à côté de moi, mais cette fois en qualité de Président de la Conférence. Depuis plus de dix ans, M. Seaborg exerce les fonctions de président de la Commission de l'énergie atomique des Etats-Unis. Au moment où il quitte ce poste, où son esprit scientifique et son éminente personnalité se sont faits sentir dans presque tous les pays du monde, je profite de l'occasion qui m'est offerte de le remercier chaleureusement d'avoir par son action personnelle et généreuse contribué à promouvoir l'utilisation de l'énergie nucléaire pour combler les écarts qui séparent les peuples, les institutions et les pays. Et mes meilleurs voeux de réussite l'accompagneront dans la suite de sa carrière.

ВЫСТУПЛЕНИЕ НА ОТКРЫТИИ КОНФЕРЕНЦИИ

Зигвард ЭКЛУНД
Генеральный Директор
Международного агентства
по атомной энергии

Первые три Женевские конференции, состоявшиеся в 1955, 1958 и 1964 годах, были посвящены обмену информацией и тщательному анализу перспектив, которые открывались в результате использования атомной энергии в мирных целях. Многие из вас несомненно помнят, какое широкое отражение нашли успехи и неудачи атомной науки и техники в материалах этих Конференций. К моменту проведения Третьей Конференции был накоплен большой опыт, который позволил нам с определенной уверенностью оценить конкурентоспособность ядерной энергетики. Разработка новых типов реакторов явилась темой, которая вызвала широкую дискуссию.

Сегодня мы достигли стадии, когда ядерная энергетика в некоторых районах может конкурировать с обычными средствами производства электроэнергии; более того, наблюдается постоянный рост доли ее установленной мощности: в настоящее время она равна 2%, ожидается, что к 1980 году она достигнет 13%, а к концу этого века - примерно 50%. Ответственность за разработку и строительство реакторов, в значительной степени, ложится на промышленность. Широкое внедрение ядерной энергетики стало делом особой важности для экономистов, плановиков и сотрудников государственных учреждений. В настоящее время большинство проблем, связанных с разработкой и эксплуатацией современных реакторов, обосновано, по крайней мере теоретически, и частично - практически.

Сейчас мы стоим перед решением практических проблем эксплуатации этих реакторов, включения ядерной промышленности в национальную экономику, обеспечения соответствующей поставки ядерного топлива, ликвидации всяческих барьеров в международной торговле ядерными материалами. Мы также должны наглядно показать потребителям, что использование ядерной энергии не окажет какого-либо значительного вредного воздействия на окружающую нас среду.

Эта тенденция к использованию ядерной энергетики на коммерческой основе была одобрена Генеральной Ассамблеей Организации Объединенных Наций, где была отмечена необходимость созыва данной Конференции и подготовки повестки дня, которая отвечала бы "интересам правительственных чиновников, экономистов, плановиков, а также технических специалистов". Как вы знаете, Генеральный Секретарь с помощью Научно-консультативного комитета Организации Объединенных Наций и в сотрудничестве с МАГАТЭ выполнил нелегкую задачу.

Мы надеемся, что специалисты в области планирования и сотрудники государственного аппарата, особенно из развивающихся стран, приобретут на данной Конференции в некотором отношении бо́льший опыт, чем на предыдущих Конференциях. В то же время мы считаем, что ученые и специалисты, работающие по атомной тематике, также проявят большой интерес к проведению многих заседаний. Мы уверены, что на Конференции люди различных взглядов будут иметь возможность достичь лучшего понимания стоящих перед ними задач.

Я думаю, все мы можем согласиться с тем, что ядерная энергетика в настоящее время достигла своего совершеннолетия. Те, кто присутствовал на Всемирной энергетической конференции в Бухаресте в июне 1971 года, помнят интересные заседания, на которых ядерная энергетика рассматривалась как дополнение к нашим обычным источникам энергии. Каждый может задать себе вопрос, для чего вообще нужно проводить специальную международную конференцию по использованию ядерной энергии в свете того, о чем я только что говорил. Однако ядерная энергия из-за характера топлива, используемого для ее производства, имеет особое международное значение, что ставит ее на особое место среди обычных средств производства электроэнергии.

Современные типы реакторов представляют только переходную стадию; международное сотрудничество будет способствовать достижению следующих стадий в развитии ядерно-энергетической промышленности – коммерческого использования реакторов-размножителей на быстрых нейтронах и, в конечном итоге, термоядерного реактора.

Стратегическое значение ядерных материалов, которые могут быть использованы как для мирных, так и для военных целей, говорит о жизненно важной необходимости предпринять шаги в международном масштабе, направленные на осуществление контроля за этими материалами. Наконец, вследствие радиотоксичности и необходимости обеспечения безопасности, с ядерным топливом, особенно когда оно облучено, следует обращаться как с потенциально опасным веществом. Эти факторы приобретают особое значение, когда ядерное топливо перевозится через национальные границы. Торговля ядерными материалами постоянно расширяется, что является необходимым фактором в дальнейшем промышленном прогрессе.

Развитие ядерной энергетики зависит от снабжения ураном. Европейское агентство по ядерной энергии и МАГАТЭ периодически подготавливают совместные обзоры мировых запасов урана и тория. Они пришли к выводу, что в 80-годы необходимо будет найти более богатые месторождения урана в целях удовлетворения растущих потребностей. Если считать, что 85% залежей урана на Западе приходится только на пять стран, то можно достоверно предположить о наличии крупных неразведанных месторождений, особенно в развивающихся странах. Однако даже при самой интенсивной разработке мировых запасов урана невозможно будет удовлетворить долгосрочные потребности ядерной энергетики, если реакторы-размножители на быстрых нейтронах не начнут эксплуатироваться на коммерческой основе.

Одной из самых актуальных за последнее время стала проблема обогащения урана, которое в настоящее время осуществляется главным образом Соединенными Штатами Америки и Союзом Советских Социалистических Республик. Все более широкое использование ядерной энергии вызовет необходимость увеличения масштабов обогащения урана.

Франция предложила построить в Европе завод по обогащению урана с использованием французского газодиффузионного метода обогащения. Федеративная Республика Германия, Нидерланды и Соединенное Королевство сотрудничают в разработке и использовании процесса обогащения урана с помощью газовых центрифуг, а Южная Африка объявила о разработке нового метода обогащения. Соединенные Штаты Америки недавно заявили о своей готовности начать многостороннее рассмотрение этого вопроса с другими государствами, которые выразили заинтересованность в строительстве установок по обогащению урана на основе американской газодиффузионной технологии. Я уверен, что вопросы обогащения урана будут обсуждаться не только на официальных заседаниях, но и в кулуарах Дворца Наций и ресторанах Женевы, которые явятся местом установления многих личных контактов по этому важному вопрсу. МАГАТЭ тоже с интересом следит за развитием событий. Это объясняется ее уставными обязательствами как поставщика топлива и тем фактом, что эта деятельность будет иметь большое значение для международных гарантий.

Другим важным вопросом, который недавно вызвал беспокойство у специалистов по ядерной энергии ряда стран, является озабоченность общественности в отношении влияния ядерной энергии на окружающую нас среду. Эта озабоченность достигла такой стадии, когда она затормозила, если вообще не приостановила развитие ядерной энергетики в некоторых странах. Поистине парадоксально и достойно сожаления то, что такой отрасли промышленности как ядерная, в которой с самого начала ее развития предпринималось так много усилий, чтобы не нанести ущерба окружающей среде, и которая может гордиться обеспечением почти полной безопасности, пришлось стать мишенью для нападок со стороны благонамеренных, но не всегда достаточно информированных "инвайрэнмэнталистов". Фактически, если не считать гидроэнергетики, которая создает особые проблемы для окружающей среды, ядерная энергетика является наиболее чистым средством производства электроэнергии.

Комиссиям по атомной энергии, отраслям ядерной промышленности и заинтересованным международным организациям предстоит проделать большую разъяснительную работу. Я полагаю, что во всей этой проблеме загрязнения окружающей нас среды необходимо прийти к всеобщему взаимопониманию. Это не означает, что при производстве электроэнергии с помощью ядерной энергии не должна проявляться законная озабоченность в отношении защиты окружающей среды; следует серьезно продумать о возможных усовершенствованиях в отношении сброса термальных отходов. Хотя в окружающую нас среду выбрасываются небольшие количества радиоактивных веществ, для хранения радиоактивных отходов в течение нескольких столетий потребуются большие емкости. Учитывая перспективы развития данной отрасли промышленности, необходимо в дальнейшем совершенствовать существующую систему контроля. Я уверен, что Конференция внесет свой положительный вклад в решение многих из указанных проблем.

Генеральный Секретарь уже говорил относительно Договора о нераспространении ядерного оружия, который вступил в силу 5 марта 1970 года. В соответствии с Договором, государства, не обладающие ядерным оружием, обязуются не разрабатывать, не производить и не приобретать его от какой-либо другой страны. Государства, обладающие ядерным оружием, берут на себя обязательство не передавать ядерное оружие или взрывные устройства и не оказывать помощи в их производстве. На Агентство возложено осуществление контрольных функций по Договору, при этом государства, не обладающие ядерным оружием, соглашаются принять гарантии Агентства с целью проверки выполнения их обязательств в соответствии с Договором. В настоящее время Агентство ведет переговоры о заключении соглашений по гарантиям с государствами-участниками Договора, не обладающими ядерным оружием. Договор подписали 98 государств, не обладающих ядерным оружием, 65 из которых уже ратифицировали его.

Договор о нераспространении, при его надлежащем выполнении, должен оказать огромное влияние как на мирное использование ядерной энергии, так и на контроль за ядерным оружием. Вызывает удовлетворение тот факт, что государства, обладающие ядерным оружием, в соответствии со Статьей V Договора, касающейся мирных ядерных взрывов, опубликовали через МАГАТЭ значительное количество информационных материалов по вопросам технологии проведения таких взрывов и их потенциальных возможностей; обсуждение данной темы будет продолжено на специальном заседании Конференции. Статья IV Договора требует, чтобы все государства-участники оказывали содействие и участвовали в возможном самом полном обмене оборудованием, материалами, а также научно-технической информацией в области мирного использования атомной энергии, с должным учетом нужд развивающихся районов мира. Однако, даже если Договор будет полностью выполнен, это не решит дилемму, порожденную военным потенциалом атома. Я полностью согласен с Генеральным Секретарем, который призвал к полному запрещению испытаний ядерного оружия, что будет содействовать дальнейшим успехам в области ядерного разоружения.

В связи с развитием ядерной техники значительно возросла потребность в получении новейших информационных материалов. Эта задача может быть решена лишь с помощью электронно-вычислительных машин. МАГАТЭ недавно создало Международную систему ядерной информации (ИНИС): децентрализованную, основанную на электронно-вычислительной технике систему, которая аккумулирует в себе большую часть мировой литературы по различным вопросам мирного использования ядерной энергии. Предусмотрено расширение тематического охвата по мере развития самой системы. Выпуск одного из изданий данной системы – библиографического перечня Атоминдекс ИНИС, – основан на применении фотопечатного способа размножения на компъютерной ленте, изготовляемой в Агентстве. Список докладов Конференции, который Вы имеете перед собой, был изготовлен указанным способом.

Из 72 стран, участвующих в Конференции, около 50 стран представят свои доклады, в то время как на Третьей Конференции, состоявшейся в 1964 году, доклады были представлены 38-ю странами. Это свидетельствует о растущем интересе развивающихся стран к ядерной энергии. По ряду причин, которые станут ясными во время дискуссий, ядерная энергетика начинает внедряться лишь в немногих развивающихся странах, число которых постепенно растет. Я надеюсь, что на Конференции будут определены новые направления более широкого использования ядерной энергетики в развивающемся мире. Как Вы могли увидеть из программы, во время Конференции будет проведено совещание экспертов по вопросам внедрения ядерной энергетики в развивающихся странах. Это совещание можно рассматривать как часть активной деятельности Агентства в этой области. Осенью 1971 года будет проведено несколько совещаний более официального характера.

На Первой конференции Организации Объединенных Наций по использованию ядерной энергии в мирных целях, состоявшейся в 1955 году, я находился во время открытия Конференции на трибуне и сидел рядом с д-ром Гленном Сиборгом. Эта привилегия была предоставлена нам, поскольку мы оба были председателями заседаний Конференции. Я упоминаю об этом на данном торжестве потому, что имею возможность видеть д-ра Сиборга, сидящим снова рядом со мной, но сейчас уже в роли Председателя Конференции. На протяжении более чем десятилетия д-р Сиборг являлся Председателем Комиссии по атомной энергии Соединенных Штатов Америки. И теперь, когда он покидает этот пост, на котором его научный подход и выдающиеся личные способности оказали влияние почти на весь мир, я хотел бы воспользоваться возможностью, чтобы от всего сердца поблагодарить его за тот большой личный вклад в дело использования ядерной энергии, который способствовал взаимопониманию между народами, учреждениями и странами. Пожелаем ему всего наилучшего в его будущей деятельности.

DISCURSO DE APERTURA

Sigvard EKLUND
Director General
del Organismo Internacional de Energía Atómica

Las tres primeras «Conferencias de Ginebra», celebradas en 1955, 1958 y 1964, estuvieron dedicadas al intercambio de información y a un minucioso análisis de las perspectivas que al parecer se abrían como consecuencia del dominio de la energía atómica para fines pacíficos. Por supuesto, muchos de Vds. recordarán cómo quedaron reflejados en esas reuniones los altibajos de la ciencia y de la tecnología nucleares. Cuando se celebró la tercera Conferencia, se había acumulado suficiente experiencia - auténtica experiencia – que nos permitió evaluar con un cierto espíritu de confianza la posición de competencia de la energía nucleoeléctrica. El desarrollo de reactores de nueva concepción fue un tema que suscitó largos debates.

Actualmente, hemos llegado a un estadio en el que la energía nucleoeléctrica puede competir en algunas regiones con los medios tradicionales de generación de electricidad; es más, representa una proporción constantemente creciente de la capacidad instalada: hoy día, la cifra es del 2%, pero se espera que para 1980 llegue al 13% y a finales de siglo a alrededor del 50%. En gran parte, la industria ha asumido la labor de desarrollar y construir reactores. La implantación en gran escala de la energía nucleoeléctrica se ha convertido en una cuestión de importancia para los economistas, los planificadores y los hombres de estado. En la actualidad, se comprenden, al menos en teoría, la mayoría de los problemas que plantean los reactores actuales, problemas que incluso se han resuelto en algunos casos.

Hoy día, hemos de hacer frente a los problemas prácticos que entraña la explotación de estas centrales, integrando la industria nuclear en el marco de las economías nacionales de un modo ordenado, asegurando los apropiados suministros de combustibles nucleares, suprimiendo toda barrera que se oponga al comercio internacional de materiales nucleares y demostrando al usuario que el empleo de la energía nucleoeléctrica no ejercerá efecto nocivo alguno de importancia sobre el medio ambiente.

Esta tendencia hacia la comercialización de la energía nucleoeléctrica fue reconocida por la Asamblea General de las Naciones Unidas en la que se declaró que debería convocarse la actual Conferencia y se pidió que se redactara un programa que interesara a los funcionarios públicos, economistas y planificadores, así como a los técnicos. Como pueden imaginar, el Secretario General, con la asistencia del Comité Científico Consultivo y en cooperación con el OIEA, no ha tenido una tarea fácil en dar cumplimiento a tal mandato.

Esperamos que los especialistas en planificación y los funcionarios gubernamentales, sobre todo los que vienen de los países en desarrollo, encuentren una cierta orientación en esta Conferencia, cuyo alcance es en ciertos aspectos mayor que el de las anteriores. A la vez, confiamos en que los hombres de ciencia y los tecnólogos nucleares encontrarán también sesiones que les ofrezcan especial aliciente. Estamos seguros de que la Conferencia proporcionará una ocasión para que grupos diferentes lleguen a una comprensión recíproca más profunda de sus problemas y metas.

Creo que todos podemos convenir en que la energía nucleoeléctrica ha alcanzado la mayoría de edad. Aquellos de Vds. que en el pasado mes de junio asistieron en Bucarest a la Conferencia Mundial de la Energía recordarán las interesantes sesiones en las que se discutió la energía nucleoelétrica como un importante suplemento de nuestras fuentes energéticas clásicas. Puede uno preguntarse por qué se precisa en absoluto una conferencia internacional especial sobre la energía nuclear, en vista de lo que acabo de decir. Sin embargo, la energía nucleoeléctrica, dada la naturaleza del combustible utilizado para producirla, tiene especiales repercusiones internacionales que la colocan en lugar aparte de los medios tradicionales de generación de electricidad.

En primer lugar, la actual generación de reactores representa tan solo una etapa transitoria; la colaboración internacional ha de hacer posible que se alcancen los siguientes estadios en la industria de la energía nucleoeléctrica: el empleo comercial de los reactores reproductores rápidos y, finalmente, el reactor de fusión.

La importancia estratégica de los materiales nucleares que pueden utilizarse bien para fines pacíficos o bien para fines militares presta vital importancia a la adopción de medidas internacionales con miras a su regulación y control. Finalmente, debido a sus aspectos de radiotoxicidad y seguridad, los combustibles nucleares – sobre todo después de irradiados – han de manejarse como sustancias potencialmente peligrosas y estos factores adquieren especial importancia cuando se transporta a través de las fronteras nacionales. El comercio de materiales nucleares aumenta constantemente y este crecimiento es un elemento necesario para el ulterior desarrollo de la industria.

El desarrollo de la energía nucleoeléctrica depende del suministro de uranio. La Agencia Europea para la Energía Nuclear y el OIEA llevan a cabo conjuntamente estimaciones periódicas de las reservas mundiales de uranio y de torio y han llegado a la conclusión de que debe encontrarse una cantidad considerablemente mayor de uranio en la década de los años ochenta para poder satisfacer la creciente demanda. Si se tiene presente que el 85% de los yacimientos dados a conocer se encuentran en el mundo occidental, en solamente cinco países, se puede suponer razonablemente que en otros lugares existen grandes recursos por explotar, en especial en los países en desarrollo. Sin embargo, ni siquiera la explotación más intensiva de los recursos de uranio del mundo de los yacimientos de tipo convencional podría no resultar adecuada para satisfacer los requisitos a largo plazo de la energía nucleoeléctrica, a menos que entren en explotación comercial los reactores reproductores rápidos.

Otra cuestión que ha pasado recientemente a primer plano es la del enriquecimiento del uranio, que en la actualidad llevan a cabo principalmente los Estados Unidos y la Unión Soviética. La difusión del empleo de la energía nucleoeléctrica hará preciso aumentar la capacidad de enriquecimiento.

Francia ha sugerido una planta europea de enriquecimiento, basada en el método francés de difusión gaseosa. La República Federal de Alemania, los Países Bajos y el Reino Unido están colaborando en el desarrollo y explotación del proceso de centrifugación en fase gaseosa, y Sudáfrica ha anunciado el desarrollo de un nuevo método de enriquecimiento. Los Estados Unidos han declarado recientemente que están dispuestos a entrar en negociaciones exploratorias multilaterales con otras naciones que han manifestado su interés por construir instalaciones de enriquecimiento de uranio basadas en la tecnología norteamericana de difusión gaseosa. Además de los debates que se desarrollen en las sesiones oficiales en torno al enriquecimiento del uranio, estoy seguro de que los pasillos del Palacio de las Naciones y los restaurantes de Ginebra serán lugar de reunión para tratar, mediante contactos personales, este importante tema a lo largo del transcurso de la Conferencia. El OIEA está siguiendo también estos acontecimientos con interés, tanto en vista de la función estatutaria del Organismo como suministrador de combustible como a causa de su futura importancia en relación con las salvaguardias internacionales.

Otra cuestión de gran interés actual – y que ha dado lugar recientemente a quebraderos de cabeza en los círculos nucleares de diversos países – es la preocupación pública en torno a los efectos de la producción de energía nucleoeléctrica sobre el medio ambiente. Tal preocupación ha llegado al punto de reducir el ritmo de desarrollo de la energía nucleoeléctrica en algunos países, si no a impedirlo del todo. Ciertamente, es un hecho paradójico y desafortunado que una industria – la nuclear – que desde un principio ha adoptado tales precauciones para no ejercer efectos nocivos sobre el medio ambiente y que puede jactarse de haber logrado un record de seguridad casi perfecto, se haya convertido en el blanco de «defensores del medio ambiente», bien intencionados pero no siempre debidamente informados. El hecho es que, si prescindimos de la energía hidroeléctrica, que plantea problemas ambientales especiales, la energía de origen nuclear constituye el medio para producir electricidad que menos contribuye a la contaminación del ambiente.

Las comisiones de energía atómica, la industria nuclear y las organizaciones internacionales interesadas tienen ante sí una importante labor educativa por realizar. En toda la controversia en torno al medio ambiente, creo que es muy necesario tener las ideas claras. Ello no quiere decir que no haya lugar a preocuparse legítimamente por el ambiente en relación con la producción de electricidad de origen nuclear; basta con considerar los perfeccionamientos que aún caben respecto del desprendimiento de energía térmica. Igualmente, aunque sólo se descargan en el medio ambiente dosis de radiactividad muy pequeñas, es necesaria una contención para las cantidades mucho mayores que no se descargan, a veces por periodos de varios siglos. Ante el previsto crecimiento de la industria nuclear, es de vital importancia que se sigan aplicando en el futuro, e incluso perfeccionando aún más, los excelentes controles que se han venido aplicando hasta ahora. Confío en que esta Conferencia contribuya de un modo positivo a la resolución de algunos de estos problemas.

El Secretario General ha mencionado ya el Tratado sobre la no proliferación de las armas nucleares (TNP) que entró en vigor el 5 de marzo de 1970. En virtud de este Tratado los Estados no poseedores de armas nucleares renuncian a desarrollarlas, fabricarlas o recibirlas de ningún otro país. Por su parte, los Estados poseedores de las citadas armas se comprometen a no facilitar armas o dispositivos explosivos nucleares y a no ayudar a su fabricación. El Organismo fue designado órgano de control del Tratado, en virtud de lo cual los Estados no poseedores de armas nucleares convienen en aceptar las salvaguardias del Organismo, al objeto de verificar el cumplimiento de sus obligaciones en virtud del Tratado. Actualmente, el Organismo está procediendo a negociar acuerdos de salvaguardia con los Estados no poseedores de armas nucleares Partes en el Tratado. Este ha sido firmado por 98 Estados no poseedores de armas nucleares, 65 de los cuales lo han ratificado ya.

El Tratado sobre la no proliferación, debidamente aplicado, debe tener una influencia tan grande sobre la utilización pacífica de la energía nuclear como sobre el control de las armas nucleares. Es motivo de satisfacción el que los Estados poseedores de armas nucleares, actuando en consonancia con el artículo V del Tratado, hayan dado a conocer, por conducto del OIEA, importante información sobre el estado actual de esta tecnología y las posibilidades que ofrece; este punto se examinará en mayor detalle en una sesión especial de esta Conferencia. El artículo IV del Tratado exige de sus Partes que faciliten y participen en el más amplio intercambio posible de equipo, materiales e información científica y tecnológica relativa a la utilización de la energía atómica con fines pacíficos, teniendo debidamente en cuenta las necesidades de las regiones en desarrollo del mundo. Pero el TNP por sí solo - aunque se le dé pleno cumplimiento - no resolverá el dilema planteado por el potencial militar del átomo. Convengo plenamente con el Secretario General en su llamamiento a una proscripción total de las pruebas, que debería abrir el camino hacia nuevas medidas de desarme nuclear.

La tecnología nuclear ha de hacer frente a una explosión de información, situación que sólo podrá resolverse recurriendo a otra tecnología: la de las computadoras. El OIEA ha puesto recientemente en marcha un Sistema Internacional de Documentación Nuclear (INIS); se trata de un sistema descentralizado, basado en el empleo de computadoras, que abarca la mayoría de la literatura nuclear del mundo, en sectores especializados. Conforme se vaya desarrollando el Sistema, se tiene previsto ampliar su repertorio de temas. Uno de los productos de este Sistema, una lista bibliográfica denominada «INIS Atomindex», se compone por fototipia utilizando la cinta producida por la computadora del Organismo. La lista de las memorias presentadas en esta Conferencia que se ha distribuido se ha preparado de esta forma.

De los 72 países que participan en la actual Conferencia, presentarán memorias unos 50, en comparación con 38 en la tercera Conferencia celebrada en 1964. Ello demuestra el creciente interés de los países en desarrollo por la energía nuclear. Por razones que se aclararán en el curso de las deliberaciones, la energía nucleoeléctrica está todavía limitada a un pequeño grupo - aunque constantemente creciente - de países en desarrollo. Confío en que la Conferencia nos dé nuevas indicaciones sobre la forma en que podemos acelerar la proliferación de la energía de origen nuclear en el mundo en desarrollo. Como se indica en el «Programa», durante la Conferencia se reunirá un grupo de expertos sobre la implantación de la energía nucleoeléctrica en los países en desarrollo. Este grupo de expertos puede considerarse como parte de los esfuerzos intensificados del Organismo en este sentido y será complementado en el próximo otoño en reuniones de carácter más oficial.

En la primera Conferencia de las Naciones Unidas sobre la Utilización de la Energía Atómica con Fines Pacíficos, en 1955, asistí a la sesión de apertura desde la galería, sentado al lado del Dr. Glenn Seaborg, distinción que se nos concedió ya que ambos habíamos de presidir sesiones de la Conferencia. Menciono esta circunstancia en esta solemne ocasión en que me cabe el privilegio de ver de nuevo al Dr. Seaborg próximo a mí, esta vez en su calidad de Presidente de la Conferencia. Durante más de una década, el Dr. Seaborg ha venido prestando servicios a su patria como Presidente de la Comisión de Energía Atómica de los Estados Unidos. Ahora que cesa en su cargo, desde el que ha influido, con su visión científica y su sobresaliente personalidad, prácticamente sobre el mundo entero, deseo aprovechar la oportunidad para agradecerle de todo corazón su generosa aportación personal a la causa de servirse de la energía nuclear para salvar las barreras que separan a las personas, las instituciones y los pueblos. Le deseo todo género de éxitos en sus futuras actividades.

OPENING ADDRESS

I. I. RABI
Member of the United Nations Scientific Advisory Committee

Through the decades and even the centuries it has been the dream of the great spirits in the various countries to create an organization which would unite the aspirations of peoples to live in peace. The United Nations is the most recent realization of this aspiration. The United Nations now is the congress of humanity which was born out of the fire and agony of the great war of 1939 to 1945, and which will be remembered as the time when the products of the highest technology were perverted to the wholesale destruction of people and their cultural monuments. The United Nations is the latest attempt of mankind to seek a political instrument for the advancement of peace. Real peace means more than the absence of violent war. To fulfil human expectations, peace must be a condition which permits the release of the latent creative energies of all people to the end of enhancing and elevating the quality of human life on this globe.

The development of atomic weapons has given an absolute urgency to practical action towards what might otherwise have been only a shining ideal. The power which existing knowledge of the structure of matter has given to men was manifested through the atomic bomb, and is a reality which has already been painfully and fully demonstrated in war twenty-six years ago. This conference, however, and the preceding three conferences have been devoted to the benign quality, the other face so to speak of man's Promethean gifts. Just as fire can be used to destroy, it can be even more powerful in the creative arts of peace.

It has been my great privilege to have been a member of the Scientific Advisory Committee which advised the Secretary-General of the United Nations, first Dag Hammerskjold and now U Thant, for all the four conferences from the first in 1955 until now, sixteen years later. While the total impact and meaning of these Geneva Conferences still await the historian of the future and also the release of many secret documents which describe the problems of atomic politics in all their profundity and confusion, yet the fact remains that we are here, representatives of many nations assembled in the thousands which shows that these meetings are held to be of value and promise.

Many here will still remember the joyous atmosphere of the first Geneva Conference of September 1955. Then for the first time scientists from the Western countries and from the Socialist countries met in large numbers, free to talk about their scientific problems and to realize their common humanity and to renew the special bonds which united them in the universal culture of science. An important by-product of this first conference, held under the high auspices of the United Nations, was that as a result of the pressure of preparing for a world conference, governments permitted a great release of scientific and technical knowledge hitherto kept secret in the bureaucracies of the various countries. The open and free discussions which took place made possible a more realistic assessment of the time scale and scope for the practical applications of nuclear energy. This conference and the subsequent two led to a better understanding of the promise and danger of atomic energy in all Member States. Indeed, without these conferences it is perhaps doubtful whether the immensely important International Atomic Energy Agency would have been created at all; almost certainly it would not have been created as soon as it actually was.

Standing before you on this podium and recalling the great occasions of past conferences I must commemorate a few of these great figures of the past who are no longer with us. First of all, Dag Hammerskjöld, the heroic Secretary-General of the United Nations whose deep understanding of the meaning of science to humanity and whose skilful guidance brought these conferences into being; secondly, Dr. Homi Bhabha of India, the president of our first conference, a great theoretical physicist, a man of universal talents, a real renaissance figure and leader and head of the Indian Atomic Energy Authority. We still mourn his tragic and early death in an aeroplane accident while en route to a meeting of the Scientific Advisory Committee of the International Atomic Energy Agency.

Sir John Cockcroft of the United Kingdom, Professor Ernest Lawrence, Director of the great Radiation Laboratory in Berkeley, California, and Academician V.I. Veksler of Dubna, were the inventors and founders of the techniques of modern nuclear and high energy physics and Nobel Prize Laureates of the greatest distinction. Unfortunately they are no longer with us to lend even greater eminence and inspiration to this conference. Last of all I must recall Professor Nils Bohr of Denmark, one of the greatest figures in the history of physics of all times and whose memorable lecture at the first conference is still treasured. He was the first great world figure who pointed out to us the moral problems inherent in the application of atomic energy and the need for an open world.

Atomic energy, although far from mature, is nevertheless no longer in its infancy. It is now a very big business, both private and governmental. Its applications lead into almost every important activity in industry, in science, in health, in archeology and even astronomy. I will not speak to you about atomic technology or the future of fission and fusion technology. Dr. Seaborg and Dr. Eklund and many in the audience know very much more about it than I ever hope to learn. Rather, I wish to devote my brief remarks more to the basic meaning of science and the scientific spirit for all mankind.

Increasingly there is a basic contradiction within ourselves and in our cultures which we as a race must either resolve or mankind will perish from the earth just as other species which somehow failed to meet the necessities of a changed environment. This lesson, as has been pointed out by the anthropologists, is the basic meaning of evolution for the present day. Species which were too limited by the past are now extinct. From now on into the future the advance of science and technology brings us to the brink of change in our human environment in a possibly fatal and irreversible way. In the past, vast geological and meteorological changes affected human life and indeed all life, changes like ice ages, the continental drift, huge volcanic explosions or the rise of new species of diseases. The possible changes of environment which I now discuss are man-made rather than so-called "acts of God". In many cases the works of man now surpass in their effects the catastrophic results of spontaneous natural events.

The population explosion coupled with a desire for a so-called higher standard of living puts enormous stresses on the environment, as is evident in atmospheric and water pollution and in the disposal of waste inherent in the daily life of people who consume vast amounts of material not only for food but in the obsolescence attending a modern standard of living such as old cars, old furniture, newspapers, worn-out clothing, plastic which are not degraded by bacterial action, etc. There is no purpose in continuing this weary catalogue. Even atomic energy itself poses other vast and novel problems of waste disposal. The exhaustion of mineral resources and raw materials like coal, gas and oil keeps on occurring in euphoric haste. We proceed blindly in the faith that science will find a solution to the problems of diminishing natural resources. To meet some of these problems, which involve the natural desire for love of children and the devotion to religious and other customs, these basic human feelings must ultimately be partially diverted for the greater common good of mankind. The biblical injunction of the past to increase and multiply becomes the pressing danger of the present and the future. The population explosion may indeed prove to be the central cause from which other problems follow.

The Mayas of Central America in their methods of cultivation of maize so exhausted the soil at their sites that after a certain number of years they had to then move on to other territories. Human populations are now so dense and widespread that soon no other sites for exploitation will be available. Mankind was once a small perturbation to the enormous resources and the general ecology of the oceans and the continents. Now in almost every region man is the principal factor. We begin to realize that we have only one earth, and that gone there is no other. Nature now survives only by human sufferance and human planning. We must remember that the elimination of many species of life, through human action or neglect, may be only the prelude for the elimination of mankind itself.

It certainly has not escaped the notice of this intelligent audience that I have so far failed to mention the most immediate danger of all, nuclear warfare. This senseless threat to human culture and indeed to human survival has no precedent in history. Surely there is no ideal or pretended goal of any nation which is high enough to endanger the very existence of all humanity for its achievement. Perhaps Hitler in his maddest last moments wished to bring down all of humanity in his defeat, but for responsible statesmen otherwise sane, to play such a role is to me and many of my fellow scientists, incomprehensible. Perhaps the situation can be attributed to an over-emphasis on local and tribal history which has been the basic tradition of the past, and a failure to appreciate the sacred meaning of mankind as a whole. Most unfortunately there is a lack of political invention which would create political means for statesmen to act rationally when it comes to controlling these vast dangers inherent in our developing science and technology.

Thus far, we have dealt with science in reference to its practical applications in the technologies of industry, agriculture, health, communication, etc. Important as these are, both in benefit and danger to mankind, they represent only the externals of human life, the problems of health, comfort and life support. However, the most important part of a person's life is within himself and his deeper meaning and his relation to his fellow men, to life itself and the universe outside himself. Self-understanding and self-realization in this context are the basic ends which humans need to satisfy. As the poets have reiterated through generations, each man is alone and basically afraid, alone in a universe into which he was born.

The explorations of modern science connect mankind most directly with the universe as a whole. From the basic laws of physics one can begin to understand the special properties of the various atomic species which make possible life itself and the same basic laws extend universally from the most distant parts of space to the innermost fastnesses of matter of the infinitesimally small. The special properties of matter which make life possible turn out to be no accident, but rather a direct result of the most basic general laws of physics as manifested in quanti-mechanics and relativity. From these studies we learn that man is unique and yet a part of the totality, subject to universal laws. It is part of the glory of the race that these laws were discovered by mankind.

It has been stated that the proper study of mankind is man, but we now see that this cannot be approached narrowly but only through the whole, which is science. Mankind is the mind and the developing consciousness of the universe.

We can hope that if indeed we survive into the future, that men will realize deeply that their most noble goal is to understand themselves within the universe and that this goal will override all the petty and parochial aims that so disturb the peace and endanger mankind's future existence.

MESSAGES FROM HEADS OF STATE OR GOVERNMENT

MESSAGE FROM MR. PIERRE ELLIOT TRUDEAU, THE PRIME MINISTER OF CANADA

On behalf of the Canadian people, I send greetings to the Delegates and warm wishes for the success of the Fourth United Nations Conference on the Peaceful Uses of Atomic Energy.

Your conference takes place at a time when nuclear energy is achieving notable success as a viable, economical source of power and in so doing is easing our concern over the depletion of non-renewable world energy resources. It is a time, too, when radioactive materials are being used in an increasing number and variety of ways for the benefit of mankind.

May this Fourth General Conference provide the inspiration and the means for us all to discharge better our responsibilities as members of the UN family in meeting the challenges of the nuclear age.

A translation into French follows.

MESSAGE DE M. PIERRE ELLIOT TRUDEAU, PREMIER MINISTRE DU CANADA

Au nom du peuple canadien, j'exprime aux délégués nos meilleurs vœux pour le succès de la quatrième Conférence des Nations Unies sur l'utilisation pacifique de l'énergie atomique.

Cette conférence a lieu à une époque où l'énergie nucléaire se manifeste de plus en plus comme une source d'énergie sûre et économique, qui contribue à alléger notre inquiétude devant l'épuisement des ressources non renouvelables du globe, à une époque, également, où l'on découvre sans cesse de nouvelles façons d'utiliser les substances radioactives pour le bien de l'humanité.

Puissent vos travaux nous inspirer à tous la détermination et les moyens de mieux faire face, comme nous en avons la responsabilité en tant que membres de la grande famille des Nations Unies, aux défis de l'ère nucléaire.

MESSAGE DE M. GEORGES POMPIDOU, PRESIDENT DE LA REPUBLIQUE FRANÇAISE

Je tiens à féliciter l'Organisation des Nations Unies d'avoir organisé cette quatrième Conférence internationale sur l'utilisation de l'énergie atomique à des fins pacifiques et à dire l'intérêt que la France attache aux travaux qui vont se dérouler au cours de cette manifestation.

L'effort qui a été accompli depuis plus de trente années, après avoir été scientifique ou militaire, débouche aujourd'hui largement sur des applications industrielles.

La France s'est engagée résolument dans cette voie.

Elle est disposée, dans ce domaine où le poids de la recherche et des investissements est considérable, à coopérer avec d'autres Nations en vue de l'amélioration des conditions de vie et du progrès de l'humanité.

A translation into English follows.

MESSAGE FROM MR. GEORGES POMPIDOU, THE PRESIDENT OF THE FRENCH REPUBLIC

Permit me to congratulate the United Nations on convening this Fourth International Conference on the Peaceful Uses of Atomic Energy, and to stress the great interest that France attaches to the work which is to be accomplished during the proceedings.

The endeavour that has been put forth for more than 30 years, after having at first been scientific or military, is today largely devoted to industrial applications.

France is resolutely committed to this path.

In a field such as this, where the onus of research and investment is considerable, France is prepared to co-operate with other nations for the improvement of living conditions and for the progress of mankind.

MESSAGE FROM MR. GUSTAV W. HEINEMANN, THE PRESIDENT OF THE FEDERAL REPUBLIC OF GERMANY

With the first three Geneva Conferences on the Peaceful Uses of Atomic Energy held in 1955, 1958 and 1964, the United Nations provided both a good start and a further impulse for the world-wide exchange of knowledge and experience in the fields of nuclear sciences and technology, and for better co-operation between individual nations. In the meantime, great progress has been achieved in these sectors, and the manifold benefits which mankind can derive from the peaceful uses of atomic energy are manifest. I congratulate the United Nations on having, at this time, called anew for a world-wide exchange of experience, both oral and written, and also visual by means of illustrations and models. The aims of this venture – namely, demonstrating the progress made and enabling all peoples to partake in this progress – is welcomed by the Federal Republic of Germany. This Fourth International Conference on the Peaceful Uses of Atomic Energy is to show the world the benefits which can be gained for mankind from this new source of energy. This natural power is to be employed solely in the interests of peace and the welfare of nations. I wish the Conference every success and request you, Mr. President, to convey my best wishes and greetings to all participants.

MESSAGE FROM MRS. INDIRA GANDHI, THE PRIME MINISTER OF INDIA

New technologies open the doors of opportunity but also raise new problems. Nuclear technology is proving true to this record. So great are its scope and power that its potential contribution to human welfare is appreciated in the developing countries no less than in the industrialized countries. But the promotion and application of nuclear science and technology raise awesome social and political problems, within nations and between them. Among the important challenges facing mankind is the solution of these problems on the basis of equality of opportunities, benefits and responsibilities. We, in India, look to the conference to chart the route and indicate the milestones.

Twenty years ago, when the generation of electricity through atomic reactors was still a dream, the possibility of securing clean power was amongst the most exciting prospects involved. Today, when many nations have launched or are about to launch major nuclear power programs, the situation is different and a source of concern. I hope that this conference will be an occasion for mankind to pledge its collective ingenuity, integrity and self-restraint to ensure that nuclear industry becomes an ally rather than a threat to the quality of our environment.

In India, we believe that science and technology are a means to our objective of improving the quality of life of our people as rapidly as possible. This is the spirit which has led us to promote nuclear science and technology and to apply them for peaceful purposes. We are resolved to pursue that course with steadfast determination, while actively striving to ensure that the benefits of atomic energy are extended to all, within the framework of a just international system.

On behalf of the people and Government of India, I send greetings and good wishes to the conference.

MESSAGE FROM MR. EDWARD HEATH, THE PRIME MINISTER OF THE UNITED KINGDOM

I am happy to extend to this Conference the good wishes of Her Majesty's Government in the United Kingdom.

The speed with which atomic energy has been harnessed for economic progress is a matter for pride and satisfaction. When the first of the UN Conferences was held in 1955, atomic power was still a dream, and few had the knowledge and the materials needed to use atomic energy. After only sixteen years, atomic power stations are an important source of energy in many countries – in the United Kingdom they produce about 10% of all the electricity we use.

These Conferences have made a valuable contribution to this spread of the benefits of atomic energy. If progress is to be maintained both knowledge and materials must continue to be available. An important material is enriched uranium, and the demand is increasing rapidly as nuclear power becomes more widely used. We all hope that the gas centrifuge project, which is being developed jointly by United Kingdom, Netherlands and German Federal Republic organizations, will make an important contribution to meeting this demand.

While the peaceful uses of atomic energy goes forward there has also been advance in the establishment of safeguards. The Non-Proliferation Treaty has received world-wide support; and the safeguards procedures developed by the IAEA to serve the needs of this Treaty will represent an important reassurance that nuclear material is not being misused. We hope that both the Non-Proliferation Treaty and the IAEA's Model Safeguards Agreement will win yet wider acceptance.

MESSAGE FROM MR. RICHARD NIXON, THE PRESIDENT OF THE UNITED STATES OF AMERICA

My warmest greetings to all who are attending the Fourth International Conference on the Peaceful Uses of Atomic Energy in Geneva.

It is difficult to believe that 16 years have passed since the first of these conferences in 1955. I was serving as Vice President at that time and I remember well the strong favourable reaction in all parts of the World when President Eisenhower first suggested that such a conference be brought together. And I recall, too, the challenge which President Eisenhower presented in his message to that first conference when he declared that the atom must become man's "obedient and tireless servant ..."

Since that time, there have been tremendous strides in the effort to make nuclear energy the servant of mankind. The International Atomic Energy Agency has played an increasingly important role in that process and its work deserves the most generous commendation. The most important thing about this progress of the past is that it can serve as the foundation for even greater progress in the future.

In the last few years, the human race has shared in a remarkable new experience: the ability to look upon our planet as it appears from outer space. In that act, we have gained a new appreciation both of the beauty of our earth and of its fragility. We have been reminded of the artificiality of political boundaries and of the obligation we all share to reach across such boundaries for the sake of improving our common home.

At a time when the limits of many natural resources are becoming much more apparent, our capacity to manage resources and to find alternatives where necessary is becoming even more acute. It is here one of the most important benefits of nuclear energy can be realized. This fact was emphasized in my recent message to the United States Congress concerning our domestic energy program and I would underscore this point again in addressing this distinguished international group.

I extend my very best wishes for a most productive conference.

ПОСЛАНИЕ ПРЕДСЕДАТЕЛЯ СОВЕТА МИНИСТРОВ СССР А.Н.КОСЫГИНА

От имени Советского Правительства приветствую участников IV Международной конференции ООН по мирному использованию атомной энергии.

Прошло всего 16 лет с того времени, когда на I Женевской конференции Организации Объединенных Наций по мирному использованию атомной энергии ученые и специалисты различных стран впервые встретились на широком международном форуме для обсуждения путей использования мирного атома на благо человека. За такой сравнительно небольшой срок достигнут значительный прогресс в этой новой области науки и техники. От этапа научных поисков и разработок 50-х годов атомная энергия вступила в период широкого использования в целом ряде стран и в самых различных областях человеческой деятельности.

Все более тесное объединение усилий людей науки различных стран несомненно будет способствовать скорейшему решению важнейших проблем мирного использования атомной энергии, в особенности связанных с удовлетворением все возрастающих энергетических потребностей человечества.

Советский Союз, достигший больших успехов в деле практического применения атомной энергии, неуклонно выступает за такое международное сотрудничество в области использования атомной энергии в мирных целях, которое в полной мере отвечает целям и принципам Устава Организации Объединенных Наций, Международного агентства по атомной энергии и положениям Договора о нераспространении ядерного оружия.

Нельзя забывать о том, что имеются и немирные области применения атомной энергии, оказывающие серьезное и опасное, с точки зрения сохранения мира, влияние как на общий политический климат, так и, в частности, на возможности более широкого развития сотрудничества в мирных целях. Вот почему Советский Союз последовательно борется за решение проблемы ядерного разоружения в целом и за принятие отдельных мер, постепенно подводящих к этой цели. Мы придаем большое значение реализации выдвинутых Советским Союзом предложений, касающихся мероприятий, направленных на достижение как ядерного разоружения, так и всеобщего и полного разоружения.

Советское правительство выражает уверенность, что IV Женевская конференция, проходящая под девизом "Выгоды для человечества от использования атомной энергии в мирных целях", будет способствовать расширению международного научно-технического сотрудничества.

Разрешите пожелать всем участникам этой конференции дальнейших успехов в деле мирного использования атомной энергии в интересах всего человечества.

Москва, Кремль

A translation into English follows.

MESSAGE FROM MR. A.N. KOSYGIN, THE CHAIRMAN OF THE COUNCIL OF MINISTERS OF THE USSR

On behalf of the Soviet Government, I extend greetings to all those attending the Fourth International Conference on the Peaceful Uses of Atomic Energy.

Sixteen years have passed since the First Geneva Conference on the Peaceful Uses of Atomic Energy, when scientists and experts from different countries met together for the first time, on a broad international basis, to discuss peaceful ways of utilizing atoms for the good of mankind. Over this relatively short period considerable headway has been made in this new branch of science and technology. From the stage of scientific research and development in the 1950s atomic energy has moved on to a time when it is being used on a wide scale in a large number of countries and in the most varied areas of human endeavour.

The ever more closely merging efforts of men of science in different lands will undoubtedly promote the rapid solution of the most important problems involved in the peaceful utilization of atomic energy, especially those associated with meeting man's continuously growing energy requirements.

The Soviet Union, which has made great advances in the practical application of nuclear energy, stands resolutely in favour of the kind of international co-operation in atoms for peace which fully accords with the purposes and principles of the United Nations Charter, the Statute of the International Energy Agency and the provisions of the Treaty on the Non-Proliferation of Nuclear Weapons.

It must not be forgotten that there are also non-peaceful areas in which atomic energy is used, and that from the standpoint of preserving peace they exert a serious and hazardous effect on the overall political climate and, more particularly, on the opportunities for broader development of peaceful co-operation. This is why the Soviet Union is consistently campaigning for settlement of the problems of nuclear disarmament as a whole, and for the adoption of specific measures that will gradually lead to that end. We attach great importance to the implementation of the Soviet Union's proposals relating to measures for achieving both nuclear disarmament and general and complete disarmament.

The Soviet Government is firmly convinced that the Fourth Geneva Conference with its theme of "Benefits for mankind from the peaceful uses of atomic energy" will help to expand international co-operation on the scientific and technical plane.

Allow me to wish all those taking part in the Conference further success in the peaceful use of atomic energy in the interests of the whole of mankind.

Moscow, Kremlin

SPECIAL TALKS

NUCLEAR ENERGY AND WORLD PEACE

The Honourable Mitchell SHARP
Secretary of State for External Affairs of Canada

It is an honour for me and for my country that I should be the first foreign minister to address one of these important conferences. Canada has a long experience in the development of the peaceful uses of nuclear energy, going back to the late 1940s. The decision to concentrate our resources on this aspect of nuclear science is one we have never regretted and that through the years has enjoyed the support of an overwhelming majority of the Canadian people.

Sixteen years have passed since the first of these conferences opened in this hall. That first conference in 1955 caught the attention of the world and gave rise to great expectations. Until then the words "atomic energy" brought to mind only the mushroom cloud, the firestorm and the helplessness of man in face of this new catastrophic weapon. Until 1955 only a few scientists knew of the technical accomplishments and positive possibilities that had been shrouded in secrecy. It was here, in this Palais des Nations, that the shrouds were torn away and the world saw that man could use his new knowledge and this new power source as well for his betterment as for his destruction.

The new expectations of 1955 were balanced, perhaps overbalanced, by man's continuing fear of the nuclear weapons race. The public heard about the more fascinating uses of isotopes and about the prospects for megawatts of electrical power, generated by atomic energy. But for most of the next decade much more was heard about megatons and megadeaths than about megawatts. Fall-out was the new plague to be feared and ICBMs were targetted on many of the world's great cities and unfortunately still are. To the age-old fears of war and oppression was added a new fear, of instant widespread destruction brought about by the pressure of a finger on a button, bringing into doubt the capacity of statesmanship and diplomacy to keep the peace.

In more recent years, our fears seem to have diminished. This is the normal human reaction to an ever-present threat; the farmer who tills the slopes of a volcano year after year learns to stop worrying about an eruption that may never come. Our fears have been lulled by our recognition that the two great military powers of the world are for the time being in a state of equilibrium, an equilibrium that neither can disrupt without risking its own and possibly mankind's destruction.

Canada welcomes the initiatives taken by the United States of America and the Soviet Union towards strategic arms limitation, the SALT talks. The two nuclear powers have begun to carry out their obligations under Article VI of the Non-Proliferation Treaty. The task they have undertaken is both complex and difficult. The joint announcement by the United States of America and the Soviet Union on 20 May 1971 that they had reached an understanding in principle to concentrate this year on working out an agreement for the limitation of the deployment of anti-ballistic missile systems and that together with this ABM systems agreement they would agree on certain measures with respect to the limitation of offensive strategic weapons, is heartening evidence of progress. We shall all watch with eager anticipation their efforts to translate this understanding into concrete agreements in the coming months. It is to be hoped that the SALT agreements will include measures to curtail the nuclear arms race in its qualitative as well as its quantitative aspects.

The Non-Proliferation Treaty, which came into force on 5 March 1970, and the safeguarding procedures that have been recently worked out by the International Atomic Energy Agency's Safeguards Committee offer some hope that the further spread of nuclear weapons will be limited. The solemn declarations of states party to the Treaty to renounce this kind of military force and their agreement to allow international personnel to inspect their nuclear installations justify a cautious optimism. There are, however, states that have not signed the Treaty, and its effectiveness will be diminished if some important nuclear and so-called "near-nuclear" nations continue to stand aside. I am pleased to announce today that our negotiations are proceeding favourably and that Canada expects to conclude the Safeguards Agreement, that is the Canadian agreement, with the Agency before the end of the year.

The measure of confidence arising out of the Non-Proliferation Treaty will be strengthened if it is brought into smooth and effective operation. The states that have renounced nuclear weapons have done so in the belief that their own interests are best served by this renunciation; they recognize that they have less to fear from others when they show that others have nothing to fear from them. The mutual trust and confidence born of this renunciation will endure only to the extent that these same states now co-operate with the International Atomic Energy Agency and its inspectors in the operation of safeguards.

All of us must keep carefully audited records of our production, movement and consumption of fissionable materials if we ourselves are to feel confident that we have good internal control. The records that we need for good housekeeping at home fulfil most, if not all, the requirements for international inspection. For this reason, I do not believe that safeguards impose a great new burden as is sometimes suggested. I know that some organizations fear that in submitting to detailed inspections their commercial secrets might be compromised, but the real commercial secrets lie in unaffected areas, such as the design and manufacture of components, and these fears are exaggerated. It is now in the interests of each state to be generous in its co-operation with the Agency's inspectorate and to demonstrate to the rest of the world community that its intentions are wholly peaceful.

The peace of the world may not be quite as precarious as it was a few years ago, but the dangers are still real. The Moscow Partial Test Ban Treaty of 1963 has stopped many – but by no means all – of the nuclear explosions that contaminate our atmosphere. To some extent this Treaty can be looked upon as a major public health measure rather than as arms control. Our newspapers no longer give us those daily fall-out readings to remind us that nations are developing nuclear weapons to even higher levels of effectiveness. But the testing goes on underground – this kind of activity has accelerated since the signing of the Partial Test Ban – and the development of ever more sophisticated nuclear weapons continues.

With these realities in mind, many states of the world, including Canada, have concluded that the time is ripe for a renewed and determined effort to achieve a ban on underground nuclear tests. Seismological investigation, investment in improved facilities, and the possibility of international co-operation in seismic data exchange have all begun to give grounds for believing that adequate seismological methods of discriminating between undergound nuclear explosions and natural seismic events can be found. Problems and ambiguities remain – particularly with explosions of extremely low yield, where verification trails off into the realm of the improbable. But the potential for seismological identification has sharply narrowed and made more manageable the issue of verification that has for too long bedevilled efforts to achieve an underground test ban.

The verification problem is in the last analysis a political rather than a technical question, and in our view, as well as that of a very large number of non-nuclear nations, the time has come for the two major nuclear powers to take up again their efforts to resolve this problem where they left off eight years ago. At the same time, we should not ignore the desirability of all nuclear powers adhering to the Moscow Treaty and joining with others in an effort that would lead to a complete ban on all nuclear tests. Until such a ban can be reached I urge the two major nuclear powers to scale down their underground tests, starting with the biggest.

As I address you today I am aware – uneasily aware – of the fact that a quarter of mankind, the people of China, is unrepresented amongst us. I accept the assurance of Mr. Chou En-lai that Chinese intentions are peaceful but I am sure we will all be happier when the representatives of that ancient civilization and powerful modern state are taking part in our deliberations rather than observing them in silence. Canada will do all it can to ensure that this is the last conference on nuclear energy in which a quarter of mankind goes unrepresented.

In the sixteen years since our first conference in 1955, nuclear scientists and engineers have forged ahead. In most situations, large quantities of electricity can now be produced by the fission of uranium as cheaply as by burning coal or oil. Fears of a world energy crisis have been postponed, perhaps for centuries. It is now our task to apply the technology that has been developed to bring to all men a supply of energy sufficient to meet their needs. The technology is ready, the world needs electricity, and we can expect to see a continuing shift away from new fossil-fuel stations towards new nuclear stations.

As you know, a great and exhausting debate has been raging between those who question the safety of nuclear power plants and those who defend them. The emotion generated by this discussion must not be allowed to conceal the essential facts of the situation. The nuclear industry has an outstanding record of safe operation. No other industry – and this for obvious reasons – has been as conscious of its obligations to protect its workers, the public and the environment itself. In a world in which everyone every day is exposed to innumerable hazards, we must keep a sense of proportion. Man would be foolish indeed to deny himself a source of energy that he sorely needs. This planet has yielded up the fossil fuels that permitted us to launch our industries. But fossil fuels cannot sustain us through the centuries, and I say this in the full realization that mankind may have to learn to limit its energy consumption. When we consider the risks of nuclear power, we must also weigh against them the risks that will arise if we turn away from nuclear power. Not only the risks that arise from the alternatives that we can temporarily employ — coal, oil and gas — but also the risks that would arise were the nations, facing a global shortage of energy, to come into conflict over the sharing of what was left.

I do not wish to be misunderstood on this question. I do not suggest that problems do not exist or that they are capable of simple solutions — rather that they are capable of management at an acceptable cost if adequate resources are brought to bear.

Peace is more than the absence of war, as Dr. Rabi has reminded us. To have peace we must build a world society in which man can express his personality and develop his potential without attacking his neighbour or coveting his goods. That is why nuclear fission has such a great contribution to make to the building of a peaceful world, and to the eradication of poverty. Substantial efforts have been made by the United Nations, by the International Atomic Energy Agency, and by individual countries in this great endeavour. My own country has played an important part by co-operating with developing countries in their own nuclear power programs.

Perhaps it is well, however, to add a word of caution based upon our own experience. Nuclear energy is only one tool for economic development. It has its limitations. It is massively expensive. Only the richest and most highly industrialized countries can afford the experimentation that is essential to the development of technology.

For example, the production of electricity from nuclear reactors has now reached the state where it is possible to contemplate the building of large generating stations wherever there is a demonstrable need for large amounts of electrical power, and where the power generated can be brought to bear effectively on the solution of existing problems. The question is: how many developing countries can meet these criteria?

We have all heard of the "agro-industrial complex" and particularly the project that is under study in India. This would involve the use of nuclear power to pump deep underground water to the surface for irrigation. As I understand it, nuclear power would also be used for the local production of fertilizer. If successful, such a complex would offer the potential for a major new step in the "green revolution" that has already had such beneficial effects in the Indian sub-continent. Its success could open an important new chapter in the story of man's fight against hunger and malnutrition.

The application of nuclear energy to the large-scale desalting of sea-water is another, and I am sure you will admit, a more difficult question. The need undoubtedly exists, and this could be the concept that will start new "green revolutions" in the deserts of the world. But just as nuclear energy is not always the most economical means of generating electricity, so we must be careful not to mislead peoples and governments into believing that the dream of large-scale desalination of sea-water is just about to become a reality.

In the course of the next days, you will devote much of your time to the large-scale use of atomic energy for the production of electricity and for desalting sea-water. You will also consider the numerous applications of isotopes and radiation — in research, in industry, in agriculture and in medicine. There have been remarkable achievements, particularly with the new nuclear techniques for the diagnosis and treatment of cancer and of some of the other diseases that afflict mankind. You will seek to evaluate what contributions these can make to the improvement of life in the developing countries.

Isotopes and radiation are tools — their use is not an end in itself. We must, as I have said, identify what our aims are and then see whether atomic energy provides the best tool for achieving them. For example, the developing countries have a great need to find better ways of preventing the wastage of food in storage. Pests and various forms of decay destroy a large fraction of what is produced. Irradiation may help to conserve this food, but until this has been demonstrated and its economic feasibility established, better known techniques — dehydration, canning or refrigeration — are still probably more appropriate in most situations, and their use ought not be neglected.

Another problem is the provision of sterile medical supplies, often under adverse conditions remote from the facilities of modern hospitals. One technique is now well established: it involves first sealing medical supplies in hermetic packages and then irradiating them to ensure complete sterility. The supplies are safe from any infection until the moment when the packages are opened — and, of course, this can be at the moment they are needed for use. I believe this technique is ready for immediate adoption in developing countries. It is best if the choices can be made in the developing countries themselves I suggest — by their own scientists and economists, their own entrepreneurs. To do this they must have their own centres of excellence where innovators are encouraged and where proper evaluations can be made in relation to local needs and local priorities.

We have come to Geneva to discuss the silver lining of the nuclear cloud, a happy circumstance that unfortunately does not permit us to disregard the cloud itself. The achievements and possibilities of the peaceful uses of atomic energy on which I have touched this afternoon justify a sense of pride and hope. Nevertheless, we are discussing a force that, if misused, has a destructive capacity difficult for any of us, scientist or layman, to comprehend fully.

Meeting here in this ancient and free city where so many of mankind's hopes for peace have centred, you constitute a body of expertise on nuclear questions that is unique. As I wish you well in your discussions of peaceful nuclear technology I urge you to keep in mind your special responsibility to all mankind, and above all to the rising generations born into a nuclear world they did not make.

Today there is an equilibrium, albeit an accelerating one, between the great nuclear powers, the United States of America and the Soviet Union. These powers are now seeking ways to limit the nuclear arms race — I hope, to find an equilibrium at a lower and less menancing level. I have suggested to you that China may soon be a nuclear power to be reckoned with. There are others standing in the wings. This will call for a new equilibrium, and the sooner China comes fully into the councils of the world, the better for us all.

So I leave with you this thought. The peoples of the world need the energy and other benefits that nuclear science has to offer. They accept reluctantly and fearfully the mutual balance of nuclear deterrence that offers them a measure of security. But many of those without the special knowledge and expertise you enjoy look upon nuclear energy as inherently dangerous and threatening, like a half-domesticated beast. You, ladies and gentlemen, as the managers of nuclear knowledge and technology, are uniquely equipped to bring home to your governments, directly and by moulding world public opinion, their responsibility to see to it that the beast is fully domesticated and kept at useful work for the benefit of all.

L'ENERGIE NUCLEAIRE ET L'AVENIR

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I. L'importance de l'énergie pour le développement économique est généralement reconnue. Le rapide accroissement de la consommation d'énergie sous toutes ses formes nous oblige de plus en plus à des recherches minutieuses dans les domaines de l'exploitation des ressources énergétiques et de la satisfaction des besoins énergétiques du monde.
De telles recherches concernent:
- la détermination qualitative et quantitative des besoins en énergie dans l'avenir,
- la confrontation de ces besoins avec les ressources énergétiques du monde,
- les possibilités techniques de leur utilisation.

Chacun de ces trois éléments comporte plusieurs inconnues, qui ne peuvent pas être déterminées à l'heure actuelle.

Les recherches et études, au fur et à mesure de leur développement, permettent de préciser certains problèmes de plus en plus exactement et de connaître de mieux en mieux les ressources énergétiques du monde. On constate ainsi que les différences entre les pronostics globaux relatifs aux besoins en énergie diminuent. Par contre il existe de grandes différences entre les contributions particulières à la satisfaction des besoins globaux et entre les méthodes d' exploitation des diverses ressources en énergie.

II. En fait, pendant la période de cent ans s'étendant du milieu du XIX^{e} siècle jusqu'à 1950 les besoins d'énergie dans le monde ont augmenté régulièrement d'environ 2% par an [1]. Ce n'est qu'au cours des dernières décennies qu'on a observé une augmentation sensible de la consommation d'énergie, en raison de l'accélération du développement industriel. On sait que la consommation d'énergie dépend du revenu national par habitant et que le taux d'accroissement de la consommation d'énergie et celui du revenu national sont étroitement liés (fig. 1). Un accroissement particulièrement rapide du revenu national et de la consommation d'énergie peut être observé dans deux groupes de pays: les pays hautement développés d'une part; les pays qui n'avaient jusqu'à présent que peu développé leur économie mais qui ont pris le chemin d'une prompte évolution économique, d'autre part.

Dans le premier cas, nous avons le facteur de la révolution scientifique et technique. Dans la majorité des pays hautement développés la moyenne annuelle de l'accroissement de la consommation d'énergie est de plus de 5%. Dans certains cas, par exemple en Finlande, en Italie et au Japon, les valeurs dépassent 10% par an. Généralement on peut constater une montée jusqu'au niveau d'un certain assouvissement, soit 2 à 4 tonnes équivalent charbon par habitant, après quoi les accroissements annuels se stabilisent à un niveau de 3, 5 à 5, 5%.

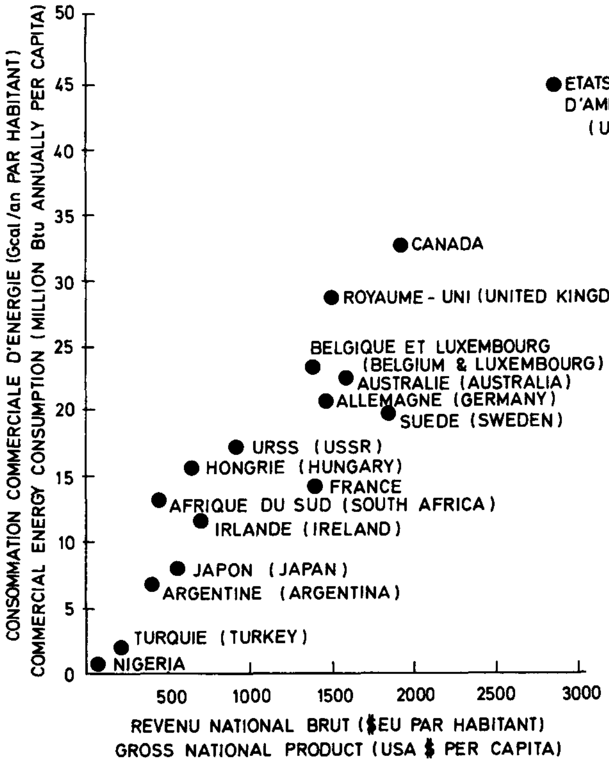

FIG 1. Consommation d énergie et revenu national brut dans différents pays (tiré de [10]).

Dans les pays en voie de développement, dont l'économie doit se développer à partir d'un niveau très bas, l'accroissement annuel au premier stade de l'industrialisation s'élève généralement à 20% pour diminuer ensuite très rapidement jusqu'à 10% et moins. Cependant ces grandeurs relatives n'ont actuellement aucune signification pratique dans le cadre de la consommation mondiale d'énergie. Un tiers de l'humanité consomme plus de quatre cinquièmes du combustible et de l'énergie produits. Ces disproportions vont encore augmenter au cours de la prochaine décennie car la forte expansion démographique que l'on peut constater dans les pays en voie de développement ne s'accompagne pas d'un accroissement proportionnel de la consommation d'énergie. Ainsi on peut admettre que dans la prochaine décennie c'est la consommation d'énergie dans les pays économiquement développés qui déterminera le niveau de la consommation mondiale. Ces disproportions diminueront cependant dans la dernière décennie de notre siècle. A la VII^{e} Conférence mondiale de l'énergie, qui s'est tenue à Moscou en 1968, deux hypothèses ont été présentées concernant l'évolution de la demande jusqu'à l'an 2000. Puisque entre-temps on a constaté que la consommation d'énergie en 1970 avait atteint le niveau correspondant à l'hypothèse la plus élevée, ce sont ces données qui sont reproduites au tableau I [2].

Les taux observés d'affaiblissement de l'accroissement de la consommation dans chaque pays nous conduisent à admettre que la consommation mondiale d'énergie se développera selon une «fonction de saturation» (fig. 2) et que nous nous trouvons au stade initial de ce processus.

Si les pays consommant le plus d'énergie ont le moindre accroissement relatif, il faut toutefois prendre en considération le fait qu'à un moment donné la part essentielle de la consommation d'énergie dans le monde sera le résultat du développement des pays qui font actuellement leurs premiers pas sur la voie de l'industrialisation; en outre l'augmentation démographique de ces pays est supérieure à la moyenne mondiale.

III. L'énergie consommée l'est par trois secteurs principaux: a) l'industrie; b) les transports; c) les ménages et le commerce. On peut constater qu'actuellement c'est l'industrie qui consomme le plus d'énergie (40 à 60%) dans les pays développés. Les transports, selon le degré de motorisation, la densité de la population, le rapport trafic terrestre/par eau, consomment 12 à 30% de l'énergie. Les 18 à 30% restants vont aux utilisations domestiques et municipales. [3-5]. Ce dernier chiffre dépend surtout du climat. Dans un climat froid, le chauffage consomme beaucoup de combustible. Dans un climat chaud, les installations de climatisation consomment de plus en plus d'énergie. L'amélioration des conditions de logement a une grande influence sur l'augmentation de la consommation des ménages et des services publics. Le développement de la motorisation et des échanges internationaux influencent la consommation d'énergie par les moyens de transport. L'amélioration du niveau de vie et l'augmentation parallèle de la production industrielle conduisent également à une consommation accrue d'énergie et de combustible dans l'industrie. Cependant les améliorations technologiques, qui permettent de diminuer la consommation unitaire d'énergie et de combustible, s'opposent à cette tendance. La production de fonte brute en est un exemple: grâce à une préparation soigneuse de la charge, à l'augmentation de la pression et de la température de l'air et à l'augmentation du rendement du four, on a obtenu une diminution régulière des quantités de coke nécessaires. De même la fabrication des engrais artificiels (azotés), qui, de tous les procédés chimiques, consommait le plus d'énergie, est devenue grâce à la rationalisation des méthodes technologiques indépendante au point de vue de la consommation de l'énergie. C'est pourquoi dans certains pays on prévoit une petite diminution de la part de l'industrie dans l'ensemble de la consommation d'énergie.

Les écarts importants qu'on constate dans la consommation d'énergie peuvent être illustrés par les chiffres suivants: en 1969 certains grands pays en voie de développement utilisaient 0,16 tonne équivalent charbon par habitant, alors que les pays hautement développés en utilisaient 9,5 et prévoyaient que la consommation aurait passé à 17,5 tonnes équivalent charbon par habitant en l'an 2000 [2].

IV. On peut satisfaire ces besoins en ayant recours à différentes sources d'énergie primaire (houille, pétrole, gaz naturel, etc.) ou secondaire (par exemple l'énergie électrique). Les principaux critères économiques

TABLEAU I. STRUCTURE DE LA CONSOMMATION COMMERCIALE DE MATIERES PREMIERES ENERGETIQUES DANS LE MONDE [2]

Année	1900	1920	1940	1950	1960	1970	1980	1990	2000
Monde (t équiv charbon)	-	-	-	2520	4230	6650	9820	15 600	274 000
Participation (%)									
Houille	94,2	86,7	74,6	62,4	52,1	32	28,7	22,8	16,8
Pétrole	3,8	9,5	17,9	25,2	31,3	46	41,0	39	34,6
Gaz naturel	1,5	1,9	4,6	10,8	14,6	20	14,4	27,6	29,0
Energie hydraulique	0,5	2,0	2,9	1,6	2,0	2	2,3	2,3	2,1
Energie nucléaire	-	-	-	-	-	-	3,6	8,3	17,5

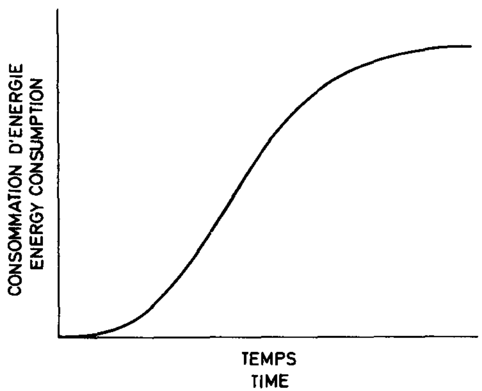

FIG.2. Taux prévisible d'accroissement de la consommation d'énergie

qui guident le choix des combustibles et des formes d'énergie, outre le critère décisif de leur convenance dans chaque cas particulier, sont:
- le prix unitaire de la chaleur,
- l'importance des investissements nécessaires,
- les investissements secondaires,
- les frais d'exploitation,
- l'influence sur le milieu de l'homme.

Le gaz naturel est un combustible idéal pour toutes les installations stationnaires. Les frais d'exploitation en sont inférieurs à ceux du pétrole. Les installations utilisant le gaz naturel comme source de chaleur sont beaucoup moins chères que celles chauffées au fuel-oil ou à la houille [6]. Les foyers à gaz peuvent être facilement automatisés. Le rendement de combustion est pratiquement indépendant de la puissance thermique. Le gaz naturel utilisé dans le réseau urbain ne produisant ni soufre ni cendres, il est du point de vue de la protection du milieu un combustible de choix. Les frais de distribution sont constitués pour la plus grande part par des charges fixes; le stockage du gaz étant coûteux, une distribution régulière est préférable.

Le gaz naturel n'est pas seulement un combustible, il constitue aussi une précieuse matière première chimique. Sa grande efficacité et l'entretien assez facile des petits foyers, ainsi que ses produits de combustion inoffensifs pour l'environnement font du gaz naturel un combustible parfait pour les ménages et services publics qui, avec l'industrie chimique, sont les utilisateurs les plus importants de ce combustible. Du fait de ses grandes qualités ce combustible est de plus en plus largement consommé et les pronostics pour la période allant jusqu'à l'an 2000 prévoient qu'il pourrait jouer dans le bilan énergétique un rôle plus important que la houille (fig. 3).

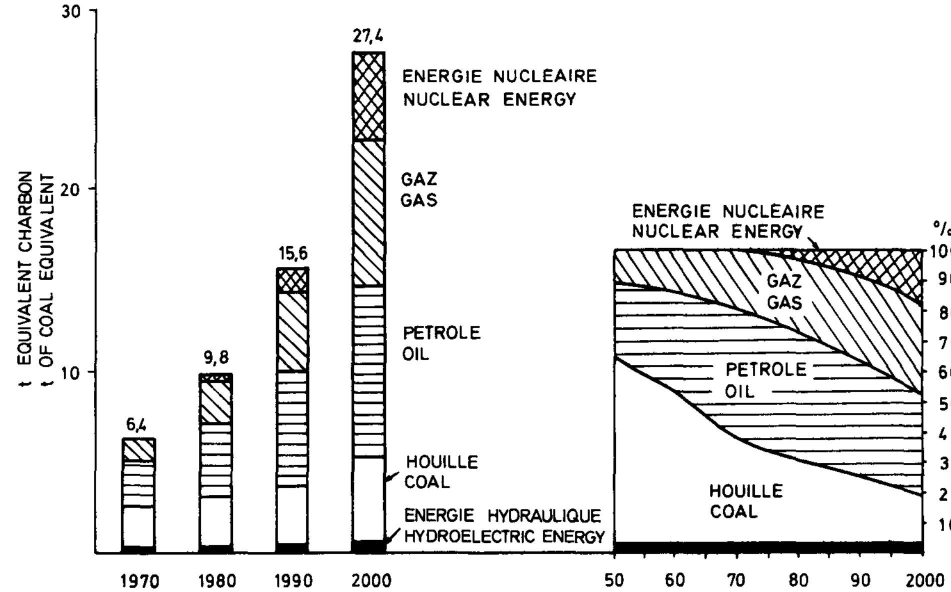

FIG. 3. Consommation mondiale prévue de matières premières énergétiques jusqu' à l' an 2000.

L'intérêt des combustibles liquides ne contenant pas de soufre n'est pas inférieur à celui du gaz, et leur stockage est plus facile. En outre, les frais d'investissement sont plus faibles que pour la houille ou l'uranium; c'est pourquoi on peut les utiliser parfaitement dans des installations à bas facteur de charge. Ils constituent le combustible le plus couramment employé pour les transports aériens, routiers et maritimes. Ils concurrencent avec succès la traction électrique sur les lignes de chemin de fer. Cependant le rôle du pétrole et de ses dérivés a été affecté par les exigences relatives à la protection du milieu. Les bateaux-citernes, pendant le déchargement et surtout lors de la vidange des cales, polluent les mers et les océans. Le naufrage d'un navire avec sa cargaison, que se répand à la surface de l'eau, souille les plages et détruit la vie biologique des côtes. Les déchets des raffineries polluent les fleuves et les eaux littorales. De même les gaz d'échappement des moteurs à combustion interne constituent un danger pour l'atmosphère.

Ceci explique l'intérêt qu'il y aurait à mettre au point, pour les villes et les banlieues, un moyen de transport autre que l'automobile à moteur à combustion interne. Si l'on parvenait à remplacer le moteur à combustion interne par un moteur électrique alimenté par des accumulateurs chargés au réseau, les besoins en pétrole pourraient changer radicalement, d'autant plus que la protection du milieu rend impossible la combustion de grandes quantités de fuel-oil dégageant beaucoup de soufre dans les centrales. La désulfuration du fuel-oil ou des gaz d'échappement augmente considérablement les frais d'exploitation et diminue la capacité de concurrence des combustibles liquides, qui, à la suite des dernières augmentations du prix du pétrole, a déjà très fortement baissé au profit d'autres combustibles. Certain pays ont déjà réagi à l'augmentation du prix du pétrole en élargissant leur programme de construction de centrales nucléaires.

Les projections effectuées jusqu'à maintenant prévoyaient un rapide accroissement de la consommation de pétrole, qui avait déjà, dans le bilan des combustibles pour 1969, devancé la houille, avec une consommation supérieure à celle de chacun des autres combustibles. La dernière hausse de prix du pétrole, qu'on peut considérer comme reflétant une conjoncture générale, pourrait faire pencher la balance en faveur du gaz et de l'énergie nucléaire, compte tenu des exigences relatives à la protection du milieu.

La houille, le second combustible dans l'histoire après le bois, passe par une période de stagnation. Son extraction pendant les dix dernières années s'est maintenue à un niveau d'environ de 2 milliards de tonnes. Dans la même période l'extraction du lignite a légèrement augmenté. La stabilisation des quantités de combustibles solides extraites s'explique par la concurrence du pétrole. Pour un coût de la chaleur à peine inférieur la houille entraîne des investissements supérieurs dans les installations qui l'utilisent. Une centrale brûlant de la houille est de 20 à 25% plus chère qu'une centrale utilisant le fuel-oil. Les frais d'exploitation sont supérieurs et l'évacuation des cendres pose des problèmes. Des installations de dépoussiérage correctement construites et bien exploitées ont éliminé la pollution de l'air, mais le problème du stockage de grandes quantités de cendre existe toujours. Lorsque le rendement des foyers n'est pas élevé, comme c'est le cas pour la houille, l'entretien est laborieux et l'automatisation difficile à réaliser.

C'est pour cette raison que dans les ménages la houille a été remplacée par le gaz, l'électricité ou le fuel-oil. Seuls les grands établissements, comme par exemple les centrales thermiques, utilisent encore la houille, en raison de son prix moins élevé mais surtout parce qu'elle renferme moins de soufre. La houille est en outre le combustible utilisé pour la métallurgie.

Bien que l'exploitation de la houille ait progressé toujours plus lentement pendant les 20 dernières années et qu'on prévoie que sa participation dans le bilan énergétique du monde diminuera, on peut penser que les prochaines décennies verront un constant accroissement de l'extraction de la houille, qui s'élèvera à 2,5 à 3,5% par an. Le ralentissement a sa source dans les tendances généralement à la baisse dans ce domaine en Europe occidentale. Les causes en sont l'augmentation des frais d'exploitation et la difficulté de trouver de la main-d'œuvre pour les mines. La modernisation des conditions de travail peut changer cet état de fait. On peut citer comme exemple la mine de charbon «Jan», en Haute-Silésie (Pologne), complètement automatisée, où le rendement par mineur est plusieurs fois supérieur au rendement dans une mine conventionnelle.

L'énergie nucléaire connaîtra un taux de développement très élevé: 50% par an dans la prochaine décennie, puis, les années suivantes, 14%, soit un accroissement relatif plus rapide que dans le cas du gaz ou du pétrole. L'énergie nucléaire possède des caractéristiques complètement différentes de celles des combustibles liquides. Les dépenses d'investissement sont plus élevées que pour les autres combustibles, par contre les frais de production de la chaleur sont plus bas. Le rendement est d'autant meilleur et les frais d'investissement d'autant plus bas que les unités sont plus grandes, et les coûts décroissent avec l'augmentation de la puissance plus rapidement que dans d'autres installations énergétiques (voir tableaux II à IV). Ainsi l'utilisation de l'énergie d'origine nucléaire est actuellement économiquement justifiée dans des installations de grande puissance à facteur de charge élevé, c'est-à-dire dans de grandes centrales de base, dans de grandes centrales alimentant simultanément en chaleur les établissements industriels, pour le dessalement de l'eau de mer, ou dans de grands complexes agro-industriels, actuellement en cours d'étude. Le transport des combustibles nucléaires étant peu coûteux, les centrales nucléaires peuvent être construites directement auprès des centres de consommation. Elles peuvent aussi l'être dans des zones fortement peuplées puisqu'elles ne polluent pas l'atmosphère et que leur sûreté est presque absolue.

TABLEAU II. COMPARAISON DES FRAIS DE COMBUSTIBLE POUR DES CENTRALES TOTALISANT 500 MW (UNIPEDE, 1961)

Combustible	Puissance (MW)	
	4 × 125	2 × 250
Houille	1,0	0,92
Fuel-oil	0,85	0,78
Gaz naturel	0,833	0,77

TABLEAU III. FRAIS D'INVESTISSEMENT POUR DES CENTRALES DE 500 ET 1000 MW
(Frais en $EU/kW, première charge non incluse, en 1970; tiré de [6])

Combustible	Puissance (MW)	
	500	1000
Houille	165	140
Fuel-oil	140	115
Energie nucléaire (PWR ou BWR)	190	150

TABLEAU IV. FRAIS D'INVESTISSEMENT POUR DIVERS TYPES DE CENTRALES
(Valeurs de 1969; tiré de [9])

Combustible	Nucléaire			Fuel-oil		
Puissance (MW(e))	300	500	1000	300	500	1000
Frais $/kW	311	248	191	177	152	132

Ces frais estimatifs comprennent les frais directs et indirects, les intérêts intercalaires et l'augmentation des prix pendant la construction

Ces qualités expliquent le développement extraordinairement rapide de l'énergie nucléaire qui, vers la fin du siècle, occupera probablement dans le bilan de l'électricité une place comparable à celle des combustibles classiques.

Dans certains pays l'énergie hydraulique peut jouer un rôle important; cependant elle aura dans le bilan énergétique du monde une position marginale. Les coûts de construction d'une centrale hydraulique sont généralement plus élevés; c'est pourquoi pour la production d'énergie seule, les centrales thermiques classiques ou nucléaires sont plus économiques. D'autres raisons cependant parlent en faveur des centrales hydrauliques: surtout l'irrigation des territoires pauvres en eau ou l'endiguement des eaux d'inondation.

V. L'énergie électrique est d'une importance particulière pour satisfaire les besoins énergétiques. Dans les évaluations ci-dessus elle n'est pas prise en considération parce que c'est une énergie secondaire provenant de la conversion en énergie électrique, soit de l'énergie d'une chute d'eau, soit de l'énergie thermique fournie par la combustion de combustibles classiques ou la fission du noyau atomique. Le rendement de ce processus de transformation est bas; il ne dépasse pas 0,4 dans le meilleur des cas. Si l'on prend également en considération les frais de transport, le rendement sera encore inférieur et le plus souvent ne dépassera pas 0,25. C'est pourquoi le chauffage électrique exige une quantité de combustible 3 à 4 fois plus grande que celle qui est nécessaire en cas de consommation directe. Pourtant des raisons technologiques et de commodité conduisent à l'augmentation de la puissance des installations thermo-électriques. Par contre, l'éclairage ainsi que la commande des installations stationnaires sont exclusivement du domaine de l'électricité.

L'accroissement annuel de la consommation d'énergie électrique dans le monde a atteint récemment environ 7%. Cela signifie que la consommation a doublé tous les dix ans. Dans les pays en voie de développement cet accroissement dépasse parfois 14%, mais il diminue au fur et à mesure de l'augmentation de la consommation et beaucoup de pronostics prévoient qu'il diminuera d'environ 1% au cours de chaque décennie. La grande commodité d'emploi de l'énergie électrique pourrait amener une forte augmentation de la consommation si les frais d'exploitation étaient abaissés. En outre, comme nous l'avons dit plus haut, la propagation de l'automobile électrique à batteries d'accumulateurs pourrait aussi conduire à un accroissement important de la consommation d'énergie électrique. Puisque dans ce cas le rendement final de la source primaire d'énergie serait inférieur à celui du moteur à combustion interne, on assisterait à une augmentation générale de la consommation d'énergie.

VI. Le rapide accroissement de la consommation d'énergie a pour corollaire une accélération de la consommation des réserves énergétiques; cette accélération est plus forte dans le cas des combustibles dont les réserves sont les moins importantes, c'est-à-dire le gaz naturel et le pétrole. Il faut alors confronter la consommation avec les réserves. L'étude détaillée de ces réserves peut conduire à reviser les évaluations initiales concernant les quantités disponibles et leur mode d'utilisation. Nous retiendrons ici les données du tableau V [7, 8]. Les données concernant l'uranium sont modérées, mais les chiffres seraient plusieurs fois plus élevés si l'on prenait en considération les réserves dont l'extraction est plus coûteuse. Si les besoins en pétrole et en gaz naturel continuent à augmenter au rythme prévu, alors en l'an 2000 environ, la moitié de ces ressources sera épuisée. D'après l'hypothèse de Hubbert [7] l'exploitation se déroulera selon le schéma suivant: les 10 premiers et les 10 derniers pour-cent des matières premières seront exploités lentement;

TABLEAU V. RESSOURCES ENERGETIQUES INITIALES DANS LE MONDE [7]

	Quantité	Energie (10^{15} kWh(th))	%
Houille et lignite	7600×10^9t	56	59
Pétrole et gazoline	280×10^9t	3,35	3,5
Gaz naturel	283×10^{12} m^3	2,94	3,1
Uranium (U_3O_8) [a]	1700×10^3t	33	34,4
Total		95,29	100,0

[a] Coût d'extraction inférieur à 22 $EU/kg.

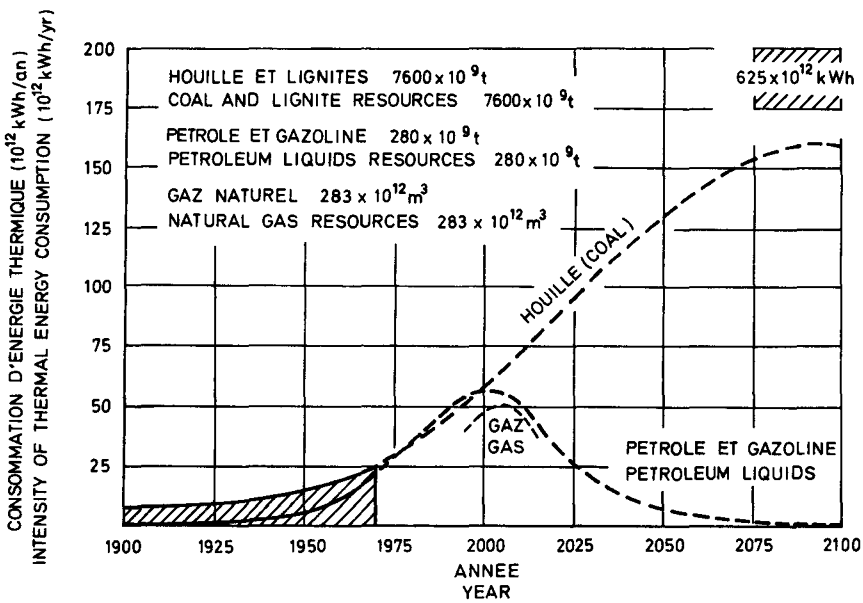

FIG.4. Taux prévisible d' épuisement des ressources mondiales (énergie thermique fournie par les combustibles fossiles).

la partie principale, c'est-à-dire 80%, le sera dans un temps relativement court. On peut prévoir que l'extraction diminuera après que la moitié environ des réserves aura été utilisée. Ainsi, après l'an 2000 la contribution du pétrole et du gaz diminuera probablement et leur place sera prise par l'énergie nucléaire et la houille, dont l'extraction augmentera (fig.4). Les données concernant d'autres ressources, comme par exemple l'énergie géothermique, l'énergie des marées et l'énergie solaire, sont encore insuffisantes pour nous permettre d'évaluer le rôle qu'elles pourront jouer dans le bilan total des combustibles. Les réserves d'énergie dont l'exploitation a été maîtrisée au point de vue technique suffiront pendant des centaines d'années et il est impossible de faire des prévisions exactes pour une période si longue. A l'heure actuelle on ne peut pas prendre en considération l'énergie thermonucléaire, car on n'en possède pas encore la maîtrise. Il ne s'agit pas de se protéger contre un manque d'énergie mais d'assurer une exploitation optimale des combustibles et de l'énergie.

Les conséquences de l'accroissement de la consommation d'énergie sont diverses et souvent défavorables pour l'environnement. On peut les ramener à trois problèmes essentiels:

– la concentration des établissements de production et de transformation des combustibles et de l'énergie,
– les transports,
– l'influence nuisible sur le milieu.

L'augmentation des besoins provoque la concentration des installations d'extraction et de transformation des combustibles, qui permet l'abaissement des frais de construction et d'exploitation des mines, des centrales électriques et des raffineries. Dans ces conditions l'entretien des petits établissements de ce genre n'est pas rentable, non plus que l'exploitation de petits gisements de houille, la construction de petites centrales hydrauliques ou de centrales électriques équipées de petites unités, qui ne peuvent concurrencer les établissements de grande taille. Cette situation constitue un handicap pour les pays économiquement développés. Comme les réserves de combustible ne sont pas réparties uniformément, leur utilisation à l'endroit de l'extraction est très souvent impossible. Il faut alors transporter des milliards de tonnes de houille, de pétrole et de gaz liquide ou faire circuler ce gaz et ce pétrole dans de longs pipelines. La rentabilité est proportionnelle à la capacité de transport. Cela constitue aussi un handicap pour les gros utilisateurs. Le transport du pétrole dans des bateaux-citernes entraîne la pollution des mers et des océans, qui se produit pendant les transbordements, pendant le nettoyage de la cale, et, dans une mesure catastrophique, par suite d'avaries graves au pétrolier ou de son naufrage. Ces catastrophes sont de plus en plus dangereuses puisque la capacité des pétroliers augmente toujours.

Le transport terrestre de la houille grève considérablement les transports par chemin de fer. La plus grande partie des investissements réservés aux transports publics finit par être consacrée au transport des combustibles.

La pollution du milieu pendant le transport des combustibles n'est pas élevée par rapport à celle que causent la conversion et la combustion des combustibles. Les raffineries et les cokeries bouleversent l'environnement. La combustion de toutes sortes de combustibles remplit l'atmosphère d'oxydes d'azote, très souvent d'oxydes de soufre, et, dans le cas des combustibles solides, de cendre. Même le gaz carbonique, estimé inoffensif, n'est par sans danger pour l'atmosphère terrestre. L'anhydride sulfureux ou les polluants dont on ne ressent pas les effets lorsque les concentrations restent faibles sont en mesure de détruire la vie biologique de l'environnement quand est dépassée une certaine valeur seuil. On a constaté aussi que l'échauffement des eaux superficielles par la chaleur provenant de la condensation de la vapeur dans les condensateurs, jugé jadis inoffensif, peut détruire la vie biologique des eaux. La prévention de ces conséquences nuisibles pour l'environnement, qui résultent de l'utilisation des combustibles, entraîne des frais qui ne sont pas sans influence sur les proportions relatives des divers combustibles utilisés.

VII. Ces considérations mettent en évidence l'importance de l'énergie nucléaire et expliquent dans une certaine mesure son développement rapide. Le doublement de la puissance des centrales nucléaires tous les deux ans prévu pour la présente décennie est sans précédent.

L'énergie nucléaire n'est pas utilisée que dans les centrales électriques. La construction de centrales «force-chaleur» est projetée et l'utilisation des réacteurs à haute température comme source de chaleur pour les procédés métallurgiques et chimiques est en cours d'étude.

La raison principale du développement si dynamique de l'énergie nucléaire est sa supériorite, du point de vue économique, sur les combustibles classiques. La chaleur est produite dans un réacteur à moindres frais, la charge dans le bilan du commerce et de l' importation des combustibles est inférieure, et les frais de transport sont negligeables. En outre l'environnement n'est pas affecté. Les centrales nucléaires sont d'autant plus concurrentielles que la puissance des unités est élevée [9]. Cela conduit à une concentration de puissance beaucoup plus grande que dans le cas des centrales classiques, et il arrive souvent que la plus grande unité d'un pays soit une unité nucléaire (tableau VI). Ces particularités des centrales nucléaires freinent certainement leur introduction rapide dans les pays en voie de développement. Dans la plupart des cas la puissance du réseau, et plus particulièrement la densité de la demande (kW/km^2), est trop faible pour qu'on puisse songer à installer des unités nucléaires d'une puissance assez élevée pour concurrencer les unités classiques. D'autre part les frais d'investissement sont plus élevés que dans le cas des centrales classiques [9]. Si on envisage un taux d'intérêt élevé ou un court délai d'amortissement, le coût unitaire élevé de l'énergie reculera encore le moment où une telle centrale pourrait devenir concurrentielle. Le fait que leur lieu d'implantation est pratiquement sans effet sur les frais de combustible est une qualité très importante des centrales nucléaires. Leur innocuité pour l'environnement permet de les construire à proximité des centres de consommation de façon à maintenir au minimum à la fois les frais de transport du combustible et ceux de transport de l'énergie tout en délestant les moyens de transport d'une charge importante. La diminution des investissements secondaires dans le domaine du transport — lesquels par exemple dans le cas du transport de la houille à une distance de 600 km atteignent 40% des dépenses de la centrale même — peut compenser les frais plus élevés d'investissement de la centrale nucléaire.

L'innocuité des centrales nucléaires [9, 10] est une qualité de plus en plus estimée de l'énergie nucléaire. L'incommodité des centrales classiques, de plus en plus insupportable avec la concentration progressive de la puissance, contraste avec l'absence d'effets des centrales nucléaires sur l'environnement. Les objections qui ont été élevées à propos de l'émission de substances radioactives ne sont pas convaincantes parce que ces substances sont souvent présentes dans les gaz de combustion de la houille utilisée dans les centrales classiques. Dans les deux cas pour-

TABLEAU VI. PROJECTION DES COUTS DE L'ENERGIE POUR LES REACTEURS A EAU LEGERE JUSQU'A L'AN 2000
(tiré de [9])

Année	1975	1985	2000
Puissance du réacteur (MW(e))	1000	2000	5000
Prix de revient en $ du kW installé	170	110	70
Prix du U_3O_8 ($/kg)	17,6	20	26,5 - 57,5
Charges fixes (mills/kWh)	3,4	2,2	1,4
Cycle du combustible (mills/kWh)	1,2	1,1	1,3 - 2,0
Frais d'exploitation (mills/kWh)	0,4	0,3	0,2
Coût de l'énergie (mills/kWh)	5,0	3,6	2,9 - 3,6

tant, l'activité est inférieure à la quantité admissible de quelques ordres de grandeurs [11]. Les exigences de la protection de l'atmosphère sont particulièrement importantes dans les pays développés économiquement et à forte densité de population. La pollution de l'atmosphère y est souvent proche de la limite admissible ou elle l'a même déjà dépassée, et on ne peut pas se permettre alors d'aggraver ces conditions par la construction de centrales classiques (fig. 5, tableau VII).

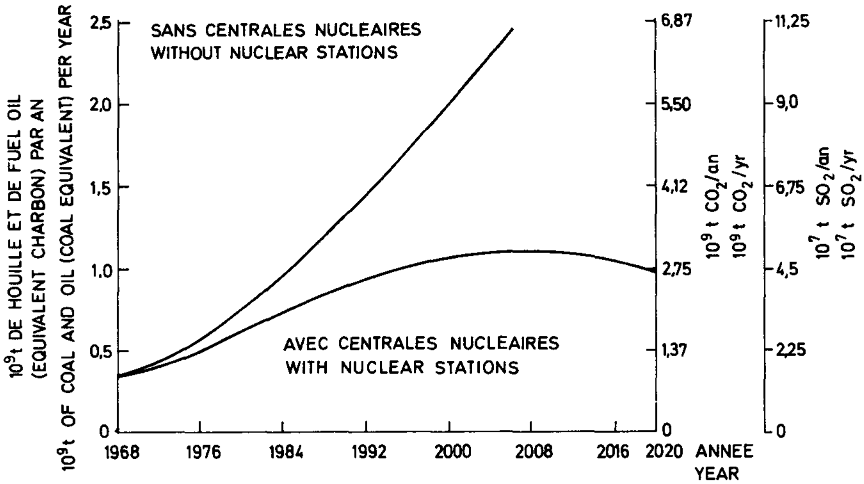

FIG. 5. Production prévue de SO_2 et CO_2 par l'industrie électro-énergétique (tiré de [10]).

TABLEAU VII. COMPARAISON DE L'ACTIVITE REJETEE PAR LES CENTRALES NUCLEAIRES ET CLASSIQUES
(tiré de [11])

	Houille	Nucléaire (PWR)
Puissance (MW(e))	1000	462
Hauteur de la cheminée (m)	240	60
Hauteur efficace de la cheminée (m)	460	0
Dégagements à la cheminée		
Cendres pulvérulentes (g/an)	$4,5 \times 10^9$	-
Ra-Th (mCi/an)	47,9	-
Gaz rares (Ci/an)	-	3,7
Effluents liquides		
Produits de fission (Ci/an)	-	3,8
Tritium (Ci/an)	-	1,735
Dispersion maximale (m)	35 000	840
Organe critique	os	corps entier
Dose maximale admissible CIPR		57
(µrem/h)	333	57
Débit de dose (µrem/h-MW(e))	$35,2 \times 10^{-6}$	$1,2 \times 10^{-6}$
Fraction de dose CIPR par MW(e)	$10,6 \times 10^{-8}$	$2,1 \times 10^{-8}$

L'énergie nucléaire est devenue un facteur complémentaire dans le bilan énergétique du monde, de plus en plus tendu; elle permet aussi de résoudre beaucoup de problèmes pressants de l'économie contemporaine, comme par exemple la réduction des frais de transport des combustibles et la protection de l'environnement de l'homme. Dans les pays industrialisés et surpeuplés, il ne serait pas possible de résoudre le problème du développement de l'énergie électrique en assurant la protection de l'environnement sans la participation des centrales nucléaires. Les dépenses en devises pour l'importation des combustibles nucléaires s'élèvent, par rapport aux dépenses en devises pour l'importation de la quantité équivalente de houille, à 60% si on importe les éléments finis, et à 35% seulement si on importe de l'uranium enrichi et vend en même temps l'uranium et le plutonium régénérés.

Les réacteurs surgénérateurs permettront de tirer meilleur parti de l'uranium et la demande de combustible diminuera sensiblement. Les dépenses principales seront alors celles du traitement du combustible.

VIII.a) L'énergie nucléaire a enrichi les ressources énergétiques du monde d'un apport nouveau et particulièrement important.

b) Le fait que les centrales nucléaires n'affectent pas l'environnement rend possible le développement de l'énergie dans les régions où la concentration industrielle et la pollution de l'atmosphère ne permettent plus de construire de centrales utilisant des combustibles classiques.

c) Cette qualité ainsi que les frais de transport négligeables permettent de construire les centrales nucléaires auprès des centres de consommation de l'énergie, sans frais notables de transport des combustibles et de transport de l'énergie même.

d) La non-dépendance des frais de l'énergie de ceux du transport du combustible, l'économie d'investissements dans le domaine de transport facilitent grandement l'utilisation des ressources naturelles dans les pays en voie de développement possédant un réseau de voies de communication peu développé.

e) Pour que la participation de l'énergie nucléaire augmente dans les pays en voie de développement, l'intérêt des constructeurs d'installations destinées aux centrales nucléaires doit se concentrer sur les réacteurs de puissance moyenne.

f) L'utilisation rationnelle de l'énergie nucléaire dans les centrales de grande taille à fort coefficient d'utilisation exige d'associer des centrales nucléaires de base à des installations de pointe, ainsi qu'à de petites centrales thermiques utilisant des combustibles classiques tels que le gaz, le fuel-oil et la houille.

Bien sûr, l'énergie atomique n'est pas la panacée qui permettra d'éliminer toutes difficultés dans l'industrie des combustibles et de l'énergie, mais il est certain qu'elle contribuera à résoudre des problèmes qui, sans elle, seraient très difficiles à régler ou même insolubles.

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A translation into English follows.

NUCLEAR ENERGY AND THE FUTURE

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I. The importance of energy for economic development is generally recognized. The rapidly growing consumption of energy in all its forms compels us to research more and more carefully into the exploitation of energy resources and the satisfaction of world energy requirements. Such research involves:

The qualitative and quantitative determination of energy requirements in the future,

Collation of these requirements with world energy resources;

The technical feasibility of utilizing the latter.

In each of these three factors there are several unknowns which cannot be ascertained at present.

As research and investigation proceed, certain aspects of the problem can be worked out in ever greater detail, the world energy resources become better known, and we then see that the differences between the overall predictions regarding energy requirements are on the wane. Conversely, there are big differences between the specific forms of contribution to the meeting of overall needs and the methods used to exploit the various energy resources.

TABLE I. STRUCTURE OF COMMERCIAL CONSUMPTION OF PRIMARY ENERGY SOURCES [2]

	1900	1920	1940	1950	1960	1970	1980	1990	2000
World (equivalent tonnes of coal)	-	-	-	2520	4230	6650	9820	15 600	27 400
Contribution (%)									
Coal	94.2	86.7	74.6	62.4	52.1	32	28.7	22.8	16.8
Oil	3.8	9.5	17.9	25.2	31.3	46	41.0	39	34.6
Natural gas	1.5	1.9	4.6	10.8	14.6	20	24.4	27.6	29.0
Hydroelectric energy	0.5	2.0	2.9	1.6	2.0	2	2.3	2.3	2.1
Nuclear energy	-	-	-	-	-	0.1	3.6	8.3	17.5

II. During the hundred years elapsing between the middle of the nineteenth century and 1950, energy requirements throughout the world consistently increased by about 2% p. a. [1].[1] It is only during the most recent decades that an appreciable increase in energy consumption has been observed, due to the speed-up in industrial development.

It is known that energy consumption depends upon per capita national income and that the growth-rates for energy consumption and national income are closely related (Fig. 1).[2] An especially rapid growth in national income and in energy consumption can be observed in two groups of countries: (1) the highly developed countries, and (2) those countries which so far have been poorly economically developed but which have now embarked upon the road to rapid economic progress.

In the first-named category we have the factor of the scientific and technological revolution. In the majority of highly developed countries, the mean annual increase in energy consumption is more than 5%. In certain cases, for example in Finland, Italy and Japan, the figures exceed 10% p. a. Generally speaking, there is an increase until a certain degree of saturation is reached, represented by 2-4 t of coal equivalent per capita, after which the annual increase levels off at a figure between 3. 5 and 5. 5%.

In the developing countries, where the level at which economic development begins is very low, the annual growth at the initial stage of industrialization usually amounts to 20% and then drops down very quickly to 10% or less. At the present time, however, these relative growth figures have hardly any practical significance in the context of the world consumption of energy. One third of mankind consumes more than four fifths of the present fuel and power output. Over the next decade this disproportion will increase still more. The high population increase observable in the developing countries is not accompanied by a proportional increase in energy consumption in absolute terms. It may thus be assumed that during the next decade it will be the energy consumption in economically developed countries that determines the level of world consumption. This disproportion, however, will be reduced in the last decade of the century. At the 7th World Power Conference held in Moscow in 1968 two predictions were made with regard to the development of energy requirements up to the year 2000. Since, in the meantime, it has been observed that the energy consumption for 1970 reached the higher of the two levels predicted, it is these data that are shown in Table I [2]. The rate of fall-off in the increase in energy consumption for different countries leads us to believe that world energy consumption will develop in accordance with a kind of saturation function as shown in Fig. 2,[3] and that we are at present witnessing the initial phase of this process.

Although the countries consuming most energy show the lowest relative growth, it must be remembered that at any given moment the bulk of the energy consumed in the world will be the result of the development of

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[1] The References will be found at the end of the French version of this paper, p. 110.

[2] Fig. 1. Per capita energy use and gross national product in selected countries (taken from Ref. [10]). For all Figures see the French version of this paper.

[3] Fig. 2. Estimated growth-rate of energy consumption. For all Figures see the French version of this paper.

countries that are at present passing through the first stages of industrialization; moreover, the population increase in these countries is above the world average.

III. The energy generated is consumed by three main sectors: (a) industry; (b) transport; (c) domestic users and commerce. It can be seen that at the present time industry consumes most of the energy (40-60%) in the developed countries. Depending on the degree of motorization, population density and ratio of land to water traffic, transport takes 12-30% of the energy. The remainder is accounted for by domestic appliances and municipal services [3-5]. This latter figure is mainly dependent on climate. In cold climates heating takes a great deal of fuel. In hot climates air-conditioning equipment is consuming more and more power. Improvement in housing conditions brings about a marked increase in energy consumption by households and municipal services. The development of motorization and of international relations affects the amount of energy consumed by transport. Improvement in living standards and a parallel increase in industrial output also result in a higher consumption of fuel and power in industry. Technological improvements, however, which make it possible to decrease the unit energy consumption, run counter to this trend. The production of pig-iron is an example· through careful preparation of the charge, increased pressure and temperature of the air, and improved furnace efficiency, there has been a systematic decrease in the quantity of coke required. Similarly, the manufacture of artificial (nitrogen) fertilizers, which used to consume more energy than any other chemical process, has become self-sufficient in terms of energy consumption, thanks to the rationalization of the technological processes. This is why in certain countries a slight decrease is foreseen in the part played by industry in the overall energy consumption.

The big differences to be observed in energy consumption can be illustrated by the following figures: in 1969 some of the larger developing countries were consuming 0.16 t of coal equivalent per capita, while the highly developed countries used 9.5 t and estimated that the consumption would have reached 17.5 t of coal equivalent per capita by the year 2000 [2].

IV. These requirements can be met by resorting either to various primary sources (coal, oil, natural gas, etc.), or to secondary sources (e.g. electricity). The main economic criteria motivating the choice of fuels and forms of energy (apart from the decisive factor of their suitability in each individual case) are:

The unit price of heat;
The size of the investment involved;
Secondary investments;
Operating costs;
The effect on the environment of man.

Natural gas is an ideal fuel for all stationary installations. Operational costs are lower than for oil. Installations using natural gas as a source of heat are much less expensive to run than those using fuel oil or coal [6]. Gas furnaces can easily be automated. The efficiency of combustion is virtually independent of the calorific value. Natural gas used for the mains supply does not produce any sulphur or ash, and is an excellent fuel from the standpoint of protecting the environment. Distribution costs are mainly made up of fixed charges; since storage of the gas is costly, regular distribution is desirable.

Natural gas is not only a fuel, but also a valuable chemical raw material. Its high efficiency, the relative simplicity of maintaining small gas furnaces, together with the fact that its combustion products are not harmful to the environment, make it a perfect fuel for households and municipal services which, together with the chemical industry, are the main consumers of this fuel. Because of its excellent qualities it is consumed in increasing quantities. Predictions for the period up to the year 2000 foresee that, in the overall energy balance, gas consumption may be higher than that of coal (Fig. 3).[4]

Sulphurless liquid fuels are just as valuable as gas, and it is easier to store them. Furthermore, the investment cost is lower than for coal or uranium and hence they can be used efficiently in installations operating with a low load factor. They are the fuels most commonly employed at the present time for air, road and sea transport. They can also compete successfully with electric traction on the railways. However, the role of oil and its derivatives has been affected by the requirements of environmental protection. When unloading their oil, and particularly when the holds are being cleaned up, oil tankers pollute the seas and oceans. The shipwreck of a tanker together with its cargo, which spreads to the surface of the water, leads to soiling of beaches and the destruction of biological life along the coasts. Waste products from refineries pollute rivers and off-shore waters. Similarly, exhaust gas from internal combustion engines constitutes a hazard for the atmosphere.

This explains the advantage to be gained by developing some means of transport other than the automobile engine for cities and their surrounding areas. If the internal combustion engine could be replaced by an electric motor powered by mains-charged accumulators, oil requirements would undergo a radical change, especially since protection of the environment forbids the burning of large quantities of fuel oil releasing excessive sulphur at power stations. Desulphurization of fuel oil or exhaust gases makes for a considerable increase in operating costs and reduces the competitiveness of liquid fuels, which, following the latest oil price increases, has already substantially declined to the advantage of other fuels. Some countries have already responded to the increased cost of oil by expanding their program for the construction of nuclear power stations.

The projections made to date envisage a rapid growth in oil consumption, which had already outstripped coal in the fuel balance for 1969, with a consumption higher than that of any other fuel. The latest oil price increase, which can be considered to reflect the overall market situation, may tip the balance in favour of gas and nuclear energy, in view of the need to protect the environment.

Coal, the second fuel in history after wood, is going through a period of stagnation. Over the last 10 years the coal output has remained at a

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[4] Fig. 3. Predicted world consumption of primary energy resources up to the year 2000.
For all Figures see the French version of this paper.

level of about 2000 million tons. Over the same period the output of lignite has slightly increased. The stabilization of the amount of solid fuel mined is explained by competition from oil. At a cost of heat that is only just lower, coal involves greater investments in the installations that make use of it. A power station operating on coal costs 20-25% more than one using oil. The operating costs are higher and disposal of the ash gives rise to problems. Properly constructed and operated dust-filtering units have eliminated air pollution, but there is still the problem of handling large amounts of ash. When the efficiency of furnaces is not very high - as is the case with coal – maintenance is a laborious process and automation is difficult. This is why on a domestic level coal has been replaced by gas, electricity or fuel oil. Only larger plants, such as thermal power stations, still use coal, as it is cheaper than heavy oils and especially because it contains less sulphur. Up to the present time coal has been the main fuel used in metallurgy.

Despite a slower growth-rate in the use of coal over the last 20 years and the decrease expected in its contribution to the world energy balance, it seems that the next few decades will witness a steady rise in coal production, by 2.5 - 3.5% p.a. The slackening off is due to the general trend in Western Europe towards a decline in this respect. The reasons for this are the higher operating costs and the difficulties involved in finding labour for the mines. Modernization of working conditions might change this state of affairs. An example that may be quoted in this connection is the Jan coal mine in Upper Silesia (Poland), which is completely automated and where the output per miner is several times greater than that in a conventional mine.

Nuclear energy will experience a very high rate of development: 50% p.a. over the next decade, and then 14% during the following years, i.e. a faster relative increase than for gas or oil. Nuclear energy possesses features that differ totally from those of liquid fuels. Investment costs are higher than for other fuels, while, on the other hand, heat production costs are lower. The larger the units the greater their efficiency and the lower the investment required, and costs decrease more rapidly with output than in other power plants (see Tables II-IV). Thus, the use of nuclear energy is at the present time economically worthwhile in high-capacity power plants with a high load factor, i.e. large base-load power stations, large power stations simultaneously producing heat for industrial establishments or for the desalination of sea-water, or large agro-industrial complexes at present at the design stage. Since the transport of nuclear fuel is not very costly, nuclear power stations can be built in direct proximity to centres of consumption. They can also be constructed in densely populated areas, since they do not pollute the atmosphere and are almost perfectly safe. These advantages explain the inordinately fast development of nuclear energy, which by the end of the century will probably occupy a place in the electricity balance on a par with conventional fuels.

In certain countries hydroelectric energy may play an important part, but in the world energy balance it will occupy only a marginal position. The cost of constructing a hydroelectric power station is usually higher, hence as regards the production of power alone, conventional thermal stations or nuclear plants are economically preferable. Other factors militate in favour of hydroelectric power stations, particularly the irrigation of water-depleted land or the damming of flood waters.

TABLE II. COMPARISON OF FUEL COSTS FOR 500-MW POWER PLANTS (UNIPEDE, 1961)

Fuel	Capacity (MW)	
	4 × 125	2 × 250
Coal	1.0	0.92
Fuel oil	0.85	0.78
Natural gas	0.833	0.77

TABLE III. CAPITAL COSTS FOR 500-MW AND 1000-MW POWER STATIONS
(Costs in $/kW, 1970 US dollars, first core not included; taken from [6])

Fuel	Capacity (MW)	
	500	1000
Coal	165	140
Fuel oil	140	115
Nuclear energy (PWR or BWR)	190	150

TABLE IV. INVESTMENT COSTS FOR VARIOUS TYPES OF POWER STATION
(1969 values, taken from [9])

Fuel	Nuclear			Fuel oil		
Capacity (MW(e))	300	500	1000	300	500	1000
Cost ($/kW)	311	248	191	177	152	132

These estimated costs include both direct and indirect expenditure, interest during construction, and price escalation during construction.

TABLE V. INITIAL ENERGY RESOURCES IN THE WORLD [7]

	Quantity	Energy content (10^{15} kWh(th))	(%)
Coal and lignite	7600×10^9 t	56	59
Petroleum liquids	280×10^9 t	3.35	3.5
Natural gas	283×10^{12} m^3	2.94	3.1
Uranium (U_3O_8) [a]	1700×10^3 t	33	34.4
Total		95.29	100.0

[a] Extraction cost lower than US $22/kg.

V. Electrical power is of particular importance in meeting energy needs. In the evaluations given above it has not been taken into consideration, since it constitutes a secondary source, stemming from the conversion of the energy of a waterfall or of the thermal energy created by the burning of conventional fuels or by nuclear fission. The efficiency of these conversion processes is low at best it never exceeds 0.4. If we also take transport costs into consideration, the efficiency is still lower and often remains below 0.25. Hence electric heating requires three or four times more fuel than is needed in the case of direct consumption. However, technological factors together with considerations of convenience are leading to the increased capacity of thermoelectric plants. On the other hand, both lighting and operation in stationary plants belong exclusively to the realm of electrical power.

The annual growth in the world consumption of electrical energy has recently attained some 7%. This means that consumption has been doubling every ten years. In the developing countries the increase is at times greater than 14%, but falls off as higher levels are reached, and there are many predictions that it will drop by about 1% during each decade. If operating costs were lower, the fact that electrical energy is so convenient to use might result in much higher consumption. Furthermore, as pointed out above, the large-scale adoption of battery-powered electric cars could also bring about a considerable increase in the consumption of electrical energy. Since in such a case the final efficiency of the primary energy source would be lower than that of the internal combustion engine, there would be a general increase in energy consumption.

VI. The corollary of the rapid increase in energy consumption is accelerated utilization of energy resources; this acceleration is greater in the case of fuels of which there are smaller reserves, namely natural gas and oil. Consumption should therefore be collated with the reserves. A detailed study of these reserves could lead us to a reappraisal of the initial estimates relating to quantities available and how they should be used. The data in Table V [7, 8] illustrate this; the data on uranium are conservative, but the figures would be several times higher if the reserves for which the mining costs are higher were taken into account. If the oil and natural gas requirements continue to increase at the anticipated rate, half of these resources will have been used up by the year 2000. According to the hypothesis put forward by Hubbert [7], exploitation of the resources will conform to the following pattern: the first and last 10% of the raw material will be extracted over a prolonged period, while the bulk of it, i.e. 80%, will be obtained over a relatively short time. We can expect extraction to decrease when roughly half of the reserves have been used up. Thus, after the year 2000 the contribution of oil and gas will most likely decline and their place will be taken by nuclear energy and coal, extraction of which will be increased (Fig. 4).[5] The data for other resources, for example, geothermal, tidal and solar energy, are not yet sufficient for us to evaluate the role they could play in the total fuel balance. The energy reserves for which, from the technical standpoint, the exploitation techniques have been fully mastered, will suffice for hundreds of years to come,

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[5] Fig. 4. Foreseeable depletion rate for world resources (thermal energy supplied by fossil fuels). For all Figures see the French version of this paper.

and it is not possible to make any exact forecasts for so long a period. At the present time thermonuclear energy is not in the running, since controlled nuclear fusion is not yet a reality. The problem is not one of taking precautions to avert a dearth of energy, but of ensuring optimal exploitation of fuel and power.

The results of the growth in energy consumption are varied and often unfavourable for the environment. They can be summarized in the form of the following main problems:

Concentration of plants producing and processing fuel and power;
Transport;
Deleterious effects on the environment.

Increased energy needs bring about the concentration of fuel extraction and processing facilities, a factor which helps to reduce the cost of constructing and operating mines, power stations and refineries. Under these conditions it is not profitable to maintain small plants of this kind, to work small coal deposits, or to construct small hydroelectric power stations or small-unit thermal power stations, since they cannot compete with large facilities. This situation is a handicap to economically developed countries. Since the fuel reserves are not uniformly distributed, it is often impossible to make use of them at the point of extraction. Thus enormous quantities of coal, oil and liquid gas have to be transported, or the gas and oil pumped through long pipelines. Profitability is proportional to transport capacity. This is also a handicap for large consumers. The carriage of oil in tankers involves pollution of the seas and oceans, for example when the oil is shipped or when the tanks are cleaned out, and causes a disastrous degree of pollution when a tanker meets with a serious accident or is wrecked. The hazards inherent in such incidents are even greater in that the carrying capacity of oil tankers is growing continuously.

Overland shipment of coal is a considerable burden on rail transport. The bulk of investments earmarked for public transportation end up by being spent on the shipment of fuel.

Pollution of the environment during fuel transport is not very high compared with that caused by the conversion and combustion of fuels. Refineries and coke works have an adverse effect on the environment. The combustion of various kinds of fuel fills the air with nitrogen oxides, in many cases with sulphur oxides and, in the case of solid fuel, with ash. Even carbon dioxide, considered to be harmless, is not without hazard for the earth's atmosphere. Sulphur dioxide and pollutants, the effects of which are not felt in small concentrations, are capable of destroying the biological life of the environment when a certain threshold value is exceeded. It has also been noted that the heating of surface water by heat produced by the condensation of steam in condensers, at one time thought to be harmless, may destroy the biological life in the water. Prevention of the deleterious effect on the environment resulting from the use of fuel involves expenditure that plays a big part in deciding the relative proportions of the various fuels used.

VII. These factors bring out the importance of nuclear energy and partly explain its rapid progress. The expected doubling of nuclear power station capacity every two years during the present decade is something without precedent.

TABLE VI. PROJECTION OF ENERGY COSTS FOR LIGHT-WATER REACTORS UP TO THE YEAR 2000
(taken from Ref. [9])

Year	1975	1985	2000
Reactor capacity (MW(e))	1000	2000	5000
Unit cost ($/kW installed)	170	110	70
U_3O_8 cost ($/kg)	17.6	20	26.5 - 57.5
Fixed charges (mills/kWh)	3.4	2.2	1.4
Fuel cycle (mills/kWh)	1.2	1.1	1.3 - 2.0
Operation and maintenance (mills/kWh)	0.4	0.3	0.2
Energy cost (mills/kWh)	5.0	3.6	2.9 - 3.6

Nuclear energy is used not only in power stations producing electricity alone. The construction of dual-purpose heat and power stations has been projected and the use of high-temperature reactors as a heat source for metallurgical and chemical processes is under study.

The main reason for this dynamic development of nuclear energy is its economic advantage over conventional fuels. The heat is produced in a reactor at lower cost, the expenditure involved in buying and importing fuel is modest, and transport costs are negligible. Furthermore, the environment is not affected. The higher the capacity of nuclear power stations, the more competitive they are [9]. This leads to a much greater concentration of capacity than in the case of conventional power stations, and it often happens that the largest plant in a given country is a nuclear one (Table VI). These features of nuclear power stations are certainly inhibiting their rapid adoption in developing countries. In most cases the capacity of the system, more especially the density of requirements (kW/km^2), is too small to entertain the idea of installing nuclear plants of sufficient capacity to compete with conventional stations. On the other hand, the investment costs for nuclear stations are higher than for conventional plants [9]. If a high interest rate or rapid amortization is envisaged, the heavy expense of the first plant means that the time when it could become competitive is further off. The fact that the siting of these power stations hardly affects the cost of fuel at all is a very important advantage of nuclear power stations. Their safety vis-à-vis the environment means that they can be built and operated as near as required to centres of consumption, thereby keeping to a minimum the fuel transport and energy transmission costs while relieving transport vehicles from a heavy burden. The decrease in secondary investments in fuel transport costs — which, for example, in a case where coal is shipped a distance of 600 km, amount to 40% of the outlay for the station itself — may offset the higher investment required for a power station operating on nuclear energy.

The safety of nuclear power stations [9, 10] is a characteristic of nuclear energy that is gaining more and more recognition. The inconvenience of conventional power stations, which becomes more and more intolerable as concentration of capacity progresses, contrasts sharply with the fact that nuclear power stations do not affect the environment adversely. The objections that have been raised in connection with the release of radioactive materials are not convincing, since the same materials are often present in the combustion gases produced by coal in conventional power stations. In both cases, however, the activity is lower than the permissible concentration by several orders of magnitude [11]. The need to protect the atmosphere is especially important in economically developed countries with a high population density. The degree of environmental pollution in these countries is often close to, or already higher than, the permissible limit, and we therefore cannot afford to aggravate the situation by building more power stations of the conventional type (Fig. 5; Table VII).[6]

TABLE VII. COMPARISON OF ACTIVITY RELEASED BY NUCLEAR AND CONVENTIONAL POWER STATIONS
(taken from Ref. [11])

	Coal	Nuclear (PWR)
Capacity (MW(e))	1000	462
Stack height (m)	240	60
Effective stack height (m)	460	0
Stack discharges		
Fly ash (g/yr)	4.5×10^{9}	-
Ra-Th (mCi/yr)	47.9	-
Noble gases (Ci/yr)	-	3.7
Liquid effluents		
Fission products (Ci/yr)	-	3.8
Tritium (Ci/yr)	-	1.735
Maximum dispersion (m)	35 000	840
Critical organ	bone	whole body
ICRP dose limit (μrem/h)	333	57
Dose rate (μrem/h · MW(e))	35.2×10^{-6}	1.2×10^{-6}
Fraction ICRP dose/MW(e)	10.6×10^{-8}	2.1×10^{-8}

Nuclear energy has become a complementary factor in the world energy balance, which is being subjected to ever greater strain. This form of energy also enables us to cope with a host of urgent problems in the present-day economy, for example reduction of fuel transport costs and protection of man's environment. In the highly industrialized and over-populated countries it may not be possible to increase electrical capacity and, at the same time, safeguard the environment without the use of nuclear power plants. The cost in foreign currency of importing nuclear fuel amounts to 60% of

[6] Fig. 5. Projected SO_2 and CO_2 production by the electrical power industry. For all Figures see the French version of this paper.

the cost of importing the equivalent amount of coal if fabricated elements are purchased and only to 35% if enriched uranium is imported and the regenerated uranium and plutonium are sold.

Breeder reactors will allow better utilization of uranium, and fuel requirements will therefore be appreciably decreased. The main expenditure will then relate to fuel reprocessing.

VIII. (a) Nuclear energy has added a very important new contribution to world energy resources,

(b) The fact that nuclear power stations do not affect the environment makes it possible to develop nuclear energy in areas where the concentration of industry and pollution of the atmosphere are such that we can no longer afford to build power stations operating on conventional fuels;

(c) This positive characteristic, plus the negligible transport costs, enables nuclear power stations to be built near energy consuming centres without the need for appreciable expenditure on fuel transport and on transmission of the power itself;

(d) The fact that energy costs are independent of fuel transport costs, together with the saving on investments in the transport sector make it much easier to use natural resources in developing countries with an underdeveloped communications network;

(e) To increase the part played by nuclear energy in the developing countries, manufacturers of plant intended for nuclear power stations should concentrate their efforts on medium-power reactors;

(f) The efficient use of nuclear energy in large-size power plants with a high utilization factor necessitates the combination of base-load nuclear stations with peak-load facilities and with small thermal power stations operating on conventional fuels such as gas, oil and coal.

Obviously, atomic energy is not a panacea for all the ills existing in the fuel and power industry, but it can certainly help to solve problems which, without it, would be very difficult or even impossible to deal with.

SUMMING-UP AND CLOSING OF THE CONFERENCE

ОБЗОР РАБОТЫ КОНФЕРЕНЦИИ

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Республик

Начиная свой обзор, я хотел бы прежде всего выразить благодарность за ту большую честь, которая была оказана мне – представителю советской науки – предложением сделать итоговый доклад. Вместе с тем, я должен откровенно сказать, что поставлен в очень затруднительное положение, поскольку теперь атомная наука и техника настолько развились, что одному человеку практически невозможно глубоко вникнуть во все ее аспекты. Поэтому в данном обзоре я буду вынужден остановиться лишь на самых основных, по моему мнению, достижениях, о которых говорилось на этой Конференции. Здесь я, разумеется, приложу все силы для максимально объективного освещения всех главных аспектов, хотя несомненно возможно, что некоторый остаток субъективного подхода, некоторая субъективность трактовки все же будут иметь место, поскольку круг моих интересов ограничен определенными рамками.

IV Конференция, и это необходимо констатировать в первую очередь, вызвала большой интерес и привлекла большое количество участников. Несомненно, что происшедший на ней международный обмен научными и техническими идеями, показ полученных в разных странах достижений должен оказать самое существенное влияние на дальнейшее развитие атомной науки и техники.

79 стран прислали своих представителей на эту Конференцию для обсуждения проблем, связанных с использованием атомной энергии. За семь лет, прошедших со времени проведения III Женевской конференции, практически во всех странах мира интенсивно развивалась атомная наука и техника, которая, как недавно заявил на Генеральной Ассамблее ООН Генеральный директор МАГАТЭ доктор Зигвард Эклунд, достигла своего совершеннолетия. Анализируя доклады ученых и специалистов из многих стран, можно с уверенностью подтвердить, что IV Женевская конференция показала, что работы, связанные с практическим использованием ядерной энергии, бурно развиваются.

Если перед проведением I Женевской конференции в 1955 году атомная энергетика была представлена только единственной атомной электростанцией (Обнинская атомная электростанция мощностью 5 МВт), то перед проведением IV Конференции количество действующих и строящихся энергетических реакторов достигло более 230. По данным МАГАТЭ на конец апреля 1971 года работало 102 реактора и находился в стадии строительства 131 энергетический реактор. Достижения в области ядерной технологии и ее применения в мирных целях привлекали внимание не только ученых и инженеров, но и государственных деятелей.

В настоящее время у целого ряда стран имеются пятилетние или долгосрочные национальные программы развития атомной науки и техники. Наличие таких национальных программ, а также сотрудничество в рамках

МАГАТЭ и других специализированных международных организаций позволяет более целеустремленно решать важнейшие проблемы использования атомной энергии. Значительный вклад в эффективное решение проблем использования атомной энергии в мирных целях внесен представленными на эту Конференцию докладами и теми творческими обсуждениями, которые проводились в залах Дворца Наций, на выставке и в самых разных местах в городе Женеве.

Итак, я позволю себе кратко остановиться на обзоре отдельных вопросов, рассмотренных на IV Женевской конференции по использованию атомной энергии в мирных целях.

Имея в виду международный характер работ, проводимых в области использования атомной энергии в мирных целях, мне бы не хотелось выделять роль той или иной страны, поскольку все наши достижения в этом плане идут в общую копилку международных достижений. Оценивая характер и основные результаты предыдущих Женевских конференций по использованию атомной энергии в мирных целях, многие ораторы подчеркивали, что III Женевская конференция 1964 года продемонстрировала такое состояние, когда ядерная энергетика уже вышла из стадии эксперимента, ядерные электростанции начали конкурировать с обычными электростанциями и, более того, нашли свой путь развития.

В начале нашей работы, здесь в Женеве, нам напомнили те задачи, которые Генеральная Ассамблея поставила перед IV Женевской конференцией: она должна быть полезной не только для ученых и инженеров, но также для организаторов промышленности, администраторов и экономистов. Такой прицел исходил из сознания того, что к моменту созыва IV Конференции ядерная энергетика достигла этапа зрелости.

Ход Конференции подтвердил эти исходные предпосылки и позволяет считать, что поставленная цель достигнута. Персональный состав Конференции и характер представленных материалов свидетельствует о том, что атомная энергия продолжает укреплять свои позиции в самых разнообразных сферах деятельности человека, а самая крупная область ее применения – ядерная энергетика – получила широкое распространение во всем мире.

Именно этот факт выдвигает на первый план ряд важных проблем, которые могли на более ранних этапах развития не находиться в центре внимания широких кругов. Сюда относятся, прежде всего, вопросы воздействия на окружающую среду, безопасность населения, вопросы захоронения отходов, проблемы работы атомных электростанций в энергосистемах, исследования по выбору оптимального топливного цикла для различных типов реакторов, изучение стойкости конструкционных материалов.

Обзор как мировых потребностей в энергии, так и энергетических ресурсов показывает, что к концу этого столетия с помощью атомной энергии должна, по-видимому, вырабатываться половина всей электрической энергии, производимой в мире. Говоря о цифрах, можно отметить, что к концу столетия мощность ядерной энергетики по представленным здесь прогнозам возможно приблизится к 3 млн.МВт. Расчеты потребностей показывают, что в 1980 году мощность ядерных станций составит примерно 300 000 МВт (эл), а за 20 последующих лет производство электрической энергии от атомных электростанций должно увеличиться примерно в 8-10 раз. Мало сказать, что это очень сложная и трудная проблема, в решении которой примут участие ученые, инженеры и организаторы производства всего мира. Эта задача приближается к фантастической. Однако решение этой задачи уже началось широким внедрением энергетических тепловых реакторов и отработкой инженерных проблем быстрых реакторов.

Реакторы на тепловых нейтронах прошли значительный период изучения и освоения и эксплуатируются сейчас в промышленности. Это, прежде всего, относится к реакторам с водяным замедлителем и, в значительной мере, к реакторам с графитовым замедлителем – как с газовым, так и с водяным теплоносителем. Сейчас многие страны уже располагают достаточно богатым опытом их эксплуатации. На этом пути были и успехи, и трудности. Теперь уже ясно, что трудности, в основном, преодолены, накопленный опыт создал хорошую предпосылку начавшегося бурного роста ядерной энергетики. Изложение опыта развития и эксплуатации этих реакторов – очень важная тема, затронутая нашей Конференцией.

Следующий круг научно-технических проблем, привлекший большое внимание участников Конференции, – обеспечение безопасной эксплуатации атомных электростанций. Эта проблема имеет разнообразные аспекты: правильное конструирование реакторов и их систем охлаждения; достаточно полный учет природных факторов и обоснованный выбор мест расположения атомных электростанций; развитие специальных норм, правил и процедур, направленных на обеспечение безопасности атомных электростанций; обеспечение и контроль качества оборудования для атомных электростанций.

Тщательное и обоснованное решение этих вопросов диктуется самими масштабами распространения атомных электростанций, необходимостью их размещения в густонаселенных районах, вовлечением в эту сферу новых масс людей, а также новых строительных и промышленных предприятий и отраслей промышленности. Наряду с рассмотрением этих узловых вопросов атомных электростанций с реакторами на тепловых нейтронах, Конференция уделила внимание развитию и конструкции усовершенствованных типов реакторов, либо обеспечивающих повышенную эффективность термодинамического цикла, либо обладающих улучшенными показателями топливного цикла. Сюда следует отнести высокотемпературные газовые реакторы, тяжеловодные реакторы различных вариантов, графитовый реактор с охлаждением кипящей водой, реакторы на солевых расплавах, на диссоциирующих газах.

Быстрые реакторы-бридеры открывают возможность лучшего использования сырьевых ресурсов ядерного топлива для целей энергетики. Программе разработки этого типа реакторов в наиболее развитых странах уделяется максимальное внимание.

Экспериментальные быстрые реакторы уже много лет эксплуатируются в США, СССР, Великобритании и Франции. Сооружаются реакторы в Италии, Японии и ФРГ. Реакторы уже доказали устойчивость и надежность работы, дали опыт для проектирования коммерческих реакторов.
К настоящему времени определилось направление и основные черты этих реакторов: натриевое охлаждение, керамическое топливо в оболочке из нержавеющей стали, трехконтурные схемы с паровыми турбинами. Однако до технического осуществления крупных коммерческих реакторов расстояние еще велико, и задачей ближайшего будущего является сооружение прототипов.

В стадии завершения строительства и монтажа находятся крупные энергетические реакторы на быстрых нейтронах в СССР, Великобритании и во Франции. Разработаны проекты демонстрационных реакторов-прототипов в ФРГ и США, в стадии разработки находятся проекты в Италии и Японии.

Интенсивные работы проводятся во многих странах по испытанию топливных элементов, испытанию оборудования. Именно эти вопросы, представленные на Конференции, характеризуют состояние в освоении реакторов-бридеров. Центр тяжести в освоении быстрых реакторов перемещается в технические проблемы обоснования надежности различного оборудования и систем контроля в реальных условиях эксплуатации. Можно ожидать, что эти задачи будут успешно решены в ближайшие несколько лет, и период после 1980 года будет периодом сооружений коммерческих быстрых реакторов, за которыми начинается новый этап энергетики — энергетики бридеров, производящих электроэнергию и топливо для дальнейшего развития.

Быстроразвивающаяся атомная энергетика, естественно, требует соответствующего развития всех звеньев топливного цикла. Нет необходимости говорить о важности обеспечения горючим. По оценке, сделанной в одном из обзорных докладов, разведанные запасы уранового сырья, из которого уран может быть извлечен по цене до 10 долларов за фунт, составляют примерно 1 млн. т. Этого количества достаточно для удовлетворения потребностей в уране только до конца семидесятых годов. В этой связи на Конференции подчеркивалась важность всемерного расширения поисковых работ по выявлению новых месторождений урана, а также по совершенствованию методов переработки руд, в особенности с низким содержанием урана.

Но мне лично кажется, что нельзя недооценивать важность развития новых методов получения ядерного горючего всевозможными способами, в том числе путем извлечения урана из морских вод, имея в виду, что там его — около 4000 млн.т.

Так как в большинстве вводимых и планируемых реакторов используется обогащенный уран, вполне объясним большой интерес, проявленный на Конференции в отношении проблем изотопного обогащения урана, разработки и совершенствования методов и технологии обогащения.

За период между III и IV Конференциями большой прогресс достигнут в области изготовления топлива и его регенерации после использования в реакторах. Вместе с тем, здесь еще предстоит многое сделать, например развить методы переработки горючего быстрых реакторов, усовершенствовать переработку торийсодержащего топлива.

Мне лично кажется, что без решения проблем быстрых реакторов нельзя решить задачу создания большой атомной энергетики.

Наконец, следующим перспективным этапом в развитии ядерной энергетики должно стать вовлечение в энергетический цикл нового ядерного горючего — высокотемпературной дейтериевой плазмы. Как и двадцать лет назад, в основе наиболее продвинутых работ по созданию высокотемпературной плазмы достаточной плотности и температур лежит идея о ее магнитной термоизоляции.

Мне хотелось бы подчеркнуть здесь, что, благодаря инициативе замечательного советского ученого, покойного академика Курчатова, в 1955 году работы по управляемому термоядерному синтезу были рассекречены, что оказало чрезвычайно благотворное влияние на все развитие этой важной области.

В настоящее время мы имеем три основных направления экспериментов в общей программе термоядерных разработок: эксперименты по получению горячей плазмы в замкнутых магнитных системах (токамак и стелларатор), адиабатических магнитных ловушках, а также в импульсных магнитных полях. Детальные исследования свойств высокотемпературной плазмы, исключительная изобретательность физиков, занятых разработкой этой проблемы, позволили найти более оптимальные режимы процессов термоизоляции плазмы и, таким образом, повысить ее главные физические параметры.

Со времени III Женевской конференции удалось почти на порядок повысить параметры плазмы и в установках с магнитными зеркалами. Известный прогресс имеется в наиболее разработанных из методов быстрого нагрева плазмы в импульсных магнитных полях.

Помимо упомянутых разделов термоядерной программы, ставших традиционными, в последние годы начали развиваться относительно молодые направления. К ним следует отнести эксперименты с установками, позволяющими создать в очень небольшом объеме чрезвычайно плотный сгусток высокотемпературной плазмы — "плазменный фокус". Правда, дальнейшие перспективы этого метода еще не ясны, поскольку условия эксперимента пока не позволяют разобраться в механизме нейтронного излучения плазменного фокуса и его зависимости от различных физических параметров.

В самое последнее время широкий размах начинают приобретать исследования, связанные с возможностью нагрева вещества мощным световым импульсом от лазера. Особая привлекательность этого метода состоит в том, что он позволяет, в принципе, отказаться от идеи магнитной термоизоляции плазмы. В экспериментах, проведенных на основе этого метода, интенсивность нейтронного излучения составляет пока 10^4 нейтронов за импульс. Однако необычайно быстрый прогресс в повышении запаса энергии в лазерном импульсе и к.п.д. самого лазера, от которых главным образом зависят перспективы этого направления, может уже в самые ближайшие годы сделать метод лазерного нагрева одним из ударных направлений во всей термоядерной программе. Делаются также первые шаги в разработке весьма привлекательных с физической точки зрения методов сверхбыстрого нагрева вещества электронным пучком большой мощности.

Анализ современного состояния проблемы термоядерного синтеза показывает, что, несмотря на появление принципиально новых направлений, она еще не вышла из стадии разработки физических основ получения таких параметров плазмы, которые позволили бы использовать происходящие в ней реакции для технического решения задач создания термоядерного реактора.

Будем надеяться, что оставшаяся часть пути будет пройдена не медленнее предыдущей.

Дальнейшее развитие ядерной энергетики в ближайшие годы будет сопровождаться накоплением все возрастающих количеств ядерных материалов.

В этой связи большое внимание на Конференции было уделено проблемам гарантий и контроля ядерных материалов, предусмотренных Договором о нераспространении ядерного оружия.

Успешная разработка Международным агентством по атомной энергии типового соглашения о контроле, а также достижения в усовершенствовании технических методов и средств контроля ядерных материалов, вселяют уверенность, что цели контроля, предусмотренного Договором о нераспространении ядерного оружия, будут осуществлены с достаточной эффективностью при умеренных затратах и без какого-либо ущерба для мирного применения ядерной энергии.

Совершенствованию методов переработки и захоронения отходов Конференция уделила большое внимание. Разрабатываемые и используемые методы закачивания отходов в грунт, отверждения, захоронение в соляные формации и другие методы позволяют надежно удалять отходы.

В этой связи мне представляется неоправданным сброс радиоактивных отходов в моря и океаны, ввиду возможного загрязнения гидросферы.

Необходимо также сказать о большом сдвиге, произошедшем со времени проведения III Женевской конференции, в области развития работ по прикладной радиационной химии и осуществлению радиационно-химических процессов в промышленном масштабе. В некоторых странах на основе процессов радиационной модификации полимерных материалов организовано промышленное производство различных материалов и изделий, обладающих уникальными свойствами, осуществлены процессы радиационного синтеза. Важно отметить, что в развивающихся странах широко развернулись исследования в области прикладной радиационной химии, направленные на промышленное осуществление радиационных процессов.

Надежная работа атомных электростанций и обеспечение безопасности человека невозможно без прогресса в области ядерного приборостроения. В настоящее время уже разработаны и выпускаются промышленностью сотни типов приборов, применяемых для радиометрии, дозиметрии и технологического контроля различных ядерных реакций. Это очень обнадеживает и создает уверенность в том, что в самое ближайшее время на основе последних достижений в микроэлектронике будут созданы комплексные автоматические системы, позволяющие надежно контролировать и управлять атомными энергетическими установками.

Период со времени III Женевской конференции характеризуется значительным прогрессом в области применения радиоактивных изотопов и излучений в различных областях медицины. Широкое развитие получили методы радиоизотопных исследований с целью диагностики различных заболеваний человека в общетерапевтической практике, хирургии и онкологии.

Основные тенденции, характеризующие современную лучевую терапию, которые нашли отражение в докладах IV Женевской конференции, заключаются:

— в расширении диапазона ядерных излучений, применяемых в радиотерапевтической практике (гамма-излучение, излучение бетатронов и линейных ускорителей, протонная и нейтронная терапия);

— в совершенствовании радиационно-физических параметров и клинико-методических обоснований лучевой терапии, оптимизации программ лучевого лечения с целью его индивидуального планирования на основе применения электронно-вычислительной техники.

Значительную роль в дальнейшем совершенствовании радиоизотопной диагностики и лучевой терапии играет также создание крупных радиологических центров и подготовка кадров специалистов. Материалы, доложенные на Конференции, свидетельствуют о серьезном внимании к изучению биологических эффектов воздействия различных типов радиации, исследования механизмов лучевого повреждения и репарации на клеточном и молекулярном уровне и возможности использования защитных средств.

Свой вклад вносит радиобиология в разрешение такой важной проблемы, как обеспечение населения земного шара достаточным количеством полноценных продуктов питания. Это достигается путем использования высокоурожайных сортов зерновых культур, полученных методом радиационной селекции, совершенствованием способа лучевой стерилизации.

Все шире используются излучения для индуцирования полезных мутаций у микроорганизмов.

Особое внимание в докладах уделялось проблеме окружающей среды. Проводятся обширные исследования путей поступления радиоактивности во внешнюю среду, проникновения и взаимодействия этих продуктов с биосферой.

В докладах на Конференции единодушно отмечено, что проблема влияния радиоактивных веществ на человека и биосферу в целом является одной из узловых в вопросах мирного использования ядерной энергии. Доклады убедительно показали, что вопросам безопасности работы атомных электростанций, загрязнения внешней среды в разных странах мира уделяется огромное внимание.

Интересна сравнительная оценка последствий работы обычных предприятий и атомных станций, приведенная на Конференции. При работе обычных предприятий потребуется в несколько тысяч раз большее количество воздуха для разбавления токсичных веществ до допустимого уровня, чем при работе атомных электростанций. Кроме того, количество рассеиваемого общего количества тепла (которое может, в конечном счете, вызвать нежелательные климатические изменения) на единицу полезной мощности атомной электростанции за счет высокого коэффициента полезного действия значительно меньше, чем при работе обычных электростанций. Использование атомной энергии не требует расхода кислорода и не ведет к непрерывному росту содержания углекислого газа в атмосферном воздухе.

Большое внимание в докладах было уделено вопросам реакции населения, общественности на развитие атомной энергетики. Безусловно, этот вопрос требует самого тщательного внимания, кропотливой работы.

В рамках Конференции было проведено интересное совещание по экологическим вопросам, на котором представители десяти стран обменялись мнениями и ответили на десятки поступивших вопросов. На совещании подчеркивалась роль ученого, проводящего объективные исследования в формировании положительного общественного мнения по признанию ядерной энергии.

В материалах Конференции широко освещены вопросы значения ядерной технологии для развивающихся стран с охватом практически всех аспектов применения атомной энергии и проанализированы пути увеличения вклада ядерной технологии в экономический прогресс.

Во всех странах, в том числе в развивающихся, наблюдается стремительно растущий спрос на энергию, и ядерная энергия является одним из путей удовлетворения этого спроса. Однако ядерная энергетика должна всегда сравниваться с более традиционными видами производства электроэнергии с учетом того, что каждый вид источника энергии имеет свои преимущества и недостатки.

Топливную базу для атомной энергетики развивающихся стран, вероятно, целесообразно развивать на региональной основе, с максимальным использованием собственного уранового сырья, поиски и разведку которого следует усилить, а для обогащения урана развивающиеся страны могут воспользоваться услугами других стран.

Созданные в развивающихся странах атомные центры способствуют подготовке квалифицированных специалистов. Они также способствуют развитию научных исследований в областях, имеющих важное прикладное значение для экономики. Построенные в этих центрах ускорители заряженных частиц и исследовательские реакторы являются надежными источниками радиации для исследований и базой для подготовки кадров. Кадры, очевидно, являются одним из важнейших факторов в деле применения атомной энергии в этих странах.

Ядерная технология лишь недавно начала давать свой вклад в экономический прогресс ряда стран, и есть все основания к тому, что ядерная технология и многие ее экономичные применения будут способствовать экономическому и научно-техническому развитию большого числа стран с растущей эффективностью.

Особое место в докладах на Конференции было отведено международному сотрудничеству в области подготовки кадров. Многие развитые страны предоставляют техническую помощь для подготовки персонала из развивающихся стран. Большую роль в налаживании такого сотрудничества, особенно многостороннего, играет МАГАТЭ, с тем чтобы подготовка специалистов велась с учетом их специфических нужд и возможностей.

В этом смысле IV Женевская конференция по использованию атомной энергии в мирных целях явилась большим вкладом в международное сотрудничество. Двухнедельный живой обмен опытом по науке, технике и экономике, по правовым и политическим аспектам, по обмену информацией и подготовке кадров сыграют свою положительную роль.

В приветственных посланиях глав ряда стран-участниц Конференции отмечалась необходимость расширения международного сотрудничества по мирному использованию атомной энергии и его положительная роль в деле смягчения международной напряженности и укрепления мира во всем мире, подчеркивалась необходимость продолжать усилия в направлении ограничения гонки ядерных вооружений.

В этой связи еще раз отмечалась важность Договора о нераспространении ядерного оружия, вступившего в силу 5 марта 1970 года. Тот факт, что Договор подписали 98 государств и ратифицировали 3 государства, обладающие ядерным оружием, и 64 государства, не обладающие этим оружием, свидетельствует о широком международном признании важности Договора.

Разработка Международным агентством по атомной энергии проекта типового Соглашения о контроле вселяет уверенность, что цели контроля, предусмотренные Договором, будут осуществлены с достаточной эффективностью.

В заключение разрешите мне сделать ряд общих замечаний.

Эта Конференция была посвящена чисто прикладным, жизненным вопросам. Она была спланирована так, чтобы быть непосредственно полезной не только для ученых и инженеров, но и для организаторов промышленности, администраторов и экономистов.

И все же мне хотелось бы подчеркнуть основополагающую роль фундаментальной науки. Поскольку мне предоставили возможность выступить с обзором работы Конференции, я хотел бы обратить особое внимание на роль фундаментальной науки – той науки, исследования в которой в данный момент, казалось бы, не представляют пользы даже для ученых смежных специальностей.

Лишь впоследствии оказывается, что, вроде бы, чисто теоретические фундаментальные исследования часто дают тот задел, который приводит к созданию новых областей техники. В связи с этим вспомним, например, что в тридцатые годы исследования в области атомного ядра считались многими настолько абстрактными, настолько оторванными от жизни, что высказывались даже сомнения в целесообразности их, хотя бы скромного, финансирования.

Далее, задолго до появления самой идеи об управляемой термоядерной реакции успешно развивался чисто абстрактный, теоретический подход к изучению плазмы, так сказать, ради собственного интереса. И вот такие исследования нашли затем широкое поле для своего приложения в проблеме управляемого термоядерного синтеза.

Я не буду здесь приводить большое число аналогичных примеров. Скажу лишь, что в настоящее время мы имеем, по-видимому, аналогичное положение в физике высоких энергий, иначе говоря – в физике элементарных частиц.

Пока здесь не чувствуется выхода в большие приложения, но,по моему глубокому убеждению, несомненно, что то проникновение в тайны глубинной структуры материи, в законы взаимодействия ее основных микроблоков – элементарных частиц, которое постепенно достигается, должно привести к большим, может быть совершенно неожиданным, практическим приложениям.

Вообще, конечно, все интересуются плодами науки, и это естественно, но при этом какое-то внимание следует уделять и тем глубоко зарытым корням того дерева, на котором такие плоды могут расти.

Что можно сказать в заключение о тех перспективах, которые раскрывают перед нами уже полученные достижения в области атомной науки и техники?

Как видно из докладов на этой Конференции, перспективы здесь достаточно широкие. Это и приложения к медицине, и к биологии вообще, и к сельскому хозяйству.

На основании работы Конференции можно сделать вывод, что развитие атомной энергетики обеспечивает сохранение достаточной чистоты внешней среды, и более того, замена энергии, вырабатываемой на обычном топливе, атомной энергией приведет к значительному уменьшению загрязнения внешней среды токсичными веществами и к оздоровлению среды обитания.

Из энергоемких приложений использования атомной энергии следует особо подчеркнуть проблему опреснения воды. Ведь нельзя забывать,что в недалеком будущем вопрос о получении пресной воды может стать исключительно острым. И именно благодаря большой энергоемкости этой проблемы атомная техника должна сыграть здесь решающую роль.

В заключение – о проблеме конструирования и совершенствования атомных двигателей. Уже сейчас имеются морские суда с атомными двигателями. И когда придет время полета на отдаленные планеты, нет сомнения, что как раз атомные двигатели будут построены для этой цели, помогая человеку завоевывать космос.

A translation into English follows.

REVIEW OF THE WORK OF THE CONFERENCE

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In commencing this review I would first like to express my gratitude for the great honour that has been accorded me, as a representative of Soviet science, by the proposal that I should give an address summing up the work of the Conference. I should say frankly, however, that it has put me in a very awkward position inasmuch as nuclear science and engineering have now developed to the extent that it is virtually impossible for one man to deal thoroughly with all aspects of the matter. In this review I shall therefore be compelled to deal only with what I consider to be the most fundamental achievements reported at the Conference. In so doing I shall, of course, make every effort to cover all the main points with maximum objectivity, although there is no doubt that there may still be a certain subjectivity and a somewhat subjective approach in my interpretation, since the range of my interests lies within certain limits.

This Conference – and this is the first thing that has to be stated – has aroused great interest and attracted a large number of participants. There is no doubt that the exchange of scientific and technical ideas that has taken place, and the demonstration of the gains achieved in various countries, will have a very considerable effect on the further development of atomic science and engineering.

Seventy-nine countries have sent their representatives to the Conference to discuss the problems involved in using nuclear energy. Over the seven years that have passed since the Third Geneva Conference there has been intensive development of nuclear science and engineering in virtually all countries of the world and, as Dr. Sigvard Eklund, Director General of the IAEA, recently stated in the General Assembly of the United Nations, nuclear science has come of age. Analysing the papers presented by scientists and experts from many countries, we can say with confidence that the Fourth Geneva Conference has demonstrated that the practical application of nuclear energy is developing by leaps and bounds.

Whereas before the First Geneva Conference in 1955 nuclear power generation was represented by only one atomic power station (the Obninsk Atomic Power Station with a capacity of 5 MW), before the Fourth Conference the number of power reactors in operation or under construction had reached more than 230. According to figures supplied by the IAEA, 102 of these power reactors were in operation and 131 were under construction by the end of April 1971. The developments in nuclear technology and its use for peaceful purposes have attracted the attention not only of scientists and engineers, but also of statesmen.

At present a large number of countries have five-year plans or long-term national programs for the development of nuclear science and engineering. The existence of these national programs, together with co-operation within the framework of the International Atomic Energy Agency and other specialized international organizations, affords the most apposite means of solving the key problems involved in the utilization of nuclear energy. A considerable contribution to the effective solution of the problems attending the utilization of nuclear energy for peaceful purposes has been made by the papers presented at this Conference and by the creative discussions that have been held here at the Palais des Nations, at the Governmental Scientific Exhibition, and in a great variety of other places in Geneva.

And so I will make some brief comments on some of the topics that have been considered at the Fourth Geneva Conference on the Peaceful Uses of Atomic Energy.

In view of the international character of the work being done on the peaceful application of nuclear energy, I do not wish to single out the part played by any one country, since all our achievements in this connection are a contribution to the common storehouse of international attainment. In evaluating the previous Geneva Conferences on the Peaceful Uses of Atomic Energy and assessing their principal results, many speakers have stressed that the Third Conference held in 1964 demonstrated that nuclear power generation had already passed beyond the experimental stage, and that nuclear power stations had begun to compete with conventional power stations and, furthermore, had taken their own path of development.

At the beginning of our work here in Geneva we were reminded of the tasks set by the General Assembly of the United Nations for the Fourth Geneva Conference: it was to be useful not only for scientists and engineers, but equally for industrial planners, administrators and economists. This aim was based on the knowledge that by the time the Fourth Conference was convened, nuclear power production would have come of age.

The course of the Conference has confirmed these initial premises and makes it clear that the set purpose has been achieved. The persons taking part in the Conference and the kind of papers presented are an indication that nuclear energy is becoming firmly entrenched in a very wide variety of human activities, and that the most important sphere of application, namely nuclear power production, has reached the stage of extensive development on a world-wide scale.

The widespread adoption of nuclear power brings into prominence a number of important problems that may have escaped the attention of many people at an earlier stage. I have in mind, first and foremost, the effect on the environment, the safety of the population, problems of radioactive waste disposal, the incorporation of nuclear power stations into power grids, the selection of the optimum fuel cycle for various reactor types, and the study of the strength of construction materials.

A review of world demands for energy and of energy resources indicates that by the end of this century half the total electric power produced in the world will be generated by nuclear power plants. In terms of figures, according to the forecasts made here, nuclear power output may reach three million megawatts by the end of this century. Calculation of requirements shows that in 1980 the capacity of nuclear power stations will be approximately 300 000 MW(e), and that over the following twenty years the output of electrical power from nuclear power stations should increase by a factor of approximately 8 - 10. It is an understatement to say that this is a highly complex and difficult problem requiring the participation of scientists, engineers and industrial planners throughout the world for its solution. It is a task that approaches the fantastic. But the solution of these problems is already well under way through the widespread introduction of thermal power reactors and the surmounting of the difficulties involved in fast-reactor engineering.

Thermal neutron reactors have undergone a considerable period of development and have now been adopted on an industrial scale. This relates first and foremost to water-moderated reactors and, to a considerable extent, to graphite-moderated reactors with both gas and water cooling systems. At present a large number of countries have already gained extensive experience in operating these types. Many ups and downs have been encountered in this work. It is now clear that the difficulties have by and large been overcome and that the experience gained has enabled the stage to be set for the very rapid development of nuclear power production beyond its present level. The experience acquired in developing and operating these reactors has been a very important topic of discussion at the Conference.

The next set of scientific and technical questions which has been of considerable interest to those attending the Conference is that of the safe operation of nuclear power stations. There are various aspects to this problem: the proper design of reactors and their cooling systems, adequate allowance for natural factors; correct siting; the devising of special standards, rules and procedures for ensuring safety of operation; the quality control of power station equipment.

Careful and sound solutions of these problems are called for by the actual scale of deployment of nuclear power stations and by the need for siting them in thickly populated regions and for bringing large numbers of additional people into this sphere of activity, along with new construction and industrial undertakings of various kinds. Besides considering key problems relating to nuclear power stations embodying thermal reactors, the Conference has dealt with the development and construction of improved types of reactors, characterized either by enhanced efficiency of the thermodynamic cycle or improved fuel-cycle parameters. Within the same general context, attention has also been paid to high-temperature gas reactors, heavy-water reactors of various types, the graphite reactor with boiling-water cooling, molten-salt reactors and dissociating-gas reactors.

Fast breeder reactors open up the way for improved utilization of the source-material resources of nuclear fuel for power generation. Maximum attention is being devoted in the most advanced countries to the development of reactors of this type.

Experimental fast reactors have been in operation for many years in the United States of America, the Soviet Union, the United Kingdom and

France. Such reactors are being built in Italy, Japan and the Federal Republic of Germany. They have already demonstrated operational stability and reliability and are providing experience for the design of commercial reactors. By now the general trend in the design and basic features of these reactors has been established: sodium cooling, ceramic fuel in a stainless steel cladding, three-circuit systems with steam turbines. We still have a long way to go, however, before all the technological problems facing us in the construction of large commercial reactors can be solved, and our task for the immediate future is the construction of prototypes.

Large fast-neutron power reactors are in the final stages of construction and assembly in the Soviet Union, the United Kingdom and France. Designs have been completed in the Federal Republic of Germany and the United States of America for demonstration prototype reactors, other projects are in the developmental stage in Italy and Japan.

Intensive work is being carried on in many countries in connection with the testing of fuel elements and equipment. These questions, which were dealt with at the Conference, are the ones which characterize the situation with respect to the mastery of breeder-reactor technology. The focal point in the work of bringing fast reactors into general use is shifting to the technological problems of achieving reliability in various types of equipment and control systems under actual conditions of operation. It may be expected that these problems will be resolved within the next few years and that the period after 1980 will see the construction of fast reactors for commercial use. This will mark the beginning of a new stage in power engineering – that of breeder reactors producing both electric power and fuel for future development.

The rapid development of atomic power generation of course requires a corresponding development in all links in the fuel cycle. It is unnecessary to dwell on the importance of ensuring the supply of fuel. According to an estimate given in one of the review papers, the proven reserves of ore from which uranium can be extracted at a cost of up to \$10/lb amounts to approximately 1 million tons. This quantity is sufficient to satisfy uranium requirements only until the end of the 1970s. In this connection, stress has been laid during the Conference on the importance of increasing throughout the world the prospecting for new uranium deposits and also the importance of improving methods of processing ore, particularly of low-grade varieties.

It seems to me personally that one must not underestimate the importance of developing new methods for the production of nuclear fuel by all possible means, including the extraction of uranium from sea-water, bearing in mind the fact that uranium is present in the sea in quantities of the order of 4000 million tons.

Since most of the commissioned and planned reactors make use of enriched uranium, it is quite logical that during the Conference great interest has been shown in the isotopic enrichment of uranium and in the development and improvement of enrichment methods and technology.

During the period between the Third and Fourth Geneva Conferences substantial progress has been made in the production of fuel and the reprocessing thereof after use in reactors. But there remains much to be done, for example the development of methods for reprocessing fast-reactor fuels and improving the reprocessing of thorium-containing fuel.

It seems to me that unless the problem of fast reactors can be solved it will be impossible to resolve the problem of large-scale nuclear power production.

Finally, the next step in the development of nuclear power engineering must be the introduction into the fuel cycle of a new type of nuclear fuel, namely, high-temperature deuterium plasma. As was the case 20 years ago, the underlying notion in the most advanced work on the production of high-temperature plasma of sufficiently high density and temperature is magnetic thermal insulation.

I should like to emphasize here that it was thanks to the initiative shown by an outstanding Soviet scientist, the late Academician Kurchatov, in 1955, that work on controlled thermonuclear fusion was declassified; this fact has had an extremely beneficial effect on the overall development of this important field.

At present the overall program of thermonuclear research provides for experiments in three main directions - experiments to obtain a hot plasma in closed magnetic systems (Tokamak and Stellarator) and in adiabatic magnetic traps, and experiments with pulsed magnetic fields. Detailed studies on the properties of high-temperature plasmas and the exceptional inventive spirit of the physicists engaged on this problem have made it possible to find optimum conditions for the processes of thermal insulation of plasma and thereby to increase its main physical parameters.

Since the Third Geneva Conference it has been possible to increase the plasma parameters by almost an order of magnitude in magnetic mirror units as well. Definite progress has been made in the most advanced methods of fast plasma heating in pulsed magnetic fields.

Apart from the above-mentioned sections of the thermonuclear program, which have now become conventional, in recent years developments have started in relatively new directions. These include experiments with units which make it possible to generate a highly dense bunch of high-temperature plasma in a very small volume - the "plasma focus". It is true that the future outlook for this method is still not clear, since the experimental conditions are not yet such as to enable us to understand the mechanism of neutron radiation of the plasma focus and its dependence on various physical parameters.

Very recently, studies connected with the possibility of heating matter by a powerful laser beam have acquired wide significance. The special attraction of this method is that the concept of magnetic thermal insulation of plasma can, in principle, be done away with. In experiments based on this method the neutron radiation intensity is at present 10^4 neutrons per pulse. However, the unusually rapid progress achieved in increasing the store of energy in the laser beam and the efficiency of the laser itself, on which the prospects of development along these lines mainly depend, can even in the very near future render the method of laser heating one of the most promising in the whole thermonuclear program. Initial steps have also been taken towards the development of what are, from the standpoint of physics, highly attractive methods involving very fast heating of matter by a high-intensity electron beam.

Analysis of the present status of thermonuclear fusion shows that, in spite of the emergence of basically new trends, it has not yet gone beyond the stage of development of the physical basis for deriving the requisite plasma parameters permitting use of the reactions occurring in the plasma for the technological solution of the problem of constructing a thermonuclear reactor.

Let us hope that the remaining problems will be solved as rapidly as the earlier part has been.

The further development of nuclear power in the coming years will be accompanied by an accumulation of ever-growing quantities of nuclear materials. In this connexion, the Conference placed great emphasis on problems of the safeguarding and control of nuclear materials, as provided under the Treaty on the Non-Proliferation of Nuclear Weapons.

The success achieved by the International Atomic Energy Agency in drafting a model safeguards agreement, and the progress made in working out technical ways and means of safeguarding nuclear materials, inspire the conviction that the aims of safeguards as laid down in the Treaty on the Non-Proliferation of Nuclear Weapons will be satisfactorily fulfilled at moderate cost and without detriment to the peaceful uses of atomic energy.

The improvement of methods of processing and disposing of wastes was carefully studied by the Conference. Reliable disposal is ensured by methods now being developed or already in use, including the pumping of waste under the ground, the solidification of waste and the burying of waste in salt formations.

It seems wrong to me, however, to release radioactive waste into the seas and oceans, in view of the possible pollution of the hydrosphere.

Something must also be said about the great change which has taken place since the third Geneva Conference in the development of research on applied radiation chemistry and the application of radiation-chemical processes in industry. In some countries, the industrial manufacture of various materials and products with special properties has been organized, and processes of radiation synthesis have been applied, on the basis of methods involving the modification of polymers by radiation. It should be pointed out that in the developing countries a great research effort is under way in the field of applied radiation chemistry with a view to the industrial application of radiation processes.

Reliable operation of nuclear power stations, and the safety of man, cannot be assured without progress in the field of nuclear instrumentation. At present, hundreds of types of instruments used for radiometry, dosimetry and the technological control of various nuclear reactions have already been developed and are being produced by industry. This is highly encouraging and provides an assurance that in the very near future integral automated systems will be created on the basis of the most recent advances in microelectronics, by means of which atomic power plants can be reliably controlled and operated.

The period since the Third Geneva Conference has been marked by considerable progress in the use of radioactive isotopes and of radiations in various branches of medicine. Radioisotope techniques for the purpose of diagnosing a variety of human diseases have been widely developed in general therapeutic practice, surgery and oncology.

The main trends in modern radiotherapy which have been reflected in the papers presented to the Fourth Geneva Conference are:

A widening of the range of nuclear radiations applied in radiotherapeutic practice (gamma rays, radiation from betatrons and linear accelerators, proton and neutron therapy);
Improvement of the radiation-physical parameters and of the clinical and methodological foundations of radiotherapy, optimization of programs for radiotherapy with a view to its individual planning, based on the application of computer technology.

Of considerable importance for the further improvement of radioisotope diagnostics and radiotherapy is also the establishment of large radiological centres and the training of specialist staff. The papers before the Conference show the emphasis placed on the study of the biological effects of various types of radiation, the investigation of the mechanisms of radiation damage and its repair at the cellular and molecular levels, and the possibilities of use of protective substances and procedures.

Radiobiology is making its contribution to the solution of so vital a problem as the supply of a sufficient quantity of wholesome food for the world's population. This is being achieved by the use of high-yield varieties of grain crops obtained by the method of radiation-induced selection and by improvements brought about through radiation-induced sterilization.

Radiation is being used increasingly for inducing beneficial mutations in microorganisms.

The papers presented gave particular attention to the problem of the environment. Large-scale research is in progress on the manner in which radioactivity reaches the environment and on penetration of the biosphere by radioactive products and their interactions with it. In the papers presented at the Conference it is universally pointed out that the effect of radioactive substances upon man and the biosphere as a whole represents one of the central problems of the peaceful use of nuclear energy.

The papers show clearly that questions of the safe operation of nuclear power stations and of pollution of the environment in various countries of the world are receiving a vast amount of attention.

The comparative assessment made at the Conference of the consequences of the operation of conventional plants and of atomic stations is interesting. Conventional plants require several thousand times more air for diluting toxic substances to a permissible level than atomic power stations. In addition, the total amount of heat released (which may eventually produce undesirable climatic changes) per unit of useful output is considerably less in the case of an atomic power station, on account of its high efficiency, than in that of a conventional power station. The use of atomic energy does not involve consumption of oxygen and does not result in a steady build-up of carbon dioxide in the air.

A great deal of attention has been given in the papers to questions of the public reaction to the development of the nuclear energy industry. This matter undoubtedly requires the closest attention and painstaking work.

In the course of the Conference an interesting debate took place on ecological problems, on the subject of which the representatives of ten countries exchanged views and replied to the dozens of questions that were asked. In the debate stress was laid on the role of the scientist doing objective research in moulding a public opinion favourable to atomic energy.

Wide prominence was given in the Conference papers to the importance of nuclear technology for the developing countries; virtually all aspects of the use of atomic energy were covered, and an analysis was made of ways of increasing the contribution of nuclear technology to economic progress in the areas concerned.

In all countries, including the developing countries, there is a rapidly increasing demand for power, and nuclear power is one of the means of satisfying that demand. Nuclear power must, however, always be compared with the more traditional ways of producing electricity, since each type of energy source has its advantages and disadvantages.

It is probably desirable to develop the fuel base for the developing countries' atomic power industry on a regional basis, with maximum utilization of their own uranium resources, prospecting for which should be intensified while, for the enrichment of uranium, recourse can be had to the services of other countries.

The nuclear centres that have been set up in the developing countries are helping to train experts. They are also making possible the development of research in the fields which are of the greatest practical importance for the economy. The charged-particle accelerators and research reactors that have been built at those centres constitute dependable radiation sources for research and a basis for the training of personnel. Availability of personnel is clearly one of the most important factors in the use of atomic energy in those countries.

Nuclear technology has only recently begun to make its contribution to the economic progress of a number of countries, and there is every prospect that nuclear technology and its many economic applications will promote the economic and the scientific and technological development of a large number of countries with increasing effectiveness.

A special place in the papers at the Conference has been assigned to international co-operation in the field of personnel training. Many developed countries are giving technical assistance for the training of personnel from developing countries. An important role in organizing this co-operation, particularly multilateral co-operation, is being played by the IAEA, which seeks to ensure that the training of experts is carried out with due regard for their specific needs and potentialities.

In this sense the Fourth International Conference on the Peaceful Uses of Atomic Energy has made a great contribution to international co-operation. The two weeks which we have devoted to a lively exchange of experience on the scientific, technical and economic aspects of the subject, on its legal and political aspects, and on information services and the training of specialized personnel, will yield valuable results.

In their messages to the Conference, the heads of a number of participating States drew attention to the need for expanding international co-operation in the peaceful uses of atomic energy, and to the positive contribution of such co-operation towards relieving international tension and strengthening peace throughout the world; they likewise emphasized the need for continuing efforts to curb the armaments race in nuclear weapons.

In this connexion, attention was once again drawn to the importance of the Treaty on the Non-Proliferation of Nuclear Weapons, which came into force on 5 March 1970. The fact that the Treaty has been signed by 98 States and that it has been ratified by three nuclear-weapon States and by States not possessing nuclear weapons bears witness to the broad international recognition of the Treaty's importance.

The success achieved by the International Atomic Energy Agency in drafting a model safeguards agreement inspires the conviction that the aims of safeguards as laid down in the Treaty will be satisfactorily fulfilled.

In conclusion I should like to make a few general remarks.

This Conference has been devoted to purely practical problems of vital importance. It was planned so as to be directly useful not only to scientists and engineers but also to industrial planners, managers and economists.

Here, however, I must emphasize the fundamental importance of the part played by pure science. And since I have been given an opportunity to review the work of the Fourth Geneva Conference, I should like to stress the part played by pure science, research in which does not at any given time seem to be of use even to scientists specializing in allied disciplines.

Only afterwards does it appear that what seemed to be entirely theoretical pure research often has the incidental effect of leading to the creation of new branches of technology. We may recall in this connexion that in the 'thirties research into the atomic nucleus was considered by many people to be so abstract and so divorced from life that doubts were expressed as to the expediency of financing it, even on a modest basis.

Again, long before even the idea of a controlled thermonuclear reaction made its appearance, a purely abstract, theoretical approach to the study of plasma was successfully developed, an approach based, so to speak, on the intrinsic interest of the subject. And now this research has found a broad field of application in connexion with the problem of controlled thermonuclear synthesis.

I shall not stop to give a large number of such examples here. Let me just say that we obviously now have a similar situation in high-energy physics, i.e. in the physics of elementary particles.

There is no sign yet of this leading to broader applications, but it is my profound conviction that the penetration which is thus gradually taking place into the secrets of the inner structure of matter, into the laws governing the interaction of its basic microconstituents, the elementary particles, must undoubtedly lead to major, perhaps quite unexpected, practical applications.

Everyone is interested, of course, in the fruits of science, but at the same time thought should be given also to the deep-lying roots of the tree upon which such fruits can grow.

What can be said in conclusion about the prospects which the successes already achieved in the sphere of atomic science and technology are opening up before us?

As may be seen from the papers presented at this Conference, the outlook here is quite extensive; it includes applications to medicine, biology in general, and agriculture.

The work done by the Conference justifies the conclusion that the development of nuclear power maintains sufficient cleanliness of the environment; and what is more, the replacement of power obtained from conventional fuel by nuclear power will lead to a considerable decrease in the pollution of our environment by toxic substances and to an improvement in its quality.

Among the power-consuming applications, the desalination of water should be especially emphasized. It must not be forgotten that the problem of obtaining fresh water may become particularly acute in the not-too-distant future. And precisely on account of the vast amount of energy required to solve this problem, nuclear technology is destined to play a decisive part.

Then there is the problem of designing and improving atomic motors. Ships with nuclear propulsion already exist. And when the time comes for flights to distant planets, there is no doubt that atomic motors will be designed for this purpose, thus contributing to man's conquest of space.

CLOSING REMARKS

Sigvard EKLUND
Director General
of the International Atomic Energy Agency

We have just heard the summary of the highlights of the Conference by Academician Bogolyubov so I will not dwell on the scientific program as such. May I limit myself to reflecting somewhat on the value of holding a Conference of this magnitude – a point on which I have heard various opinions from many different people.

At the opening of this Conference, I mentioned the difficult mandate given to us by the United Nations General Assembly; that is, to draft an Agenda of interest to public officials, economists and planners as well as technologists. One means of trying to fulfil the mandate was to have general sessions with surveys, and technical sessions with detailed scientific papers. I think we are all most grateful to those who worked so hard to be able to present surveys of energy needs and uranium resources, and of foreseeable developments in nuclear power. The discussions of environmental questions have been thought-provoking and have given a better perspective on this problem. Our gratitude also goes to the scientists who shared with us the results of their latest work. However, it was inevitable that there would be some participants who found the scientific and technical papers too specific and others who found the surveys too general.

From sessions during the last couple of days, I have a feeling that the problems of the developing countries were also brought forward in an illuminating way, especially during the panel discussion on "The Introduction of Nuclear Power into Developing Countries".

The overriding value of a Conference of this type proved to be its role as a forum. The people most concerned with the development of nuclear energy have been brought together to exchange views, not just in formal discussions and sessions, but perhaps even more in the corridors and in private meetings. The value of personal contacts for the promotion of co-operation on the country-to-country level cannot, in my opinion, be overestimated.

Today, I am in a position to close my remarks by noting that this Conference can be cited as an eloquent example of the best possible collaboration between the United Nations and a member agency of the UN "family". I would like to take this opportunity to convey to Mr. Gresford, as the representative of the Secretary-General, the Agency's appreciation and thanks for the co-operation we have enjoyed. All the arrangements were made with an eye to strict economy – this Conference will ultimately cost less than one quarter of the Second Conference held in 1958.

On behalf of the Agency, I also want to thank the President, Dr. Glenn Seaborg, for the guidance he has given the Conference; the Vice-Presidents and the Chairmen; and, last but not least, the Scientific Secretariat, who contributed their best efforts to this Conference.

Translations into French, Russian and Spanish follow.

ALLOCUTION DE CLOTURE

Sigvard FKLUND
Directeur général
de l'Agence internationale de l'énergie atomique

Nous venons d'entendre le Professeur Bogolioubov résumer les aspects les plus marquants de la Conférence, aussi ne reviendrai-je pas sur la question des programmes scientifiques proprement dits. Je voudrais simplement présenter quelques réflexions sur l'intérêt d'une conférence de cette importance - point sur lequel les opinions ont varié largement.

A l'ouverture de la Conférence, j'ai fait allusion à la difficulté de la tâche que nous avait confiée l'Assemblée générale de l'Organisation des Nations Unies, en nous demandant d'établir un ordre du jour qui puisse intéresser à la fois les fonctionnaires, les économistes, les planificateurs et les technologues. Pour répondre à cette demande, nous avons pensé que la Conférence tiendrait des séances générales au cours desquelles des rapports d'ensemble seraient présentés et des séances techniques qui seraient consacrées à la présentation de mémoires scientifiques. Je crois que nous sommes tous extrêmement reconnaissants à ceux qui ont fait de si grands efforts pour pouvoir présenter des rapports sur les besoins énergétiques et les ressources en uranium ainsi que sur l'évolution probable de la production d'énergie d'origine nucléaire. Les discussions qui ont eu lieu sur les problèmes de l'environnement ont été extrêmement fructueuses et nous ont permis de voir ce problème sous un meilleur jour. Notre reconnaissance va également aux spécialistes qui nous ont communiqué les résultats de leurs travaux les plus récents. Toutefois, il était inévitable que certains participants jugent les mémoires scientifiques et techniques trop restreints tandis que d'autres reprochent aux rapports d'ensemble leur caractère trop général.

Après les séances qui ont eu lieu au cours de ces derniers jours, j'ai l'impression que les problèmes des pays en voie de développement ont été aussi mis en pleine lumière, notamment au cours de la discussion de groupe qui a eu lieu hier après-midi sur «l'introduction de l'énergie d'origine nucléaire dans les pays en voie de développement».

L'intérêt suprême d'une conférence comme celle qui vient de nous réunir a été de servir de lieu de rencontre international. Ceux qui dans le monde s'intéressent le plus au développement de l'énergie nucléaire ont eu la possibilité d'échanger des vues, et ces échanges de vues ne se sont pas limités aux séances officielles mais ils ont peut-être été encore plus intenses dans les couloirs et au cours des réunions privées. A mon avis, on ne saurait surestimer l'intérêt que les contacts personnels peuvent présenter pour le progrès de la coopération entre pays.

Aujourd'hui, je suis en mesure de conclure mes observations en ajoutant que cette Conférence peut être considérée comme un exemple éloquent de la collaboration la plus efficace qui puisse s'instaurer entre l'Organisation des Nations Unies et une institution membre de la «famille des Nations Unies». Je tiens à saisir cette occasion pour transmettre à M. Gresford, représentant du Secrétaire général, la gratitude et les remerciements de l'Agence pour le concours qui nous a été apporté. Toute la Conférence a été organisée suivant les principes de l'économie la plus stricte; en fin de compte, elle coûtera moins d'un quart du prix de la deuxième Conférence, tenue en 1958.

Au nom de l'Agence, je tiens aussi à féliciter le Président de la Conférence, M. Glenn Seaborg, pour la compétence avec laquelle il a dirigé les travaux; mes remerciements vont aussi aux Vice-Présidents et Présidents ainsi qu'au secrétariat scientifique, qui a déployé tous ses efforts pour contribuer à la réussite de la Conférence.

ЗАКЛЮЧИТЕЛЬНОЕ ВЫСТУПЛЕНИЕ

Зигвард ЭКЛУНД
Генеральный Директор
Международного агентства
по атомной энергии

Мы только что заслушали заключительное выступление академика Боголюбова, в котором излагаются основные моменты работы Конференции, и поэтому я не буду останавливаться на научной программе Конференции как таковой. Позвольте мне ограничиться лишь вопросом о значении проведения такой Конференции – вопросом, по которому мне пришлось слышать различные мнения от многих людей.

На открытии Конференции я говорил о трудной задаче, возложенной на нас Генеральной Ассамблеей Организации Объединенных Наций; трудность эта заключалась в составлении повестки дня, которая отвечала бы интересам как государственных деятелей, экономистов и плановиков, так и технических специалистов. Одним из способов решения этой трудной задачи явилось проведение общих заседаний с представлением обзорных докладов и технических заседаний, на которых рассматривались научные доклады по специфическим вопросам. Я полагаю, что мы весьма благодарны тем, кто так упорно работал, чтобы представить обзоры по энергетическим потребностям и урановым запасам, а также по перспективам развития ядерной энергетики. Обсуждение вопросов о загрязнении окружающей человека среды породило новые идеи и более четко определило перспективу решения этой проблемы. Мы благодарны также ученым, которые делятся сегодня с нами результатами своих последних работ. Однако, неизбежно нашлись участники, которые сочли научно-технические доклады слишком специфичными, в то время как другие отметили слишком общий характер обзорных докладов.

В ходе заседаний, проходивших в течение последних двух дней, у меня создалось впечатление, что проблемы развивающихся стран стали более актуальными. Особенно это проявилось в ходе дискуссии во время совещания экспертов на тему "Внедрение ядерной энергетики в развивающихся странах".

Основное значение Конференций такого типа состоит в том, что они играют роль своеобразного форума, на котором собираются люди, тесно связанные с мирным использованием ядерной энергии, для обмена мнениями не только в ходе официальных дискуссий и заседаний, но, возможно даже более откровенно, в кулуарах и при частных встречах. По моему мнению, нельзя недооценивать значения личных контактов в деле содействия сотрудничеству отдельных стран.

Заканчивая свое выступление, я хочу отметить, что эту Конференцию можно считать ярким примером самого тесного сотрудничества между Организацией Объединенных Наций и одним из учреждений, входящих в "семью" стран-членов. Я хотел бы воспользоваться этой возможностью, чтобы выразить г-ну Гресфорду, как представителю Генерального Секретаря, высокую признательность и благодарность Агентства за оказанное нам содействие. Все мероприятия по организации Конференции проводились с учетом строгой экономии, в результате чего денежные затраты на проведение этой Конференции будут на четверть меньше, чем на проведение Второй конференции 1958 года.

От имени Агентства я хочу также поблагодарить Председателя Конференции д-ра Гленна Сиборга за руководство работой Конференции, Вице-Председателей и Председателей секций, и, наконец, но не в последнюю очередь, Научный Секретариат, который внес огромный вклад в проведение Конференции.

DECLARACION DE CLAUSURA

Sigvard EKLUND
Director General
del Organismo Internacional de Energía Atómica

El Profesor Bogoliubov acaba de recapitular los puntos culminantes de esta Conferencia; por lo tanto no insistiré sobre el programa científico propiamente dicho y me limitaré a hacer algunas reflexiones sobre el valor que ofrece una conferencia de esta magnitud, punto sobre el cual he escuchado distintas opiniones de personas muy diversas.

En la sesión de apertura hablé de lo difícil que era el mandato que nos encomendó la Asamblea General de las Naciones Unidas, que consistía en confeccionar un programa de interés para los funcionarios de la administración, para los economistas y los planificadores, y para los tecnólogos. Una manera de tratar de dar cumplimiento a este mandato consistía en celebrar sesiones generales en las que se presentarían estudios de carácter general, y sesiones técnicas en las que se expondrían memorias científicas detalladas. Creo que todos sentimos el mayor agradecimiento hacia aquellos que con tanto empeño han trabajado para presentar estudios generales acerca de la demanda de energía y de los recursos de uranio, así como de la evolución probable de la energía nucleoeléctrica. Los debates en torno a las cuestiones ambientales han inducido a reflexionar y han dado una perspectiva más exacta de este problema. Deseo expresar también nuestra gratitud a aquellos científicos que han compartido amablemente con nosotros los resultados de sus trabajos más recientes. Es inevitable, sin embargo, que algunos participantes hayan encontrado las memorias científicas y técnicas demasiado específicas y que otros hayan considerado los estudios demasiado generales.

Las sesiones de estos dos últimos días me hacen pensar que los problemas que afectan a los países en desarrollo se han expuesto con la máxima claridad, sobre todo en el debate del Grupo de expertos sobre la implantación de la energía nucleoeléctrica en los países en desarrollo.

El valor más grande de una Conferencia de este tipo sigue siendo, de todos modos, el papel que desempeña en tanto que foro mundial. Las personas que más se interesan por el desarrollo de la energía nuclear se han reunido para cambiar impresiones, no solamente en debates y sesiones oficiales, sino quizá aún más en los pasillos y en las reuniones de carácter privado. A mi juicio, nunca se ponderará demasiado el valor de los contactos personales para fomentar la cooperación al nivel nacional.

Ya puedo concluir estas breves palabras afirmando que la Conferencia ha sido un ejemplo elocuente del grado máximo de colaboración que puede darse entre las Naciones Unidas y un organismo de la llamada «familia» de las Naciones Unidas. Deseo aprovechar esta oportunidad para manifestar al Sr. Gresford, en su calidad de representante del Secretario General, en cuánto estima y agradece el Organismo la cooperación de que ha disfrutado. Todos los preparativos se han efectuado ajustándose al criterio de la máxima economía; esta Conferencia costará menos de la cuarta parte que la segunda Conferencia celebrada en 1958.

En nombre del Organismo, quiero también expresar mi agradecimiento al Presidente, Dr. Glenn Seaborg, por el acierto con que ha dirigido los trabajos de la Conferencia, a los Vicepresidentes y a los demás Presidentes, así como a la Secretaría Científica, que ha aportado su máxima contribución al éxito de esta Conferencia.

CLOSING REMARKS

Guy GRESFORD
Director for Science and Technology,
United Nations

The work of this Conference over the past two weeks has maintained the standard and carried on the momentum established by the three earlier conferences convened by the United Nations on the Peaceful Uses of Atomic Energy. As Academician Bogolyubov and Dr. Eklund have mentioned, it was the intention of the General Assembly that this meeting should be of concern to a wider group than scientists and technologists, and should be directed to public officials, planners and economists. The great strides made in the application of atomic energy since the Third Conference in 1964 have made this appropriate, and this meeting has dealt, not with the scientists' hopes and dreams for the future, but with firm plans and projections concerning the major role which nuclear energy can and must play in meeting the future energy and other needs of mankind.

In recent years the international community has become increasingly worried about problems of the human environment and this concern is to find a focus at the conference being convened by the United Nations in June 1972 at Stockholm. In a sense the present Conference on atomic energy may be regarded as one of the preliminaries to the Stockholm meeting since it has emphasized the contribution which nuclear power can make to providing man with clean energy, with a minimum disturbance to the environment.

While the theme of the earlier atomic energy conferences has been atoms for peace, that for the current one has been atoms for development. In United Nations terms these are really synonymous, and the major role which nuclear technology can play in assisting developing countries has emerged very clearly from the present Conference. This will be not only for meeting their future energy needs but also in agriculture and medicine. It also has an important part in education and training. To ensure that these roles are fulfilled will require the clear definition of needs and perspectives in developing countries, and the support and assistance of developed countries, and of the international community.

As you know, the planning and mounting of this Conference has been a joint operation between the United Nations and the International Atomic Energy Agency, and it has been one which has proceeded smoothly and effectively. On behalf of the Secretary-General I wish to pay tribute to our colleagues in the Agency for their co-operation which has indeed, as Dr. Eklund has pointed out, made the exercise a model of what can be done in the United Nations family. The whole-hearted co-operation of governments and delegations who have taken part in the Conference has ensured its success. I must also acknowledge gratefully on behalf of the United Nations the assistance which has been received from other inter-governmental and non-governmental bodies and from the Scientific Advisory Committee. Mention should also be made of an innovation at this meeting — the availability of closed-circuit television — which has greatly facilitated our work.

Finally, Mr. President, I must also, on behalf of the United Nations, acknowledge your own part in presiding over the Conference. I believe that I cannot pay a greater tribute than to say that you have upheld the standards set by the great predecessors in your office.

Translations into French, Russian and Spanish follow.

ALLOCUTION DE CLOTURE

Guy GRESFORD
Directeur du Bureau de la science et de la technique,
Organisation des Nations Unies

Les travaux de la Conférence au cours des deux dernières semaines ont été d'un niveau aussi élevé que ceux des trois premières Conférences des Nations Unies sur l'utilisation de l'énergie atomique à des fins pacifiques et ont progressé dans la voie qu'elles avaient ouverte. Comme M. Bogolioubov et M. Eklund l'ont indiqué, l'Assemblée générale souhaitait que cette réunion intéresse non seulement les spécialistes et les technologues mais aussi les fonctionnaires, les planificateurs et les économistes. Les grands progrès qui ont été accomplis dans l'application de l'énergie atomique depuis la troisième Conférence, tenue en 1964, ont permis de réaliser ce souhait et les participants à la réunion ne se sont pas préoccupés des espoirs et des rêves de l'homme de science pour l'avenir mais de plans et de projets concrets concernant la manière dont l'énergie nucléaire peut et doit contribuer à satisfaire les besoins énergétiques et les autres besoins de l'humanité.

Depuis quelques années, la communauté internationale se préoccupe de plus en plus des problèmes de l'environnement et cette inquiétude trouvera à s'exprimer lors de la conférence que l'Organisation des Nations Unies va organiser en juin 1972, à Stockholm. En un sens, la réunion actuelle peut être considérée comme un prélude à la réunion de Stockholm, car elle a montré comment l'énergie d'origine nucléaire peut contribuer à apporter à l'homme une source d'énergie «propre», qui porte le moins atteinte à l'équilibre naturel.

Si les précédentes conférences sur l'énergie atomique avaient eu pour thème l'atome pour la paix, la présente Conférence a eu pour thème l'atome pour le développement. Du point de vue des Nations Unies, ces expressions sont en fait synonymes et le rôle essentiel que la technologie nucléaire peut jouer dans l'aide aux pays en voie de développement est apparu très nettement au cours des débats de la Conférence. La technologie nucléaire permettra non seulement à ces pays de satisfaire leurs besoins énergétiques mais les aidera également dans le domaine de l'agriculture et dans celui de la médecine. La technologie nucléaire a également un rôle important à jouer en matière d'enseignement et de formation. Pour qu'elle puisse remplir ces rôles divers, il sera nécessaire de définir avec précision les besoins des pays en voie de développement, les perspectives qui s'offrent à eux, l'aide que les pays avancés peuvent leur apporter et celle qu'ils peuvent attendre de la communauté internationale.

Comme vous le savez, la mise sur pied de la présente Conférence a été assurée conjointement par l'Organisation des Nations Unies et l'Agence internationale de l'énergie atomique, et la collaboration de ces deux organisations a été à la fois harmonieuse et efficace. Au nom du Secrétaire général, je tiens à rendre hommage à l'esprit de coopération de nos collègues de l'Agence qui peut servir d'exemple de ce qu'on peut faire à l'intérieur de la famille des Nations Unies, comme M. Eklund l'a souligné. La réussite de la Conférence est due en grande partie au concours généreux des gouvernements et des délégations qui y ont participé. Au nom de l'Organisation des Nations Unies, je dois aussi exprimer ma reconnaissance aux autres organisations intergouvernementales et non gouvernementales ainsi qu'au Comité consultatif scientifique. Il convient également de mentionner une innovation qui a marqué cette réunion, à savoir la retransmission des sessions par télévision en circuit intérieur — qui a considérablement facilité notre tâche.

En conclusion, Monsieur le Président, il me faut également, au nom de l'Organisation des Nations Unies, rendre hommage à la manière dont vous avez présidé aux travaux de la Conférence. Je ne crois pas pouvoir vous adresser plus grand hommage que de dire que vous vous êtes acquitté de votre tâche avec une compétence égale à celle de vos éminents prédécesseurs.

ЗАКЛЮЧИТЕЛЬНОЕ ВЫСТУПЛЕНИЕ

Ги ГРЕСФОРД
Директор Научно-технического Департамента
Организации Объединенных Наций

Работа Конференции, которая продолжалась в течение двух недель, проходила в духе тех высоких идей и традиций, которые были заложены на трех предыдущих конференциях по использованию атомной энергии в мирных целях, созывавшимися Организацией Объединенных Наций. Как отметили академик Боголюбов и д-р Эклунд, Генеральная Ассамблея ставила своей целью, чтобы в проведении Конференции были заинтересованы не только ученые и технические специалисты, но также общественные деятели, плановики и экономисты. Огромные успехи, достигнутые в области мирного использования атомной энергии с момента проведения в 1964 году Третьей Конференции по использованию атомной энергии в мирных целях, сделали настоятельно необходимым проведение Четвертой Конференции. Эта конференция затрагивает не только мечты и надежды ученых на будущее, но также твердые планы и проекты, связанные с ведущей ролью, которую ядерная энергия может и должна играть в удовлетворении будущих энергетических и других потребностей человечества.

За последние годы мировая общественность проявляет все большую озабоченность в отношении проблем загрязнения окружающей человека среды. Этому вопросу будет посвящена конференция, созываемая Организацией Объединенных Наций в июне 1972 года в Стокгольме. В известном смысле нынешняя Конференция по использованию атомной энергии может рассматриваться как одно из подготовительных мероприятий перед Стокгольмской конференцией, поскольку на ней был отмечен вклад, который ядерная энергия может внести в производство "чистой" энергии при минимальном загрязнении окружающей среды.

Если три предыдущие конференции проходили под девизом "атом для мира", то девиз нынешней Конференции – "атом на службе прогресса". На языке Организации Объединенных Наций эти термины являются синонимами, и в ходе работы Конференции со всей яностью проявилась ведущая роль, которую ядерная техника может играть в деле оказания помощи развивающимся странам. Это связано не только с удовлетворением будущих потребностей этих стран в энергии, но и с применением ядерных методов в сельском хозяйстве и медицине. Ядерная техника играет также важную роль в образовании и подготовке кадров. Для осуществления этих целей необходимо более четко определить потребности и перспективы развивающихся стран, оказать им поддержку и помощь со стороны развитых стран и мировой общественности.

Как вы знаете, подготовка и проведение данной Конференции явились результатом совместной работы Организации Объединенных Наций и Международного агентства по атомной энергии; эта работа была осуществлена быстро и эффективно. От имени Генерального Секретаря я хотел бы воздать должное нашим коллегам из Агентства за их сотрудничество, которое действительно, как указал д-р Эклунд, является ярким свидетельством того, что может быть сделано в рамках системы Организации Объединенных Наций. Тесное сотрудничество правительств и делегаций, принимавших участие в работе Конференции, обеспечило ее успех. Мне бы хотелось от имени Организации Объединенных Наций поблагодарить за помощь, оказанную другими межправительственными и неправительственными учреждениями, а также Научно-консультативным Комитетом. Необходимо отметить новшество в работе данной Конференции: наличие внутренней телевизионной сети, которая в значительной степени содействовала успешному проведению нашей работы.

В заключение, г-н Председатель, я должен также, от имени Организации Объединенных Наций, отметить Ваш личный вклад как Председателя Конференции в дело организации ее работы. Я думаю, что не смогу выразить большей благодарности, если скажу, что Вы поддерживали традиции, установленные вашими великими предшественниками на данном посту.

OBSERVACIONES FINALES

Guy GRESFORD
Director de Ciencia y Tecnología,
Naciones Unidas

Los trabajos desarrollados por esta Conferencia a lo largo de las dos últimas semanas han mantenido el nivel y conservado el ímpetu inicial de las tres conferencias anteriores convocadas por las Naciones Unidas sobre la utilización de la energía atómica con fines pacíficos. Como han señalado el Académico Sr. Bogoliubov y el Dr. Eklund, el propósito de la Asamblea General ha sido que la presente reunión interesase a un grupo más amplio que el estrictamente integrado por científicos y tecnólogos y que estuviese dirigida a los funcionarios públicos, los planificadores y los economistas. Los grandes progresos realizados en la aplicación de la energía atómica desde que se celebró la tercera Conferencia en 1964 hacen legítimo este propósito y, de hecho, en esta reunión se ha tratado, más que de las esperanzas y sueños de los científicos para el futuro, de planes concretos y de extrapolaciones relativos al papel fundamental que la energía nuclear puede y debe representar para contribuir a satisfacer las futuras necesidades energéticas y de otros tipos de la humanidad.

En estos últimos años, la comunidad internacional ha manifestado una creciente inquietud ante los problemas del medio ambiente humano, preocupación que constituirá el tema central de la conferencia que las Naciones Unidas tienen convocada para el mes de junio de 1972 en Estocolmo. En cierta medida, la actual Conferencia sobre energía atómica puede considerarse como uno de los preliminares de la reunión de Estocolmo, ya que en ella se ha puesto especialmente de realce cómo la energía nucleoeléctrica puede contribuir a que el hombre disponga de energía sin que se produzca contaminación, con una perturbación mínima del medio ambiente.

Mientras que el lema de las anteriores conferencias sobre energía atómica ha sido el de «Atomos para la Paz», la actual ha recibido el de «Atomos para el Desarrollo». Para los fines de las Naciones Unidas, ambos lemas son realmente sinónimos y en la actual Conferencia ha quedado clarísimamente de manifiesto el papel fundamental que la tecnología nuclear puede desempeñar para ayudar a los países en desarrollo. No se trata tan sólo de satisfacer sus futuras necesidades energéticas, sino asimismo de la agricultura y de la medicina. Incumbe también una importante misión a tal tecnología en la esfera de la enseñanza y de la formación profesional. Para cerciorarse del cumplimiento de estas funciones, será menester definir claramente las necesidades y perspectivas de los países en desarrollo, y el apoyo y la ayuda de naciones industrialmente adelantadas y de la comunidad internacional.

Como es sabido, el planeamiento y la organización de esta Conferencia ha sido una labor conjunta de las Naciones Unidas y del Organismo Internacional de Energía Atómica, labor que se ha desarrollado sin fallo alguno y con toda eficacia. En nombre del Secretario General, deseo rendir homenaje a nuestros colegas del Organismo por su colaboración que, de hecho, como ha señalado el Dr. Eklund, ha constituido esta tarea en un modelo de lo que puede lograrse dentro del seno del sistema de organizaciones de las Naciones Unidas. La cooperación sin reservas de los gobiernos y delegaciones que han participado en la Conferencia ha desembocado en el éxito de ésta. En nombre de las Naciones Unidas, debo también expresar nuestra gratitud por la ayuda recibida de otras organizaciones intergubernamentales y no gubernamentales, y del Comité Científico Consultivo. También debe mencionarse una novedad que ha ofrecido la presente reunión: la instalación de un servicio de televisión en circuito cerrado, que ha facilitado grandemente nuestra labor.

Para terminar, Sr. Presidente, debo igualmente agradecerle en nombre de las Naciones Unidas la labor personal que ha desarrollado presidiendo esta Conferencia. Creo que no puedo tributarle mejor homenaje que decir que ha mantenido el alto nivel establecido por las insignes personalidades que le han precedido en su puesto.

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* Throughout the published Proceedings, the papers are grouped by Agenda Item and not by Session. The Agenda Item numbers give an indication of the way the six main subject headings were divided up. The cross-reference provided here to the Session numbers is included only to complete the record of the Conference.

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AGENDA ITEM 1.1

Survey of world energy demand and resources
up to the year 2000

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Обзор мировых потребностей
в энергии и энергетических ресурсов по 2 000 год

Situación de la demanda y de los recursos mundiales
de energía hasta el año 2000

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UNITED STATES OF AMERICA
A/CONF. 49/P/033

GLOBAL EFFECTS OF INCREASED USE OF ENERGY

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Abstract–Résumé–Аннотация–Resumen

GLOBAL EFFECTS OF INCREASED USE OF ENERGY.

This paper attempts to establish global limits to man's use of energy. These limits are set by the amount of fuel and other necessary raw materials recoverable from the earth and by the environmental side effects of the production of energy. There is essentially no limit to the amount of nuclear fuel in the earth's crust or in the seas, provided successful nuclear breeders or fusion reactors are developed. The environmental side effects include global heating of the earth; local heating near power plants; residual radioactivity; and accumulation of wastes from mining low-grade rocks for nuclear fuel. If one assumes that man's total energy generation eventually will increase 60-fold to a rate of 300×10^9 kilowatts, then the average increase in the earth's temperature is 0.1°C. More accurate calculations based on a model of the atmosphere suggest that global effects on the weather will be small. Second-order effects, such as change in cloud cover, are not included in these calculations. Local heating is probably a much more difficult matter than is global heating. Possibilities for dissipating heat from large nuclear plants to the oceans appear attractive. If the budget of 300×10^9 kilowatts of heat is supplied by fission, the total accumulated radioactivity in the wastes would amount to more than 30 million megacuries, not counting the contribution of the very long-lived ^{99}Tc. Disposal of this radioactivity in salt appears feasible. The radioactive effluent therefore does not appear to limit practically the amount of energy man can generate on earth. The main conclusion is that man can generate energy at a much greater rate than at present without causing unacceptable changes in the global environment and without exhausting fuel resources for a very long time.

CONSEQUENCES SUR LE PLAN MONDIAL DE L'AUGMENTATION DE L'UTILISATION DE L'ENERGIE.

Le mémoire essaye d'établir les limites de l'utilisation de l'énergie par l'homme sur le plan mondial. Ces limites sont déterminées d'une part par la quantité de combustible et autres matériaux bruts nécessaires qui peut être extraite de la terre, d'autre part par les effets secondaires de la production d'énergie sur l'environnement. La quantité de combustible nucléaire présente dans l'écorce terrestre ou dans les océans ne constituera pas une limite, à condition que l'on réussisse à développer les réacteurs surgénérateurs ou à fusion contrôlée. Les effets secondaires sur l'environnement comprennent l'échauffement global de la terre, l'échauffement local au voisinage des centrales de puissance, les résidus radioactifs et l'accumulation des déchets provenant de l'exploitation minière des gisements à faible teneur en combustible nucléaire. Si l'on suppose que la quantité totale d'énergie produite par l'homme augmentera d'un facteur 60 pour atteindre finalement un taux de 300×10^9 kilowatts, on obtient une augmentation moyenne de la température de la terre de 0,1°C. Des calculs plus précis basés sur un modèle physique de l'atmosphère suggèrent que les effets globaux sur le temps seront de faible importance. Dans ces calculs il n'a pas été tenu compte des effets secondaires tels que les modifications du système nuageux. Le problème de l'échauffement local est probablement beaucoup plus difficile que celui de l'échauffement global. Il existe d'intéressantes possibilités de dissiper dans les océans la chaleur provenant des grandes centrales nucléaires. Si la totalité des 300×10^9 kilowatts de chaleur était produite par fission, la quantité de déchets radioactifs s'élèverait à plus de 30 millions de mégacuries, sans compter la contribution du ^{99}Tc, de très longue période. Il semble possible de stocker ces déchets radioactifs dans des mines de sel. Il semble donc que les déchets radioactifs ne limitent pas la quantité d'énergie que l'homme peut produire sur la terre. La conclusion principale est que l'homme pourrait produire une quantité d'énergie beaucoup plus élevée qu'il ne le fait aujourd'hui sans causer de changements inacceptables au milieu environnant et sans épuiser les réserves de combustible pendant très longtemps.

ГЛОБАЛЬНОЕ ВЛИЯНИЕ ВОЗРАСТАЮЩЕГО ИСПОЛЬЗОВАНИЯ ЭНЕРГИИ.

В данном докладе делается попытка установить глобальчые пределы использования энергии человеком. Эти пределы устанавливаются количеством топлива и другого необходимого сырья, добываемого из земли, а также путем побочного влияния производства энергии на окружающую среду. По существу нет предела количеству ядерного топлива в земной коре или в морях при успешной разработке ядерных реакторов-размножителей или термоядерных реакторов. Побочное влияние окружающей среды включает в себя глобальный нагрев земли; локальный нагрев около энергетических установок; остаточную радиоактивность; накопление отходов от разработки низкосортных руд для ядерного топлива. Если предположить, что общее производство энергии человеком в конечном счете увеличится в 60 раз, до объема в $300 \cdot 10^9$ кВт, то температура земли увеличится в среднем на 0,1 °С. Более тщательный подсчет, основанный на модели атмосферы, предполагает, что глобальное влияние на погоду будет незначительным. Такие второстепенные влияния, как изменение облачности, не включены в эти расчеты. Локальный нагрев, вероятно, является более сложной проблемой, чем глобальный нагрев. Возможность сброса тепла в океаны с крупных ядерных установок, по-видимому, представляет интерес. Если общее количество тепла в $300 \cdot 10^9$ киловатт поступит в результате деления, то общая накопленная радиоактивность в отходах составит более чем 30 млн мегакюри без учета добавления радиоактивности от очень долгоживущего ^{99}Tc. Представляется возможным удаление этой радиоактивности в соль. Поэтому радиоактивный эффлуент, по-видимому, практически не ограничивает количество энергии, которое человек может производить на земле. Главный вывод состоит в том, что человек может вырабатывать гораздо больше энергии, чем в настоящее время, не вызывая пагубных изменений в окружающей среде и в течение долгого времени не истощая топливные ресурсы.

EFECTOS GLOBALES DE LA UTILIZACION CRECIENTE DE ENERGIA.

En la memoria se trata de establecer los límites globales de la utilización de energía por el hombre. Estos límites vienen determinados por la cantidad de combustible y otras materias primas necesarias que se pueden extraer de la tierra y por los efectos marginales de la producción de energía en el medio ambiente. La cantidad de combustible nuclear que contienen la corteza terrestre o los mares es virtualmente ilimitada, siempre que se logre construir reactores reproductores o reactores de fusión adecuados. Los efectos marginales en el medio ambiente incluyen el calentamiento global de la tierra, el calentamiento local en las proximidades de las centrales eléctricas, la radiactividad residual y la acumulación de desechos resultantes del beneficio de minerales pobres para obtener combustible nuclear. Si se supone que la generación total de energía por el hombre aumentará con el tiempo 60 veces hasta unos 300×10^9 kilovatios, entonces el aumento medio de temperatura de la tierra será de 0,1°C. Cálculos más precisos basados en un modelo de la atmósfera sugieren que los efectos globales sobre el tiempo serán de poca importancia. En estos cálculos no se han tenido en cuenta los efectos secundarios tales como modificaciones de la nubosidad. El calentamiento local es probablemente una cuestión mucho más difícil que el calentamiento global. Parecen interesantes las posibilidades de disipar el calor de las grandes centrales nucleares con el agua de los mares. Si el total de 300×10^9 kilovatios se obtiene a partir de la fisión, la radiactividad total acumulada en los desechos excederá de 30 millones de megacurios, sin contar la actividad debida al ^{99}Tc, cuyo período es muy largo. Parece posible eliminar esta radiactividad evacuando los desechos en formaciones salinas. Por consiguiente, no parece que los efluentes radiactivos limiten en realidad la cantidad de energía que el hombre puede generar en la tierra. La conclusión más importante es que el hombre puede obtener energía en una proporción mucho mayor que en la actualidad sin causar cambios inaceptables en el medio ambiente ni agotar los recursos de combustible durante muchísimo tiempo.

INTRODUCTION

We in the peaceful nuclear energy community have been comfortable in the belief that what we have wrought over the past 30 years has been an unmitigated blessing for mankind. It comes as a disconcerting shock therefore to find that, just when nuclear energy has achieved such great success, our effort is being challenged on the most fundamental grounds. Where we claim nuclear energy is clean, safe, and necessary, critical voices, particularly in the United States, claim it is unclean, unsafe, unnecessary.

We have always conceded that, in opting for nuclear energy, mankind is assuming a certain risk. Nuclear energy *is* potentially more dangerous than other forms of energy. It is only by scrupulous attention to detail, and exertion of great care, that we can expect to maintain the safety of nuclear power plants. So far, we have been highly successful.

Yet there is a much more difficult and profound issue. We are still at the very beginning of the nuclear age. As we think about the possibilities and the dangers of nuclear power, we tend inevitably to think of nuclear power as an isolated, smallish thing. But in the very long run, nuclear energy will almost surely be the dominant energy source. At that time, will we have to confront entirely new questions of environmental impact, questions that conceivably could compromise the whole path we are now taking?

In this paper, we shall try to visualize the possible ultimate impacts of nuclear energy. We shall consider several interrelated questions. First, what is the motivation for the large-scale development of nuclear energy? Second, can we estimate, even very roughly, what the world's eventual nuclear energy budget might be? And third, can we visualize limits to the ultimate use of nuclear energy – such as limits to reserves of raw materials, global thermal effects, questions of disposal of radioactive and other wastes produced in the course of generating the ultimate budget of nuclear energy?

This paper is, by the nature of its subject matter, speculative. Yet the questions it raises in our opinion go to the very heart of the motivation for nuclear energy and the ultimate risks of the new energy source. If the motivation is sufficiently strong, we must be prepared to deal with the risks. But we cannot be content with examining the risks when nuclear energy is relatively unimportant; we must try to assess the risks ultimately, when both the need for nuclear energy and the risks of nuclear energy are much greater than they are now. These questions, though admittedly speculative, seem to us to be of great concern to all of us attending the Fourth Geneva Conference on Peaceful Uses of Atomic Energy.

THE MOMENTUM OF POPULATION GROWTH

In the world we see ahead, the race to control overpopulation subordinates all other problems. In this world it is our thesis that nuclear energy is the key resource, vital to our survival and yet controllable and manageable in its effects and by-products.

One of the most alarming aspects of the population problem is that of momentum. As yet no universally acceptable method of fertility control is in sight, but even if we had such a method now, the population would continue to increase for 50 to 80 years. Demographers [1] have identified several mechanisms which operate to produce this momentum effect. These include: the age distribution of the population, which insures a large increase even if each couple should begin at once to limit themselves to two children; the diffusion time required to introduce and educate all the people of the world in the methods of fertility control; and the time needed to develop incentive, which in many countries means that parents must acquire

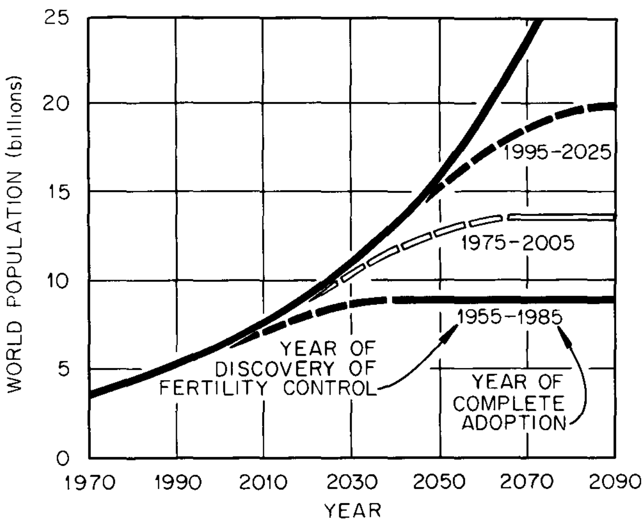

FIG. 1. The momentum of population growth, showing estimates of the world population to be expected for various dates of discovery of an effective and acceptable means of fertility control.

either sufficient material wealth for their old age or sufficient confidence that the survival of only two children will meet their needs. With respect to this last point, it may be that assuring every person adequate old-age insurance whether or not he has children would be a most important step in halting the growth of population. All these delaying factors operate most strongly in the very parts of the world where population is increasing at the highest rates.

The consequences predicted by demographers are shown in Fig. 1, with the different stable populations associated with various times of discovery of a practical birth control means. They state, and we have no choice but to accept, that an ultimate population of 10,000 million persons is very likely, that something like 15,000 million is quite likely, and that 20,000 million is not impossible.

It is our purpose, then, to assess the future consequences of our nuclear technology on a world which is highly likely to materialize. Because we are prepared to discuss the consequences of providing for 15,000 million people does not mean we recommend such a level as desirable – we accept it only because we see no acceptable, humane way to prevent it. We utilize 15,000 million as an example – we could have used 12,000 or 20,000 with equal support from authority, and with little effect on our conclusions.

ENERGY, THE KEY RESOURCE

Let us turn our attention to a time, perhaps 100 years hence, in which parents have been averaging only two children for 50 years or so, and population has finally stabilized at 15,000 million persons.

The importance of energy in such a world becomes immediately apparent: we cannot hope to feed such a population without significant *nonfarm* energy inputs, even using all the arable land on earth. With such inputs, however, in the form of fertilizer, water control, and machinery, this might be accomplished on even less land than is now used for crops. Most of this increased food can in principle be produced on existing cropland, though the possibility exists of increasing our land supply by using the desert. In previous work sponsored by the U.S. Atomic Energy Commission, some of which is to be presented at this conference by Commissioner Ramey, it has been shown that energy can convert seawater, air, and desert land into hydrogen and fertilizers, fresh water, foods, and industrial goods by means of an agro-industrial complex.

But energy is essential in another basic way, for not only is the food requirement inconsistent with subsistence agriculture, but the assumption of zero growth probably implies inherently a degree of wealth and hence of energy use. Even a fully adequate old-age insurance system requires a minimum level of wealth in the society. We assume this level to be the present U.S. level, though our argument is not changed very much even if we assume a level one-half of this.

The requirements for material resources of 15,000 million people at a high standard of living will be unprecedented in terms of our present experience, and this leads to concern as to possible exhaustion of essential supplies. This subject has been reexamined in detail during the past year by H. E. Goeller of Oak Ridge National Laboratory in a cooperative project with Resources for the Future, Inc. Goeller shows [2] that with the possible exception of phosphorus the essential resource requirements of man can be met from plentiful sources for a long time to come, provided that energy is available to do the necessary extractive work. Some substitutions, adjustments, and compromises will be inevitable, and much expensive recycling of scarce substances must be done; but the key requirements appear to be available.

COMPONENTS OF AN ENERGY BUDGET

At present, the U.S. consumption of energy in all forms has a fuel equivalent of about 300 million Btu per person per year, which is a steady rate of 10 kilowatts thermal [kW(th)] per person, as shown in Table I and published elsewhere [3]. If we assume that the entire world is gradually brought up to this same standard of living [present average is only 1.5 kW(th) per capita] and that appropriate substitutions of energy are made for those raw materials which are not in virtually limitless supply, we can calculate the total energy budget of civilization at any

Table I. The Present U.S. per Capita Budget for All Forms of Energy, Expressed in Kilowatts of Equivalent Fuel Consumption

	Household	Commercial	Transport	Industry	Other	Total
Space heating	1.14	0.13	0.03	0.14	0.07	1.5
Other heat	0.33	0.4		2	0.6	3.3
Motive use			2			2
Electricity	0.5	0.3		1	0.3	2.1
Non-energy uses				0.41	0.7	1.1
Total	1.97	0.83	2.03	3.55	1.67	10

Table II. An Augmented Ultimate per Capita Energy Budget, Making Provision for Environmental Control, Recycle of Scarce Materials, and Use of More Dilute Ores

PRESENT UNITED STATES LEVEL		10.0 kW(th)
ADJUSTMENTS FOR THE FUTURE		
STEEL, ALUMINUM, AND MAGNESIUM PRODUCTION	0.1	
RECOVERY AND RECYCLE OF SCARCE ELEMENTS (copper, zinc, tin, lead, gold, silver, mercury, titanium, etc.)	2.0	
ELECTROLYTIC HYDROGEN	2.5	
WATER BY DESALTING (100 gpd)	0.3	
WATER TRANSPORT TO CITIES	0.1	
AIR CONDITIONING TO CITIES	0.3	
INTENSIVE FOOD PRODUCTION	0.2	
SEWAGE AND WASTE TREATMENT	0.5	
TOTAL ADJUSTMENTS		6.0
CONTINGENCY		4.0
TOTAL BUDGET		20.0 kW(th)

population level. The basis for these energy inputs is developed elsewhere [4] and summarized in Table II. The final budget of 20 kW(th) per person (600 million Btu per year) is purposely generous in order to provide a margin of safety in our estimates of consequences.

SITES FOR ENERGY PRODUCTION: ENERGY PARKS

In hypothesizing a world in which energy is the basic raw material, we need to give some thought to how and where it is produced. The past few years have brought about a crisis in site selection for power stations, both nuclear and fossil. The choicest sites near plentiful cooling water are increasingly forbidden to power stations, both for financial and ecological reasons. As the trend to nuclear power accelerates, other factors appear which tend to favor very large reactors with nearby captive fuel processing plants: these might be clustered in "nuclear parks."

One of the most important factors favoring such parks is the difficulty of shipment of spent fuel elements. We have estimated that in the U.S. alone, by the year 2000, if there are 600,000 MW of fast breeder reactors, 60 to 100 batches of spent fuel will be in transit every day. For economy, one would like to ship these fuel elements with not more than, say, 30 days cooling time. But this might require dissipation of 300 kW of heat from each shipment. Even if we back off from such short cooling times, shipment of fuel looks difficult, and we believe the "nuclear parks" would be a possible alternative. We would hope that developments in long-distance electrical transmission would minimize the penalty paid for clustering the power plants.

Each park might have, say, eight reactors producing a total of 40 million kilowatts electrical [kW(e)] [100 million kW(th)] and would be heavily interconnected with other parks so that shutdown of one reactor or failure of one transmission line would have negligible effect. If all man's energy needs were produced as nuclear electricity, a total of 3000 such parks would eventually be required to produce our assumed total. Some of these parks will be on the seashore, or preferably floating offshore on huge barges. Not only would it be very difficult to find sites on the land for this many parks, but our analysis of the cost trends shows that ocean siting may become a reasonable alternative for many regions.

It is clear that major changes will be needed in the methods by which we undertake to construct power stations. To attain the assumed level of 24,000 reactors of 5,000 MW(e) each means that the world will have to add more than four reactors a week on the average for the next 100 years. In addition, if the reactors last 30 years, we shall have to build about two reactors per day simply to replace those that have worn out! To meet this kind of need, present-day methods will have to be refined into assembly lines which resemble those which now turn out automobiles; in the process, savings in cost and time should be achievable.

LIMITS TO THE USE OF ENERGY

We now explore some of the possible physical and environmental consequences of a world of 15,000 million people living at a U.S. standard and consuming a total of 9×10^{18} Btu per year (9 Q), or 300×10^9 kW(th). We expect that about 12,000 million persons will live in about a million square miles (300 million hectares) of cities covering about 2% of the earth's surface and supplied with food from efficient farms covering about 10% or less of the earth's surface.

We shall explore four kinds of limits which nature might conceivably set to the energy consumption which we have hypothesized: supply of fuel, dissipation of heat, storage and release of radioactive wastes, and storage and release of other wastes.

Limits to the supply of fuel

The supply of nuclear fuel has been much studied, and so we shall deal with it only briefly. Obviously, a steady energy budget of 300×10^9 kW(th) per year would deplete our fossil reserves of around 400 Q in a couple of generations. Moreover, it matters little whether our energy budget were, say, threefold smaller: mankind would still have but a hundred years' worth of fossil fuel.

If we discount solar energy as being too diffuse and too expensive to utilize, we shall therefore be obliged to turn to nuclear fuel: uranium, thorium, deuterium, lithium.

As is very well known by now, these materials, in the oceans of the sea and in the common rocks, provide enough energy even at the prodigious rate we contemplate, to last a *very* long time. To tap this resource we must learn to burn deuterium in D-D reactions; or, failing this, to develop ways of burning ^{6}Li, ^{238}U, or ^{232}Th.

The outlook for fusion is covered in other papers at this conference. We wish to point out, however, that there is a striking parallel between fission breeders and fusion based on D-T reactions. In both cases, a regenerating catalyst (T in the case of fusion, ^{239}Pu or ^{233}U in the case of fission) is involved in the conversion of ^{6}Li (and D) or ^{238}U and ^{232}Th into energy. We therefore propose the name *catalytic nuclear burners* for both fission breeders and fusion reactors based on D-T.

The crustal abundance of ^6Li is 2 ppm, of U + Th about 15 ppm. Since lithium yields about four times the energy of the same weight of uranium or thorium, the total energy content of each type of fuel in the earth's crust is similar. Both are immense, literally millions of times the energy content of all fossil fuels. Thus if we develop catalytic nuclear burners, either of the fusion or fission type, we have all but inexhaustible sources of fuel to keep them going.

Limits to waste heat release

Global effects

One can show that the overall temperature regime of the earth is unlikely to be noticeably affected by man-made energy. Man presently releases about 0.005×10^{12} kW(th), or one part in about 23,500 of the net solar input of 117.5×10^{12} kW(th). Our assumed ultimate load is 60 times the present one, or 0.25% of the net solar input. Estimates show that an overall warming of about 0.25°C plus a slight increase in cloudiness (earth's reflectivity changed from 0.340 to 0.34073, for example) would be a likely effect.

The overall average effects seem reassuring, but we must also consider effects on global weather patterns, which are driven by only a small fraction of the total solar energy, and which might be totally upset by the energy man releases. Although much more thorough study of such effects is needed, we can offer two kinds of specific evidence to illuminate this difficult problem.

Dr. Warren M. Washington of the National Center for Atmospheric Research has shown with computer modeling techniques that energy inputs much larger than we have assumed would not be expected to "upset" the weather, but would slightly reorient isotherm locations within normal ranges [5]. In a more recent computer simulation, Dr. Washington estimated the effect on the global weather caused by the energy input we have assumed here, 300×10^9 kW(th). Figure 2 shows the distribution of population and energy which Dr. Washington used in his atmospheric model, and Fig. 3 shows the calculated deviations of the resulting isotherms from the undisturbed pattern. The effects are of the same order as are random fluctuations in the model, and therefore the calculation gives evidence for our belief that energy inputs of this magnitude would not significantly change global weather patterns.

Dr. Jerome Namias, chief of the Extended Forecast Division of the National Weather Service, has been studying long-range weather effects caused by the presence of a ten-year-long anomalous warming in the North Pacific Ocean [6] (see Fig. 4). This warming, representing more than ten times the energy input we have assumed from man for the whole world, produced observable statistical effects on the winter climate of the eastern United States, but there were no upsets and the changes were within the range of normal and acceptable variations.

Local effects: the climate of cities

The urban "heat island" effect is now well documented. Temperatures at ground level in a city are often several degrees higher than in the nearby rural regions. In a recent summary of work on this phenomenon, Peterson [7] notes that a city's structures tend to reduce wind velocities, and that heat released by combustion processes and from solar energy stored in buildings and streets tends to form a persistent layer of well-mixed air about 100 m deep adjacent to the city's surface.

The size and energy release of our cities are now low enough that reasonable efforts at pollution control can keep the air tolerable most of the time. However, as urbanized regions grow closer together and cover hundreds of miles, heat plumes escaping from each dense area may combine to form a larger regional heat island which could produce a stronger convection cell, further reduce ambient wind speed, and feed local heat islands with already polluted air. Our assumed future cities will have to pay close attention to heat releases. An all-electric city would release much less heat, since electric processes are usually more efficient. The quantities of heat rejected in nuclear power generation, however, have to be handled separately. To prevent an aggravation of the regional heat island effect, this heat must not be released to the

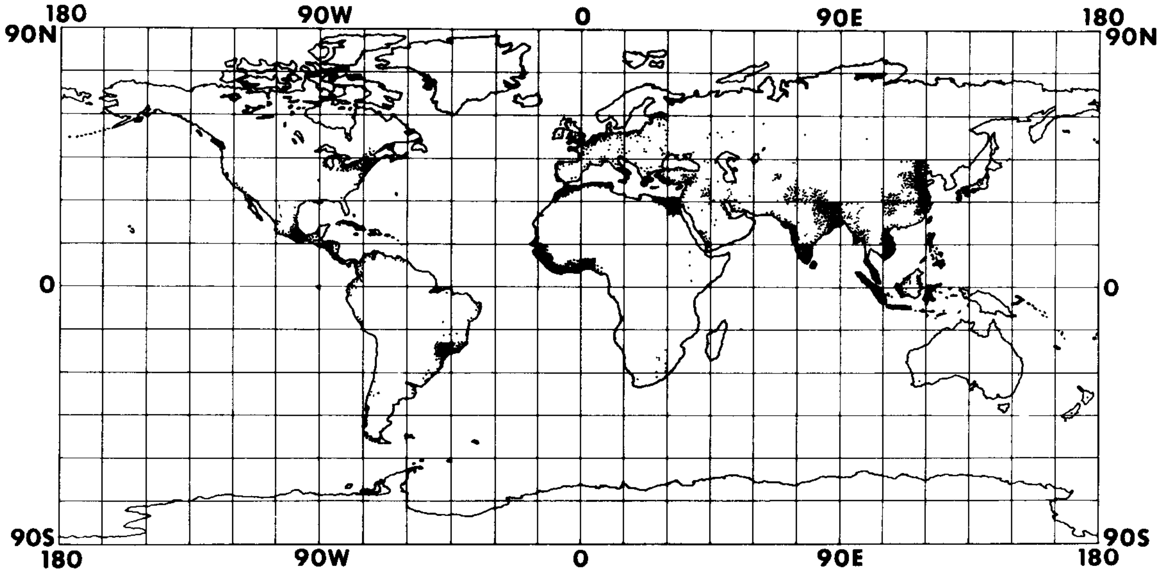

FIG. 2. Assumed distribution of a world population of 15 000 million, and of the energy inputs which they require. Each dot represents 10^8 kW(th).

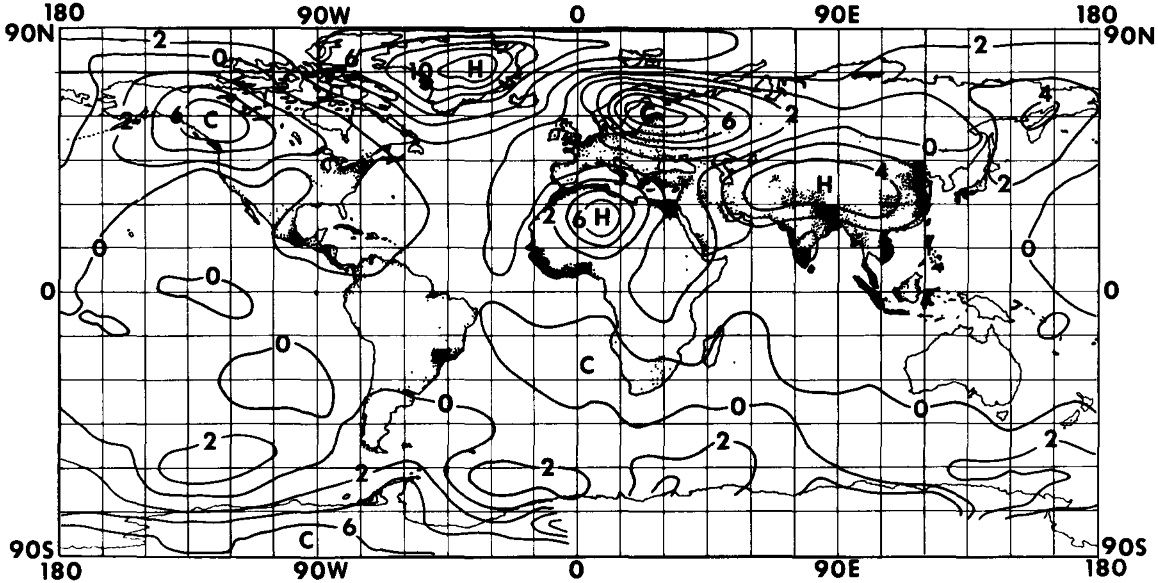

FIG 3. Assumed energy inputs and the calculated changes in world temperature patterns for month of January. Numbers give deviation of temperature from values found in control calculation with no man-made energy input. H = hot isotherms, C = cold isotherms. The deviations found in these computer simulations of the world weather are of the same order as those found when the energy input is zero but the initial conditions are changed. It is on this account that we believe the computed deviations are insignificant. The calculations were performed by W.M. Washington of the National Center for Atmospheric Research.

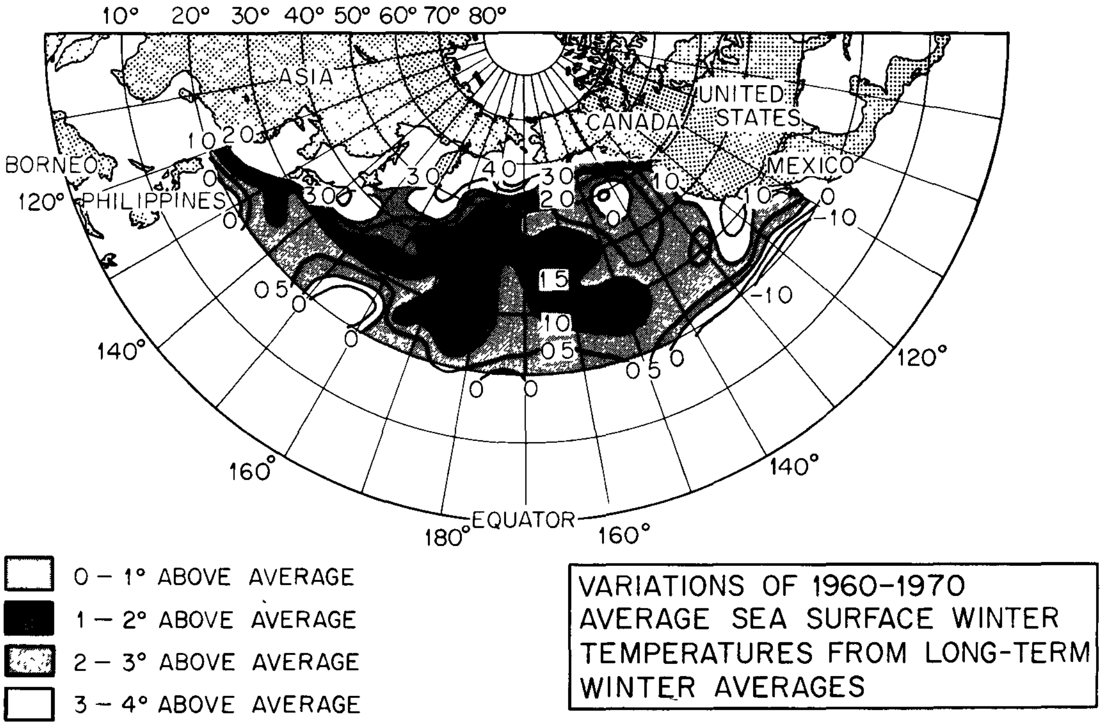

FIG. 4. Observed thermal anomaly in the north Pacific over the past 10 years, representing an enormous shift in energy.

atmosphere near the city. For a time our needs can be met with cooling ponds, lakes, and rivers; but these ultimately return the energy to the atmosphere over relatively small areas. Gradually we will find that only the ocean can furnish enough capacity to absorb heat and release it over a very large area.

Heat disposal in the ocean

The ocean has attractive properties as a site for power stations: it is large, it is cold, it is always there, and it is close to most of the large cities of the world. There is rapidly growing interest in the use of the sea for siting, and plans for constructing artificial islands and large floating structures now seem feasible. Improved transmission line systems, such as the supergrid, will be the principal step needed to permit the sea to be used for the majority of our energy sources.

In visualizing future demands upon the sea as a heat receptor, such as for the energy parks described above, we must determine whether there are effects on the sea itself, or on the climate, which would set limits to this kind of use. We would propose that ocean-cooled power stations be provided with sufficiently long intakes so that they can draw from the bottom waters – the cold portion below the region mixed by the waves – and be designed to heat this water only to the temperature of the surface waters. The discharged water would thus create no large thermal gradients, and it would be a source of increased nutrients to the surface water. Isaacs and Schmitt [8] claim that with such artificial upwelling there would be a direct correlation in increased seafood productivity with the energy input. (The cold bottom waters, being denser, will not stay on the surface unless they are warmed.)

The conclusions one can draw as to whether man's energy releases will produce tolerable thermal effects on the earth and its climate must be tentative, since much more study and measurement are needed. The indications seem promising, however, that global upsets in weather and temperature are very unlikely if we are able to distribute the energy released over wide areas of the land or into the sea. In cities, the present patterns of energy release already show local effects which would be dangerously aggravated under the projected increases. We believe that substantial research efforts should be directed to assessing and hopefully mitigating these effects.

Limits from radioactive waste

If we do not reduce fusion to reliable practice and therefore must depend on fission breeders, about 500,000 megacuries of long-lived activity producing 3.2×10^6 kilowatts of heat would be generated each year at our assumed energy budget of 300×10^9 kW(th) [3] (see Table III). Formidable though this quantity may seem, and important though a satisfactory disposal must be, the difficulties do not appear to set an insuperable limit to the use of nuclear power. The release of radioactive gases from normal operation of reactors seems to be reducible to any desired level – even the natural background level – by application of our rapidly developing containment technology.

In the fuel processing plants, however, one must be prepared to cope with the full problem. The general strategy for the next few decades is to immobilize the nonvolatile elements in ceramic matrices and to store them permanently in underground salt strata; krypton and tritium will be held in live storage until they decay. The techniques for disposal of solidified high level wastes have been developed at Oak Ridge over the past ten years and have been demonstrated in a preliminary way in the field. The U.S. Atomic Energy Commission is presently planning a full-scale field demonstration of storage in salt. The advantage of salt is that it is never in contact with ground water (provided man does not intervene by digging holes in the salt), and it is a good conductor of heat.

Though there are other formations which might serve, there is still a long future ahead even if nothing better than salt is found. We estimate, using currently conceived practices, that our future world would require about 30 square miles of salt strata for waste disposal per year. There are 500,000 square miles of salt in the United States alone and tens of millions

Table III. Amount of Radioactive Waste Created by a World Nuclear Energy Production of 300 X 10^9 kW(th)

NUCLIDE	MEAN LIFE (yr)	ACTIVITY ACCUMULATED IN ONE YEAR (MCi)	WATTS/CURIE	HEAT GENERATED [kW(th)]	STEADY-STATE VALUES	
					ACTIVITY (MCi)	HEAT [kW(th)]
				x 10^3		x 10^6
Sr^{90}	40.4	200,000	0.00702	1,404	8.1 x 10^6	56.9
Cs^{137}	43.2	279,000	0.00529	1,476	12.1 x 10^6	64.0
I^{129}	2.5 x 10^7	0.1	0.000432	0.00004	2.5 x 10^6	1.08
Kr^{85}	15.2	28,500	0.00161	46	434,000	0.70
H^3	17.7	1,800	0.0000355	0.0064	31,900	0.001
Tc^{99}	3.0 x 10^5	38	0.000677	0.0026	11.4 x 10^6	7.72
Pu^{238}	128	270	0.0330	0.89	34,500	1.14
Pu^{239}	35,200	4.5	0.031	0.14	158,000	4.90
Pu^{240}	9,750	12	0.0312	0.37	117,000	3.65
Am^{241}	660	465	0.0334	1.55	307,000	10.25
Am^{243}	11,000	47	0.0323	1.52	517,000	16.7
Cm^{244}	26.1	6,450	0.0349	225	168,000	5.86
TOTALS		516,586.6		3,155.5	35,867,400	172.9

throughout the world. Not all of this is suitable for waste disposal, but one cannot escape the impression that the foreseeable future is not endangered by the radioactive waste storage problem.

Limits from other wastes

As shown in Table IV, in 1968 the world dug up sand, gravel, ores, and fuels which had a total volume of 2.32 cubic miles; the great majority of these materials were fuels. The effect of these removals on the earth's beauty and usefulness is one which we must take into full account in considering the consequences of a large population. As fuels are consumed and as sand, gravel, and limestone are used in the construction of roads and buildings, we are left with gashes in the earth, missing hills, and subsidence from underground mines and wells. In the case of metal ores, we have in addition the tailings left by beneficiation and extraction of the desired metal; in the case of strip mining of coal, we have the piles of overburden. For each case we must ask if a limit is imposed on man's activities or comfort.

The extraction of petroleum and gas should not cause us much concern, since they will have been exhausted at the time we are considering and will cause no further effect. Coal is a different story. Where strip mining is practiced, there is often five times as much overburden to remove as there is coal to recover. Since we have assumed we will require a total of nearly 250 Q of energy in the next 100 years, and six cubic miles of coal is required to give one Q, one can see that several thousands of cubic miles of overburden may be involved if coal remains our principal fuel.

Table IV. Total Annual Volumes of Minerals Extracted from the Earth, for the U.S. and the World

	MILLION SHORT TONS		VOLUME
	UNITED STATES	WORLD	(cu mi)
SAND AND GRAVEL	918	3,700*	0.37
COAL AND LIGNITE	556	3,086	0.54
LIMESTONE	603	2,400*	0.20
PETROLEUM	495	2,090	0.53
NATURAL GAS	493	790	(0.57)
IRON ORE	95	738	0.04
COPPER ORE	150	491	0.03
PHOSPHATE ROCK	148	211**	0.02
(MARKETABLE)	(41)	(93)	
SALT	41	124	0.01
GYPSUM	9	52	0.005
BAUXITE	2	47	0.004
SULFUR + PYRITES	11	44	0.003
TOTAL EXCLUDING NATURAL GAS AND LIQUIDS			1.75
TOTAL INCLUDING NATURAL GAS AND LIQUIDS			2.32
TOTAL MASS 13,800 MILLION SHORT TONS			

*Based on World Production = 4 x United States

**World Mined/Marketable Ore Assumed Same as United States

If uranium is substituted for coal as the source of energy, the quantities of debris to be handled are reduced by two or three orders of magnitude. The ores now being used are thousands of times smaller in volume than the equivalent energy in coal; even the shales and richer granites, which will last for hundreds of thousands of years, need only a hundredth of the volume of coal to give the same energy content. The advent of nuclear power will reduce man's per capita earth moving by nearly 50% overall. The remainder is mostly sand, gravel, and limestone, which are available so profusely that we have wide choice in locating our borrow pits for minimum damage to the environment.

CONCLUSION

Though our paper is speculative, we believe we have made a plausible case for two major theses:

1. That mankind must have an alternative, essentially inexhaustible energy source. From what we now know, this source must be nuclear.

2. That there probably are no insuperable global effects even if nuclear energy from fission breeders reaches 60 times the total energy man now produces.

Thus we are persuaded that the underlying motivation for development of nuclear energy is valid, despite the noisy criticism which is being leveled at the enterprise.

Nevertheless we would do well to contemplate the *full* implications of a complete commitment to nuclear energy. Mankind, as the price of relief from Malthusian catastrophe, will have to confront all of the side effects of catalytic nuclear burners directly and realistically. Such matters as ultimate disposal of radioactive wastes, shipment of spent fuel elements, even the remote possibility of accident, which seem to be relatively minor questions today, become totally dominant when nuclear power generates the prodigious amounts of energy contemplated here.

Are we doing mankind a service in pointing out that with abundant energy, we can take care of many more people than now inhabit this earth; or would we do better to ignore these possibilities and thus force population control by tightening the Malthusian vise, by not holding out hope for this energy panacea? The answer seems clear to us: since there is no assurance that population control will work no matter what measures, what social pressures, are brought to bear, we have no choice, as compassionate technologists and human beings, but to examine ways of dealing with the population catastrophe that seems to be inevitable. Perhaps by providing a material basis for lives of dignity for the coming billions, we may be helping more to stave off the ultimate catastrophe of population explosion than by tightening Malthusian vises. It is this belief that should motivate the nuclear community in its effort to develop safe, clean, economic catalytic nuclear burners.

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REACTORES NUCLEARES EN LA AMERICA LATINA

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Abstract–Résumé–Аннотация–Resumen

NUCLEAR REACTORS IN LATIN AMERICA.

If the area, population, and income of Latin America are taken into consideration, it can be seen that the region has a relatively small share of the world's nuclear reactors, both for research and for power. There are now only ten research reactors, including Puerto Rico, and there are concrete plans to construct only three more. The development of power reactors has been even slower. Only Argentina and Puerto Rico have nuclear centres under construction and, in addition to these countries, only Brazil and Mexico plan to add power reactors to their electric systems. The small size in general of electricity systems, the enormous distances between important centres, and the availability of low-cost energy resources in some countries, contribute to the fact that, for the immediate future, nuclear centres can only be considered in the four countries mentioned. However, nuclear power in those countries will probably increase considerably: from 1000 MW in 1975 to 5000 MW in 1980 and 75 000 MW in the year 2000. In making long-range projections. the possibility that other countries in Latin America may install nuclear centres cannot be eliminated. The growth and interconnection of electricity systems, plus the increase in price of fossil fuels in the world market may make it desirable to use nuclear energy to replace traditional energy sources. The future development of small and medium power nuclear centres may considerably advance the development of nuclear power programs.

LES REACTEURS NUCLEAIRES EN AMERIQUE LATINE.

Compte tenu de sa superficie, de sa population et de son revenu, l'Amérique latine ne prend qu'une part relativement faible à l'utilisation mondiale des réacteurs nucléaires, qu'ils soient de recherche ou de puissance. Dans ces pays, Porto Rico compris, le nombre actuel de réacteurs de recherche n'est que de dix et il n'y a de projets concrets que pour trois autres. La mise en chantier des réacteurs de puissance a été encore plus lente. Seuls l'Argentine et Porto Rico ont des centrales nucléaires en construction; parmi les autres pays seuls le Brésil et le Mexique envisagent d'intégrer des réacteurs de puissance à leurs réseaux. La petite taille des réseaux électriques en général, l'énormité des distances qui séparent les centres de consommation importants, et l'existence de sources d'énergie à bon marché dans certains pays expliquent le fait que dans un avenir immédiat la construction de centrales nucléaires ne peut être envisagée que dans les quatre pays susmentionnés. Toutefois, la puissance nucléo-électrique y augmentera selon toute vraisemblance considérablement: de 1000 MW en 1975 elle passera à 5000 MW en 1980 et à 75 000 MW à la fin du siècle. Dans les prévisions à long terme on ne peut exclure la construction de centrales nucléaires dans d'autres pays d'Amérique latine. L'expansion et l'interconnexion des réseaux, ainsi que l'évolution des prix des combustibles fossiles sur le marché mondial, pourraient rendre avantageux le remplacement des sources traditionnelles d'énergie par l'énergie d'origine nucléaire. La mise au point de centrales nucléaires de taille petite ou moyenne, qui ne s'est pas encore réalisée, pourrait faire avancer considérablement le développement et la mise en œuvre de programmes d'énergie d'origine nucléaire.

ЯДЕРНЫЕ РЕАКТОРЫ В ЛАТИНСКОЙ АМЕРИКЕ.

Если учесть площадь, население и доходы стран Латинской Америки, то видно, что этот район располагает весьма незначительной долей имеющихся во всем мире ядерных реакторов, предназначенных как для исследовательских целей, так и для производства электроэнергии. В настоящее время во всем районе включая Пуэрто-Рико, имеется 10 исследовательских реакторов и разработаны конкретные планы по сооружению только трех реакторов. Разработка энергетических реакторов продвигается еще медленнее. Ядерные центры создаются лишь в Аргентине и Пуэрто-Рико. В дополнение к этим странам можно назвать Бразилию и Мексику, где планируется включить энергетические реакторы в энергосистемы. Небольшие, как правило, энергетические системы, чрезвычайно большие расстояния между основными центрами и наличие дешевых энергетических ресурсов в ряде стран говорят о том, что в ближайшем будущем создание ядерных центров может рассматриваться только в упомянутых четырех странах. Однако возможно, что производство ядерной энергии в этих странах значительно возрастет: с 1000 МВт в 1975 году до 5000 МВт в 1980 году и 75 000 МВт в 2000 году. Осуществляя долгосрочное планирование, нельзя исключать возможность создания ядерных центров в других странах Латинской Америки. Рост и объединение энергосистем, а также увеличение цен на ископаемое топливо на мировом рынке могут способствовать использованию ядерной энергии вместо обычных источников энергии. Сооружение в будущем малых и средних ядерных энергетических центров может значительно продвинуть разработку программ в области ядерной энергетики.

REACTORES NUCLEARES EN LA AMERICA LATINA.

Si se consideran la superficie, la población y el ingreso de América Latina, se aprecia que ésta, como región, tiene una participación relativamente baja en la utilización de reactores nucleares, tanto de investigación como de potencia, en el mundo. Incluyendo a Puerto Rico, el número de reactores de investigación en la actualidad es sólo de diez y existen planes concretos para la construcción de tres más. En materia de reactores de potencia, el desarrollo ha sido todavía más lento. Unicamente Argentina y Puerto Rico tienen centrales nucleares en construcción y, además de estos países, sólo Brasil y México planean la adición de reactores de potencia a sus sistemas eléctricos. En general, el pequeño tamaño de los sistemas eléctricos, las enormes distancias entre centros de carga importantes y la disponibilidad de recursos energéticos baratos en algunos países, contribuyen a que en un futuro próximo solamente pueda considerarse la construcción de centrales nucleares en los cuatro países ya mencionados. Sin embargo, en estos países la potencia nucleoeléctrica en operación adquirirá probablemente un desarrollo considerable: de 1000 MW en 1975 a 5000 MW en 1980 y 75 000 MW en el año 2000. En proyecciones a tan largo plazo es imposible excluir la instalación de centrales nucleares en otros países de América Latina. El crecimiento y la interconexión de los sistemas eléctricos, aunados a la evolución de los precios de los combustibles fósiles en el mercado mundial, pueden hacer conveniente el uso de la energía nuclear para la sustitución de recursos energéticos tradicionales. A este respecto, puede influir considerablemente en el adelanto de las fechas de iniciación de programas nucleares de potencia el desarrollo, todavía no materializado, de centrales nucleares competitivas de pequeña y mediana potencia.

En el panorama de los reactores nucleares, tanto de investigación como de potencia, en operación, construcción o planeación en el mundo, América Latina ocupa un lugar relativamente insignificante. El propósito de este trabajo es examinar las razones que pueden explicar la situación actual y prever el posible desarrollo de la energía nucleoeléctrica en esta parte del mundo.

REACTORES DE INVESTIGACION

El cuadro I muestra los reactores de investigación que existen actualmente en operación en la América Latina, así como aquéllos en construcción o en fases avanzadas de planeación. Puede verse que, aunque los primeros reactores de investigación en Argentina y Brasil alcanzaron la criticidad en fechas comparables a las de muchos otros países, el desarrollo de estos reactores en Latinoamérica ha sido en general lento, al punto de que el número de reactores de investigación en la actualidad es sólo de diez, existen tres en construcción y hay uno más ya contratado para su próxima construcción. En comparación, el número total de reactores de investigación en el mundo al final de 1970 era 366, de los cuales 132 se encontraban en Europa occidental, 38 en Europa oriental, 139 en los Estados Unidos, 33 en otros países desarrollados y 14 en el resto del mundo [1].

Las causas que han determinado la lentitud de este desarrollo son de diversa índole y seguramente ha jugado un papel importante la ausencia de una actividad científica bien establecida en la mayor parte de los países de esta región del mundo, de modo que en muchos casos no se veía la justificación, aún desde el punto de vista del desarrollo científico nacional, de la inversión relativamente considerable representada por un reactor de investigación.

De modo más fundamental, los reactores de investigación han carecido en general del poderoso estímulo que suele representar la existencia de planes inmediatos para la construcción de centrales nucleares. Por las razones que se expondrán más adelante, la energía nucleoeléctrica sólo ha encontrado aplicación en Latinoamérica recientemente y esto en un número limitado de países.

En la actualidad, puede hablarse de un resurgimiento del interés en los reactores de investigación en la América Latina. Además de los reactores en construcción en el Centro Nacional de Estudios Nucleares de Chile [2], en el Centro de Investigaciones Nucleares de Uruguay [3], [4] y en la Universidad de Rosario, Argentina, está decidida la construcción de un pequeño reactor homogéneo similar al de esta universidad por la Universidad Nacional Autónoma de México y se planea uno más en el centro nuclear proyectado por la Junta de Control de Energía Atómica del Perú.

Es interesante señalar también los proyectos de rehabilitación o de expansión de muchos de los reactores en operación. Existen planes concretos de modificaciones en Argentina, en el reactor RA-0 que será donado a la Universidad Nacional de Córdoba para fines de enseñanza y en el reactor RA-3 cuya potencia se desea aumentar de 5 a 12 MW [5] y en el Brasil, en el reactor IEA-R1 cuya potencia se había visto reducida de 5 a 2 MW y se espera ahora ampliar a 10 MW y en el reactor IPR-R1 que de 30 kW en operación continua y 100 kW por períodos limitados se piensa llevar a 140 y 250 kW respectivamente [6].

PANORAMA ENERGETICO

En muchos de los países que tienen o planean reactores de investigación, una motivación importante ha sido la perspectiva de utilizar la energía nuclear para la generación de electricidad. Es, pues, conveniente considerar el panorama energético de América Latina, para entender el futuro de la energía nucleoeléctrica, en conjunto o por países.

El consumo bruto de energía comercial en los países latinoamericanos representaba sólo el 3,1 por ciento del consumo mundial en 1966. La dotación energética media por habitante en la región es una cantidad relativamente baja que equivalió en aquel año a poco más de 490 kilogramos de petróleo, o sea 42 por ciento del consumo medio del mundo en la misma fecha. Lo que es más grave, de seguir la tendencia actual, en la próxima década América Latina acusaría en conjunto el más bajo consumo de energía por habitante, entre las regiones o grupos de países en que, para fines estadísticos, suele dividirse el mundo [7].

CUADRO I

REACTORES DE INVESTIGACION EN LA AMERICA LATINA

Nombre	Localización	Utilización	Tipo	Potencia kW(t)	Fecha 1a. criticidad	Estado actual (1° Mayo 71)
Argentina						
RA - 1	Buenos Aires	Entren., isótopos	Argonauta	8,0E+01	ENE 58	En operación
RA - 0	Buenos Aires	Exper. crítico	Tanque	5,0E-03	MAY 58	En ajuste
RA - 2	Buenos Aires	Exper. crítico	Tanque	3,0E-02	JUL 66	En servicio
RA - 3	Ezeiza	Inv., prueba, isót.	Tanque	5,0E+03	MAY 67	En operación
RA - 4	Rosario	Entrenamiento	Sól. homog.	1,0E-04	SEP 71	En construcción
Brasil						
IEA - R1	São Paulo	Inv., prueba, isót.	Piscina	5,0E+03	SEP 57	En operación
IPR - R1	Belo Horizonte	Entren., isótopos	U-ZrH, Tanque	1,0E+02	DIC 60	En operación
IEN - R1	Río de Janeiro	Entren., invest.	Argonauta	1,0E+01	FEB 65	En operación
Colombia						
IAN - R1	Bogotá	Invest., isótopos	Piscina	2,0E+01	ENE 65	En operación
Chile						
CNEN	Santiago	Inv., prueba, isót.	Piscina	5,0E+03	DIC 71	En construcción
México						
PRI	Salazar	Inv., prueba, isót.	U-ZrH, pisc.	1,0E+03	NOV 68	En operación
UNAM	México, D. F.	Entrenamiento	Sól. homog.	1,0E-04	MAY 72	En proyecto
Uruguay						
CIN	Montevideo	Inv., prueba, isót.	Piscina	1,0E+03	SEP 72	En construcción
Venezuela						
RV - 1	Altos de Pipe	Invest., isótopos	Piscina	3,0E+03	JUL 60/ OCT 65	En operación

En cuanto a la producción de energía eléctrica, la región generó 106 000 millones de kWh en 1966, lo que representó el 3,0 por ciento del total mundial, proporción que con leves variaciones se mantiene desde hace unos 20 años. Similarmente, la producción de energía eléctrica por habitante fue de 433 kWh en la misma fecha, o sea el 40 por ciento del promedio mundial [7].

Debido a la importancia de Venezuela como exportador de petróleo, la producción total de energía en América Latina duplica con creces el consumo. Sin embargo, aparte de Venezuela, sólo Bolivia, Colombia, México, Perú y Trinidad y Tabago tenían en 1966 un balance neto favorable, en materia de combustibles, en su comercio exterior [7].

En el sector eléctrico, las diferencias entre países son también acusadas. Como Argentina, Brasil y México tenían en 1967 el 71 por ciento de la capacidad instalada y el 63,5 por ciento de la generación, lo que acontece en estos tres países influye poderosamente en las tendencias regionales. Durante el decenio que terminó en 1967, el incremento medio anual de la generación en estos países fue de 6,4, 6,6 y 9,8 por ciento respectivamente, frente a 7,8 por ciento del total de América Latina y su capacidad instalada de generación se elevó por término medio en 7,3, 8,0 y 9,5 por ciento, respectivamente, frente a un promedio regional de 8,0 por ciento [7].

En América Latina, las principales fuentes de producción de electricidad han sido hasta ahora el petróleo y el agua, aunque en algunas partes también se han usado el carbón, el gas natural y la leña. La construcción en progreso de una central nuclear en Argentina de 319 MW y la decisión de construir una de 600 MW en Brasil, así como la próxima operación de una planta geotérmica en México de 75 MW son indicios de que estas nuevas fuentes de energía complementarán en algunas regiones a las fuentes tradicionales en un futuro próximo.

La hidroelectricidad, en particular, tiene todavía un futuro considerable en el conjunto de América Latina y muy especialmente en algunos países. Aunque la hidrogeneración representaba aproximadamente el 52 por ciento de la producción total en 1967, en esa misma fecha la capacidad instalada representaba sólo un 2 por ciento del "potencial económico" disponible en toda la región, estimado por la Comisión Económica para América Latina en 320 000 MW, basado en caudales medios [7].

Es interesante terminar esta rápida revisión del panorama energético con algunas predicciones sobre el desarrollo esperado del sector eléctrico en América Latina en la década de 1970. Los países latinoamericanos disponían de una capacidad generadora instalada que alcanzaba a 30 800 MW a fines de 1967, de los cuales el 42 por ciento era hidráulico. Se estima que a fines de 1979 habrán unos 83 000 MW, de los cuales el 50 por ciento aproximadamente será hidráulico. En un año hidrológico normal, la generación hidroeléctrica alcanzaría a 200 000 millones de kWh, lo que dejaría a cargo del sector térmico 130 000 millones restantes, con un factor de utilización similar al de 1967. Finalmente el cuadro II muestra el orden de magnitud de las adiciones que serán necesarias en la década 1970-79, por países [7].

CUADRO II

ESTIMACION DEL ORDEN DE MAGNITUD DE LAS ADICIONES DE POTENCIA EN LA DECADA 1970-79

País	Adición de potencia (en MW)
Argentina	8 000
Brasil	12 100
Centroamérica	2 000
Colombia	3 600
Cuba	1 200
Chile	1 700
México	10 500
Perú	2 900
Uruguay	600
Venezuela	4 100
Otros países	2 300
Total	49 000

PERSPECTIVAS NUCLEOELECTRICAS

El desarrollo de la energía nucleoeléctrica es favorecido fundamentalmente por las ventajas económicas que, todo tomado en cuenta, esta nueva forma de generación eléctrica representa. En estas condiciones, la disponibilidad y costo de los recursos energéticos tradicionales y el tamaño máximo de las unidades que pueden utilizarse en los sistemas eléctricos existentes, resultan factores determinantes para la adopción de centrales nucleares en un país.

La pequeña magnitud en general de los sistemas eléctricos, las distancias entre centros de carga importantes y la disponibilidad de recursos energéticos baratos hacen que la energía nuclear no resulte atractiva todavía para la mayor parte de los países de América Latina. Existen ya, sin embargo, las circunstancias favorables para la utilización de centrales nucleares en las áreas del Gran Buenos Aires - Litoral en la República Argentina, del Centro-Sur de Brasil y del Centro-Sur de México [8], [9].

Hay otras áreas de América Latina donde el alto costo de las fuentes primarias de energía sugiere el empleo de la energía nuclear, especialmente en aquellos casos en que podría pensarse en plantas de doble propósito para la producción de electricidad y agua potable. El pequeño tamaño de las unidades que aun en estas condiciones podrían utilizarse hacen, sin embargo, antieconómica su construcción y habrá que esperar al crecimiento de los sistemas interconectados o al desarrollo, todavía no materializado, de centrales nucleares competitivas de pequeña y mediana potencia [10].

Las diferencias considerables que existen entre países de una región tan vasta y diversa hacen necesario, si queremos profundizar un poco en el futuro nucleoeléctrico de América Latina, considerar los casos particulares de aquellos países que presentan mayores perspectivas, ya sea a corto o a largo plazo. Es innecesario subrayar que las extrapolaciones a largo plazo son de necesidad especulativas y que sólo pueden esperarse cifras razonablemente exactas para previsiones inscritas en la próxima década.

Argentina

La experiencia en el diseño, construcción y utilización de reactores de investigación; la existencia de personal calificado en número y nivel adecuados; la posesión de yacimientos de uranio de importancia apreciable y la conjunción de los parámetros que hacen atractiva la energía nucleoeléctrica, explican probablemente por qué la República Argentina ha sido el primer país de América Latina en iniciar la construcción de una central nuclear.

La central nuclear de Atucha, situada a unos 100 km de Buenos Aires, sobre el río Paraná de las Palmas; tendrá una potencia neta de 319 MW y será interconectada a la red Gran Buenos Aires-Litoral. El reactor es de uranio natural, moderado y refrigerado por agua pesada, dentro de un recipiente de presión. Las características únicas de este recipiente, aunadas a diversas causas propias de toda empresa nueva, han motivado retrasos en el calendario original, de modo que se prevé la entrada en operación comercial de esta central para fines de 1973. Es de señalarse la considerable participación de la industria argentina, no sólo en la obra civil sino también en la fabricación y montaje de componentes electromecánicos, al grado que se estima en alrededor de un 40 por ciento la fracción del costo representada por mano de obra e industria argentinas. La circunstancia de que el combustible sea de uranio natural hace factible que la fabricación de los elementos combustibles pueda ser realizada íntegramente en la Argentina en un futuro próximo.

De aquí a 1980, se prevé la entrada en operación comercial, además de Atucha I, de una unidad de 600 MW en Córdoba y de la unidad Atucha II, de unos 1 000 MW, con lo que la potencia nuclear de Argentina sería del orden de 1 900 MW en esa fecha, constituyendo aproximadamente el 13 por ciento de la potencia total instalada en el sistema interconectado [11].

Es importante hacer notar que, a pesar del precedente de la unidad de Atucha en construcción, no se ha definido en Argentina una política sobre el tipo de los reactores próximos, ni en particular sobre la clase de combustible que se emplearía en ellos.

A partir de 1980, se estima que se agregarán 1 000 MW nucleares cada 2 años hasta 1985, luego 1 000 MW por año y así sucesivamente, de suerte que la potencia nuclear total instalada sería del orden de 5 000 MW en 1985, 10 000 MW en 1990 y 30 000 MW en 2 000, lo que llegaría a constituir, aproximadamente, un 30 por ciento de la potencia eléctrica instalada en todo el país a fines del siglo.

Brasil

El interés por la energía nucleoeléctrica en el Brasil data de muchos años, como lo atestigua el número de estudios realizados al respecto y en particular los grupos de trabajo que, desde mediados de 1967, han estudiado la introducción de centrales nucleares en la región Centro-Sur [12].

En la actualidad, Brasil se encuentra en vísperas de decidir el tipo de central que, con una potencia nominal de 500 MW, se construirá en la playa de Itaorna, municipio de Angra dos Reis, a 133 km al oeste de Río de Janeiro. Esta central se integrará en 1976 en el sistema eléctrico de FURNAS, el que tendrá para entonces una potencia instalada superior a los 5 000 MW y formará parte de un sistema interconectado de unos 13 000 MW [13].

A continuación de la primera unidad nuclear de Angra, se planea ya la construcción de dos unidades más, de modo que la potencia nuclear instalada en Brasil puede ser del orden de 1 500 MW en 1980. Proyecciones realizadas muestran las cifras probables de 6 000, 13 000, 21 000 y 35 000 MW nucleares en la región Centro Sur en los años 1985, 1990, 1995 y 2000, respectivamente. Si a estas cifras se agregan las instalaciones posibles en otras regiones del Brasil, se llega a la potencia de 50 000 MW en el año 2000, lo que constituiría aproximadamente un tercio de la demanda máxima total para esa fecha [14].

Colombia

Colombia es uno de los países de América Latina en los que no se vislumbra ninguna utilización económica de la energía nucleoeléctrica en lo que resta del siglo. En efecto, si bien se prevé que la potencia eléctrica instalada en Colombia será del orden de 20 000 MW en el año 2000, se ha estimado el potencial hidroeléctrico aprovechable en 50 000 MW y existen además reservas considerables de carbón de buena calidad que permitirían complementar con centrales termoeléctricas la hidroelectricidad y lograr así una expansión más económica de los sistemas [15], [16].

Cuba

Las condiciones energéticas de Cuba no son básicamente muy diferentes de las de Puerto Rico, por ejemplo, lo que permite suponer que la energía nucleoeléctrica será atractiva en Cuba en cuanto el tamaño del sistema eléctrico permita la introducción de unidades nucleares suficientemente grandes. Se ha estimado que la potencia nuclear en Cuba puede ser de 400 MW en 1980 y 1 400 MW en 1985 [17].

Chile

El ejemplo de Chile es típico de los países con regiones de relativa importancia, carentes de recursos hidroeléctricos, con combustibles fósiles caros y con necesidades rápidamente crecientes de electricidad y agua potable. Tal es el caso de la región norte de Chile, donde sin embargo la demanda máxima alcanzará un valor de 300 MW en 1975, de modo que sería imposible pensar en una unidad mayor de 75 MW antes de esa fecha [18], lo que con el mercado actual de los reactores de pequeña potencia resulta poco atractivo. Por otra parte, el costo del combustible fósil en esa zona de Chile podría bajar considerablemente si, pese a dificultades previsibles, se abre allí un mercado para el gas natural boliviano. Adicionalmente, existe la posibilidad de que en esa región se desarrollen fuentes de energía geotérmica que servirían tanto para la producción de electricidad como de agua potable.

A más largo plazo, el sistema interconectado Central de Chile, donde la demanda máxima pasará de 3 000 MW en 1985 [18], puede ser un mercado para centrales nucleoeléctricas de tamaño mediano.

México

En México existen planes concretos para la construcción de la primera unidad de una central nuclear que, localizada en el lugar llamado Laguna Verde, sobre el golfo de México, a unos 280 km al este de la ciudad de México, alimentaría a la red del centro-sur del país [19]. Con un valor nominal de 600 MW, la primera unidad entraría en 1976 en un sistema interconectado de más de 6 000 MW, ya que para entonces la conversión del sistema de 50 Hz a 60 Hz estaría virtualmente terminada.

La situación de los energéticos en México y el tamaño de la red centro-sur permiten suponer que la potencia nuclear instalada en esa red se podría duplicar cada 5 años, hasta alcanzar el valor de unos 20 000 MW a fines de siglo, ó 30 por ciento del valor total de la capacidad en el sistema central interconectado.

La creciente interconexión de otros sistemas eléctricos de México, aunada al crecimiento propio de estos sistemas, se traducirá también en la conveniencia de instalar centrales nucleares en otras partes del país que, por el momento, no podrían utilizar económicamente centrales de mediana potencia [20].

Perú

En Perú hay todavía considerables recursos hidroeléctricos por desarrollar pero la existencia de una gran ciudad, Lima, en una zona costera carente de agua, puede hacer atractiva, a mediano plazo, la construcción de una central nuclear de doble propósito.

CUADRO III

PROYECCIONES DE POTENCIA NUCLEAR INSTALADA EN LA AMERICA LATINA

País	Potencia nuclear en GW					
	1975	1980	1985	1990	1995	2000
Argentina	0,3	1,9	5,0	10,0	20,0	30,0
Brasil	0,0	1,5	6,9	16,4	30,0	50,0
Centroamérica	0,0	0,0	0,0	0,0	1,0	2,0
Colombia	0,0	0,0	0,0	0,0	0,0	0,0
Cuba	0,0	0,4	1,4	2,5	5,0	10,0
Chile	0,0	0,0	0,5	1,0	2,0	5,0
México	0,0	1,2	2,5	6,0	12,0	25,0
Perú	0,0	0,0	0,0	1,0	2,0	3,0
Uruguay	0,0	0,0	0,7	1,5	3,0	5,0
Venezuela	0,0	0,0	0,0	0,0	0,0	0,0
Otros países	0,0	0.0	0,0	0,0	0,0	0,0
Total	0,3	5,0	17,0	38,4	75,0	130,0

Así como en el caso de las centrales nucleares las primeras aplicaciones económicas fueron en la forma de unidades relativamente grandes instaladas en sistemas eléctricos de consideración, puede preverse que la desalación de agua de mar se desarrollará a partir de la utilización de plantas desaladoras en los sistemas de agua potable de grandes urbes costeras con escasez de agua, de las que Lima es el mejor ejemplo en Latinoamérica.

Uruguay

El pequeño tamaño de la red eléctrica del Uruguay hace poco probable que, a pesar del costo del combustible fósil, resulte económica la instalación de centrales nucleares en un futuro próximo. Sin embargo, la interconexión del sistema uruguayo con el del litoral argentino a partir de 1976 haría atractiva la participación uruguaya en proyectos de energía nucleoeléctrica [21].

Venezuela

Además de las reservas de hidrocarburos, Venezuela cuenta con un potencial hidroeléctrico considerable que apenas se empieza a explotar, de modo que constituye un caso en que, aun suponiendo la conveniencia económica de colocar la totalidad del petróleo y del gas en el mercado mundial, la energía nuclear tendría por competidor, durante muchos años, la hidroelectricidad barata.

La capacidad instalada en Venezuela en 1979, excluyendo industria petrolera y autoconsumidores, ha sido estimada en 5 000 MW[22]. Una cuadruplicación en 20 años nos llevaría a 20 000 MW en el año 2000, que es del orden de la capacidad hidroeléctrica que ya se ha identificado como utilizable [23].

CONCLUSIONES

El cuadro III, basado en las consideraciones y estudios mencionados, pretende dar una idea del desarrollo de la energía nucleoeléctrica en la América Latina. Puede verse que antes de 1980 esta forma de energía será aplicada en 3 ó 4 países de la región y que en 10 años más, esto es, antes de 1990, presentará un interés económico indudable para no menos de 7 países.

A más largo plazo, las cifras que resultan, por su magnitud, inducen a la reflexión. Es posible que algunos de los valores estimados como "probables" no sean ni siquiera "factibles", si no se planea bien el esfuerzo educativo, tecnológico, financiero y hasta administrativo que su consecución implicaría.

Frecuentemente se atribuyen a la construcción temprana de centrales nucleares en un país beneficios relacionados con la introducción de una tecnología avanzada, de modo que al procurarse una participación nacional máxima, dentro de ciertos límites de costo, se pueden lograr efectos multiplicativos de consideración, tanto en la investigación y la enseñanza como en la ingeniería y la industria. En general, puede decirse que de no existir claras ventajas económicas para la energía nuclear, es poco probable que esos efectos, por sí solos, justifiquen su adopción; en cambio, en aquellos países donde se vislumbre la utilización económica de las centrales nucleares, pueden ser factores importantes que ayuden a aprovechar oportunamente todas las economías que ofrezca la energía nuclear en la generación de electricidad.

Aunque importante, la generación de electricidad no es la única aplicación de la energía nuclear y los reactores de investigación pueden proporcionar beneficios indudables facilitando, directa o indirectamente, el uso de radioisótopos y de la radiación en la industria, la agricultura y la medicina y estimulando el desarrollo científico y educativo de un país.

En todas estas tareas, de envergadura diversa pero con aspectos frecuentemente nuevos, la cooperación internacional y el establecimiento de programas multinacionales de colaboración deberán desempeñar un papel cada vez más importante.

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SURVEY OF AUSTRALIA'S ENERGY DEMAND AND RESOURCES UP TO THE YEAR 2000

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Abstract–Résumé–Аннотация–Resumen

SURVEY OF AUSTRALIA'S ENERGY DEMAND AND RESOURCES UP TO THE YEAR 2000.

The paper outlines the effects of Australia's geography, population distribution, type of economy and political organization on the energy situation in the country. Energy resources are reviewed and statistics are given for historic consumption of the various sources of primary energy. Forecasts are given for future requirements, based on researched data up to the year 1979/80 and on subjective extrapolation beyond this up to the year 2000. A separate section on electricity identifies the features of each of the separate State systems significant in consideration of the prospects for nuclear power in each. The extent and, where available, the cost of known reserves of basic energy resources are given, together with some discussion of the apparent prospects of future significant discoveries.

ETUDE GENERALE DES BESOINS ET DES RESSOURCES D'ENERGIE EN AUSTRALIE JUSQU'A L'AN 2000.

Le mémoire rend compte des effets des caractéristiques géographiques, de la distribution de la population, du type d'économie et de l'organisation politique sur le développement de l'énergie en Australie. Il passe en revue les ressources en énergie et donne des statistiques concernant la consommation d'énergie primaire provenant de diverses sources. Des prédictions sur les besoins futurs sont émises, qui sont fondées sur les résultats de recherches s'étendant jusqu'à l'année 1979/80 et sur des extrapolations subjectives au-delà de cette date et jusqu'à l'an 2000. Une section consacrée à l'électricité décrit les caractéristiques de chacun des réseaux des divers Etats australiens qui présentent une importance en raison des perspectives qui s'y offrent dans le domaine de l'énergie nucléaire. Le mémoire indique également la grandeur et, lorsqu'il peut être déterminé, le coût d'exploitation des réserves connues d'énergie de base et il examine la possibilité que des découvertes importantes soient faites dans le futur.

ИССЛЕДОВАНИЕ ЭНЕРГЕТИЧЕСКИХ ПОТРЕБНОСТЕЙ И РЕСУРСОВ АВСТРАЛИИ ДО 2000 года.

В докладе описывается влияние географических условий , распределения населения, типа экономики и политической структуры Австралии на состояние энергетики в стране. Дается характеристика энергетических ресурсов и приводятся статистические данные, касающиеся истории потребления различных источников основных видов энергии. Делаются прогнозы в отношении будущих потребностей в энергии, основанные на результатах проведенных исследований, охватывающих период до 1979/80 года, и на субъективной экстраполяции для еще более отдаленного периода – вплоть до 2000 года. В разделе, посвященном производству электроэнергии, определяются особенности энергосистем различных штатов с учетом перспектив развития атомной энергетики в каждой из них. Приводятся данные о размерах и, если таковые имеются, о стоимости известных запасов основных источников энергии, причем одновременно рассматриваются перспективы открытия значительных месторождений источников энергии в будущем.

ESTUDIO DE LA DEMANDA Y DE LOS RECURSOS DE ENERGIA EN AUSTRALIA HASTA EL AÑO 2000.

En esta memoria se exponen a grandes rasgos los efectos sobre la situación energética del país de la configuración geográfica de Australia, su distribución demográfica y el tipo de organización política y económica. Se resumen los recursos energéticos y se presentan estadísticas sobre el consumo de las diversas fuentes de energía primaria. Se consideran las previsiones de necesidades futuras utilizando datos basados en estudios que cubren hasta el año 1979/80, así como una extrapolación subjetiva desde entonces hasta el año 2000. Una sección aparte sobre electricidad identifica las características de cada uno de los sistemas energéticos de los diversos Estados australianos, tomándolas en consideración con respecto a las perspectivas de la energía nucleoeléctrica en cada uno de ellos. Se indica la magnitud y, cuando es posible, el costo de explotación de las reservas conocidas de recursos energéticos básicos, y se consideran las posibles perspectivas de futuros y significativos descubrimientos.

1. INTRODUCTION

The Australian Commonwealth comprises an area of almost three million square miles with a coastline of approximately 12 000 miles. The mainland consists of a large arid central area which has relatively well-watered fringes in the north, east and south-east. The bulk of Australia's population of 12 million live in these eastern and south-eastern fringes and the major proportion live in a few large cities. The bulk of Australia's industrial activity is therefore centred on these few large cities.

The Commonwealth is a federation of six States. The Federal Constitution confers specified powers on a central Commonwealth Parliament and leaves the residue of powers to the respective parliaments of the six States. No general responsibility for energy and energy policies is vested in the Commonwealth and consequently this is mainly a matter for the States. The States deal with their responsibilities in these matters through various departments and public authorities, for example: Mines Departments, Electricity Commissions or Gas Authorities.

The general economy is based on private enterprise and many of the energy industries are in the hands of private companies. A notable exception, however, is the electricity industry which, as far as public supply is concerned, is virtually wholly vested in government instrumentalities. In addition, the gas industry is a government undertaking in most but not all States.

Owing to the large distances involved and to historical factors the States have tended where practicable to use their own natural fuel resources to generate electricity. At one time black coal from New South Wales was used extensively by other States but their desire to minimize dependence on energy sources beyond their own control has led to a decline in this usage. Each State has developed its own energy resources. Some of these resources are now approaching the limit of their potential and fundamental changes are therefore in store.

Petroleum oil is in a special category. Until fairly recently all Australian crude oil supplies were imported, and they constituted a very important item in Australia's balance of payments accounts. The Commonwealth Government in a variety of ways has sought to assist in encouraging the exploration for oil in Australia. It has also concerned itself with the development and operation of both the refining and the distributing sides of the industry. In the result in regard to petroleum oil the main Government initiatives lie with the Commonwealth rather than the States.

2. ENERGY RESOURCES

Before considering the major energy resources in turn it may be convenient to set a perspective by indicating the contribution made by each to Australia's total primary energy consumption. In the year ending 30 June, 1970 petroleum products contributed 50%, black coal 32%, brown coal 11.3%, natural gas 1.4% and other sources (wood, hydro, bagasse and natural gas) 5.3%.

2.1. Oil

Australia's total recoverable oil reserves were estimated to be 1792 million barrels at 30 June, 1970. This contrasts very sharply with the position a decade ago when the country was totally dependent on imports of crude oil.

The largest fields so far discovered lie in the Bass Strait region offshore from Victoria. The recoverable reserves of the Barracouta, Halibut and Kingfish fields total 1565 million barrels. These fields are in a favourable position with respect to the large markets of Melbourne and Sydney.

In Queensland current reserves are estimated to be about 5 million barrels. The Moonie field contributes 4 million barrels to this and Alton 1 million.

Barrow Island in Western Australia has reserves of 162 million barrels.

Mereenie in the Northern Territory has reserves of 60 million barrels. Exploitation of these reserves is prejudiced by remoteness from major market centres and lack of sufficient size to justify construction of pipelines.

These reserves are not particularly large when compared with the total consumption of crude oil. The current search for oil must continue and significant discoveries will have to be made to offset the fast rising consumption of petroleum products. At the end of 1971 about 70% of Australia's crude oil requirement could be satisfied by indigenous crude, but this will drop to about one quarter by 1980 unless further reserves are discovered. Many prospective areas have not yet been fully explored and there are grounds for optimism that some of these will prove fruitful. Nevertheless, it is not possible to ignore the prospect that Australia might in the future return to a position of dependence on imported oil to meet its ever-growing demand for liquid fuels.

The Commonwealth Government employs a variety of means to encourage the search for oil both on and offshore Australia.

2.2. Black coal

Deposits of all the main types of black coals are found in Australia. Coals of high calorific value, however, are not known in the central and western part of the continent. High-grade coking and gas coals are confined to the eastern seaboard and this has had a decisive effect on the industrial development of Australia.

New South Wales and Queensland possess large exploitable reserves of bituminous coal which cover almost the entire range from coking to non-coking low-volatile steaming coals, as well as high-volatile gas coals. Most of Australia's bituminous coals are characterized by high ash content but generally low sulphur content. Queensland, in addition to sub-bituminous coals also has some reserves of semi-anthracites and anthracites.

In New South Wales most of the commercial mines are on the edge of the sedimentary basin which extends north, south and west of Sydney.

The Queensland coal fields extend along the coast and in some sections for several hundred miles inland. The fields of the Southern and Central Districts have, because of their geographical advantage, supplied the bulk of domestic requirements in the past, but it is the formations of the central district which are likely to be of greater economic importance through their export potential.

Victorian deposits of bituminous coal are small although very large reserves of lignite exist.

In Tasmania black coal deposits occur over a wide area but they appear as small isolated fields due to faulting and erosion. The range varies from brown coal to sub-anthracite. Most seams are high in ash and include bands of mudstone.

In South and Western Australia the highest ranking coals are sub-bituminous. The only source of coal at present exploited in South Australia is the sub-bituminous coal of Leigh Creek. This deposit is worked by open-cut methods and is fully committed for electricity generation.

In Western Australia the only deposits exploited extensively are the sub-bituminous Collie deposits, worked by both underground and open-cut methods. Costs are high by eastern States standards.

Australia is known to have at least 7000 million tons of black coal and the prospects are that additional reserves will be discovered. A part of the reserves will probably be non-recoverable within economic limits. Nevertheless, as current usage is less than 50 million tons per annum it is clear that on a national basis the reserves to consumption ratio is satisfactory. This is not to say, however, that there is no need for conservation and proving of additional reserves.

In the first place long-term sufficiency of high-quality and inexpensive black coal has been established only for the States of Queensland and New South Wales. Tasmania and South Australia in particular are seriously deficient in indigenous black coal and the Western Australia resources are not of high quality. Discovery of new deposits in these States would be welcome although the prospects of this are not regarded as high.

Secondly, the adequacy of reserves of specific coals is in doubt. In particular it is thought that Australia would benefit from the proving of additional sources of coking coal for which there is a strong domestic demand and a large and growing export market, particularly in the Japanese iron and steel industry.

Table I shows the reserves of coal for each State as at 30 June, 1969.

2.3. Brown coal

Although deposits of brown coal (otherwise known as lignite) are known to occur in New South Wales and South Australia, Victoria is by far the largest producer and consumer of brown coal in Australia.

Victorian brown coal reserves are principally in the Latrobe Valley and are calculated at 47 500 million tons proved and 37 300 million tons inferred making a total of about 85 000 million tons. Of the proved reserves 29 000 million tons has less than 100 ft of overburden over the uppermost seam and so are readily worked by open-cut methods.

Estimated proven reserves of brown coal in areas other than the Latrobe Valley are estimated at 750 million tons.

Because of the low calorific value of brown coal, the proportion of reserves which can be economically mined using open-cut techniques is very significant. Using the open-cut techniques now employed in the Latrobe Valley, the amount that could be won is about 10 000 million tons.

TABLE I. BLACK COAL

State	Reserves in situ (10^6 t)
New South Wales	4365
Queensland	1890
Western Australia	300
South Australia	380
Tasmania	n.a.
Victoria	30

TABLE II. NATURAL GAS RESERVES, RECOVERABLE PIPELINE GAS (10^{12} standard cubic feet)

Basin	Field	State	Estimated reserves at 31.12.69
Bowen-Surat	Roma-Rolleston Area	Queensland	0.223
Adavale	Gilmore	Queensland	0.028
Gippsland	Barracouta, Snapper, Marlin, Flounder, Tuna, Halibut, Kingfish	Victoria	10.019
Cooper	Gidgealpa, Moomba Daralingie	South Australia	1.460
Perth	Dongara, Mondara, Yardarino, Gingin	Western Australia	0.500
Carnarvon	Barrow Island	Western Australia	0.130
Amadeus	Mereenie, Palm Valley	Northern Territory	1.567

A continued growth of consumption at the average rate of the last 25 years (a steady 5.5% annually) gives a lifetime of about 60 years to the present 10 000 million tons of mineable reserves.

2.4. Natural gas

The search for oil in Australia has led to the discovery of several significant natural gas fields and has therefore made available to the local energy market a source of energy which is new although similar of course to the manufactured gas distributed in major towns and cities primarily for domestic use.

The estimated reserves and the location of all natural gas fields so far discovered in Australia are listed in Table II. The Roma, Gippsland, Gidgealpa and Moomba reserves are currently being exploited and plans are in hand for the exploitation of more of the fields.

2.5. Hydro power

Because of the generally low rainfall and limited areas of high relief, Australia is not well endowed with hydro resources. Total annual run-off is only 1.8 in. compared with 9.8 in. for all land areas of the globe. Thirty-eight percent of the area of Australia receives less than 10 in. of rainfall a year and a further 20% receives less than 15 in. Tasmania is the only State where a significant portion of the total area (56%) receives an annual rainfall in excess of 40 in.

On the mainland most of the potential is concentrated in that part of the Eastern Highlands lying in southern New South Wales, northern Victoria, and in northern Queensland. There is no hydro resource in South Australia and very little in either Western Australia or the Northern Territory.

Tasmania, with a surface area of only 26 000 square miles, is estimated to have about half of the total Australian hydro potential of about 23 000 million kWh/yr capable of being developed economically. This is due to a combination of heavy rainfall and a considerable area at altitudes of between 2000 and 4000 ft.

Total installed hydro capacity in Australia was 3623 MW on 30 June, 1969.

Despite the paucity of hydro potential, there are prospects that the technology will find application in the development of pumped storage schemes to assist in meeting the continually growing demand for peak load power.

2.6. Tidal power

Tidal power represents another possible major energy resource. The bays and estuaries in the Kimberley area of north-west Australia are estimated to have a tidal potential of some 300 000 MW at 50% load factor. However, exploitation of the resource is not imminent principally because of the vast distance separating it from major load centres.

The development of these tidal power resources, however, might well be undertaken ultimately in association with mineral developments in nearby areas.

2.7. Nuclear power

Australia's reserves of uranium remained fairly static for most of the last decade but recently there has been an upsurge in exploration activity. This exploration activity has been successful and the known reserves have been increasing rapidly over the last few years.

In 1967 the reported reserves were only about 15 000 short tons of U_3O_8 but by the end of 1969 they had risen to an estimated 28 000 short tons U_3O_8. Two major discoveries in the Northern Territory have recently lifted the reserves to around 130 000 short tons. Thus in only a very short time Australia has moved from a position in which there was a shortage of uranium reserves to a position where there is a comparative abundance.

There is no reason to believe that Australia's reserves will not continue to increase as a result of further exploration activities.

Known reserves are in general located remote from major centres of population but this is no great disadvantage in the case of such a concentrated energy source.

2.8. Wood

Wood had been a traditional source of fuel from the very early days of settlement, both for household consumption and rural industry. In recent years, however, its use has declined rapidly in the face of competition from more convenient types of fuel.

Most types of wood have a low calorific value, similar to that of brown coal, although some species of Australian hardwood, when thoroughly dried, have a calorific value approaching that of the lower grades of black coal.

2.9. Bagasse

Bagasse is the fibrous residue resulting from the crushing of sugar cane to extract raw sugar. The material is bulky, has a low calorific value (3000 Btu/lb) and is difficult and costly to transport. Bagasse provides the bulk of all energy consumed by Australian sugar mills, being used to produce both process steam and electricity. As such it is important in the cane industry but, although some sugar mills supply excess electricity to public supply systems, this source of energy is not really significant in the over-all energy situation.

3. PRIMARY ENERGY CONSUMPTION

Consumption of primary energy in Australia for the years 1960-61 and 1964-65 to 1969-70 is given in Table III which also shows forecasts up to the year 1979-80, subdivided for each of the major sources. The percentage contribution from the major individual energy sources is outlined in Table IV.

Total consumption of primary energy in Australia has risen from about 1140×10^{12} Btu in 1959-60 to 1955×10^{12} Btu in 1969-70. The average annual rate of increase has been about 5.7% p.a.

Nuclear power has not been used in Australia up to this time. The main reason for this has been that so far it has not been competitive with the low-cost conventional fuels which are available.

4. FORECAST PRIMARY ENERGY CONSUMPTION

Forecasts have been made of future consumption of the principal primary energy sources in Australia up to the year 1979/80 based on the premises that current economic trends continue throughout the period, and that no unforeseen technological change will have a major influence in fuel demands within the period.

Certain other assumptions were necessary (e.g. the advent of new steel-making plants) and the accuracy of the forecast energy totals will depend on the extent to which these are realized. Further, the relative

TABLE III. CONSUMPTION OF PRIMARY ENERGY. AUSTRALIA.
(Expressed in Btu × 10^{12})

Fiscal year	Black coal	Brown coal	Petroleum[a] products	Wood	Bagasse	Natural gas	Hydro and nuclear electricity	Total
Actual								
1960-61	503.0	138.3	457.7	59.1	19.3	-	15.9	1193.3
1964-65	541.8	169.9	641.9	49.0	29.6	0.12	28.5	1460.8
1965-66	561.3	191.7	701.6	46.7	28.9	0.15	24.1	1554.4
1966-67	567.5	201.6	763.3	44.4	35.0	0.15	26.5	1638.4
1967-68	591.7	209.4	833.4	42.0	29.7	0.2	26.2	1732.6
1968-69	607.4	211.0	919.0	40.7	31.4	1.1	28.2	1838.8
1969-70	629.0	222.8	975.6	38.5	32.0	27.5	30.8	1956.2
Forecast								
1970-71	667.2	225.0	1022.5	37.1	32.7	53.7	38.9	2077.1
1971-72	705.8	234.2	1078.3	35.7	33.4	81.2	39.6	2208.2
1972-73	761.4	241.7	1143.1	34.4	34.0	111.6	42.0	2368.2
1973-74	807.8	259.1	1204.9	33.6	34.7	135.7	43.2	2519.0
1974-75	841.2	276.3	1294.4	32.6	35.4	161.0	44.4	2685.3
1975-76	870.3	287.5	1392.2	31.8	36.1	182.6	47.6	2848.1
1976-77	893.3	308.2	1476.7	30.7	36.9	222.9	61.6	3030.3
1977-78	932.3	315.8	1565.9	29.8	37.7	261.9	63.8	3207.2
1978-79	979.7	322.8	1664.1	29.2	38.5	295.3	64.8	3394.4
1979-80	1050.0	332.2	1771.0	28.6	39.3	333.6	66.0	3620.7

[a] Used as fuel.

TABLE IV. CONSUMPTION OF PRIMARY ENERGY. AUSTRALIA.
(Expressed as per cent of total)

Fiscal year	Black coal	Brown coal	Petroleum[a] products	Wood	Bagasse	Natural gas	Hydro and nuclear electricity	Total
Actual								
1960-61	42.1	11.6	38.4	5.0	1.6	-	1.3	100
1964-65	37.1	11.6	43.9	3.4	2.0	0	2.0	100
1965-66	36.1	12.3	45.1	3.0	1.9	0	1.6	100
1966-67	34.7	12.3	46.6	2.7	2.1	0	1.6	100
1967-68	34.2	12.1	48.1	2.4	1.7	0	1.5	100
1968-69	33.1	11.5	50.0	2.2	1.7	0	1.5	100
1969-70	32.2	11.4	49.8	2.0	1.6	1.4	1.6	100
Forecast								
1970-71	32.1	10.8	49.2	1.8	1.6	2.6	1.9	100
1971-72	32.0	10.6	48.8	1.6	1.5	3.7	1.8	100
1972-73	32.2	10.2	48.2	1.5	1.4	4.7	1.8	100
1973-74	32.1	10.3	47.8	1.3	1.4	5.4	1.7	100
1974-75	31.3	10.3	48.2	1.2	1.3	6.0	1.7	100
1975-76	30.6	10.1	48.8	1.1	1.3	6.4	1.7	100
1976-77	29.5	10.2	48.7	1.0	1.2	7.4	2.0	100
1977-78	29.1	9.8	48.8	0.9	1.2	8.2	2.0	100
1978-79	28.9	9.5	49.0	0.9	1.1	8.7	1.9	100
1979-80	29.0	9.2	48.9	0.8	1.1	9.2	1.8	100

[a] Used as fuel.

contribution from the different sources can be in error according to the variation from estimates of the acceptance of natural gas and nuclear energy, forecasting of which is somewhat speculative.

In general, however, the estimates are assigned high confidence since they are the result of careful study with particular attention to the industrial market for fuels. Major users were contacted regarding their future consumption expectations – these accounted for 85% of consumption in the industrial sector. Another 9% was established by reference to published statistics. The balance of the industrial sector, commercial customers and the residential market are amenable to prediction on the basis of past growth-rates.

The estimates show growth-rates for total primary energy varying from about 5 to 7.5% p.a. with an over-all trend of about 6.2% cumulative, corresponding to an increase in consumption of 85% by the year 1979/80.

The growth-rate is greatest in the sparsely populated Northern Territory where current consumption is expected to increase fourfold by 1979/80 but, of course, from a very low base. Western Australia is estimated to double and Queensland to increase by 76%. Growth-rates in Tasmania, New South Wales, South Australia and Victoria will be somewhat less than the average.

Inter-fuel sharing of the market is not expected to change as dramatically as in the past. The estimates predict that coal will decline from 43 to 38% of the total market. Natural gas will likely capture something like 9% of the total market by the end of the period and liquid petroleum products will maintain about 49% of the total.

Projection past 1980 must necessarily be very subjective because of the uncertainties which are involved. The projected consumption in 1980 has been taken and extrapolated at the average yearly (compound) expansion rate for the previous 20 years (6%). This method gives an expected consumption in the year 2000 of about $11\,300 \times 10^{12}$ Btu.

The breakdown of this expected consumption between the various fuels is not attempted because of the number of unknown factors involved in any such prediction. For example the impact of nuclear generation on consumption of all the other fuels cannot yet be evaluated with any certainty in Australia. The discovery of important new energy resources (natural gas or oil fields) or of the development of new methods for supplying energy needs (e.g. fast-breeder reactors) cannot be anticipated with confidence concerning the timing of their advent.

Nevertheless it is clear that Australia, with the possible exception of crude oil, has ample traditional resources of energy for sufficient time to permit the development to the sophisticated energy production techniques that will undoubtedly be discovered in the future.

5. NUCLEAR GENERATION IN AUSTRALIA

As outlined earlier in this paper the generation of electricity in Australia is a State responsibility. Each of the States discharge their responsibility through a public Authority and in all States with the exception of Queensland generation is carried out by a single body. The only exception to this is generation in remote areas which is often carried out by a local body.

In the following paragraphs the prospect for nuclear generation and for growth of generating capacity in each of the major generating networks is discussed on a State by State basis. As 500 MW is considered the minimum size for which nuclear generation will be economic, the time at which it is expected that each State will be able to install this size unit, and the number of 500-MW units which could be installed between that time and the end of the century is indicated. It should be noted that all units installed will not be 500 MW but rather this size is used as a "yardstick" to indicate the expected growth in each system.

5.1. New South Wales

New South Wales has the largest generating system in Australia (4500 MW) and furthermore it is interconnected with the Victorian system by a strong transmission link. It is currently planning for the installation of 660-MW steam sets and therefore could accept even larger nuclear sets by the time they could be operational. The system is expected to require the equivalent of about 19 × 500-MW units between now and 1980 and the equivalent of a further 109 units by the end of the century.

As outlined previously, New South Wales is well endowed with good quality coal and the cost of this coal is very low by world standards.

Nuclear generation has an advantage, relative to coal-fired stations, of flexibility of siting. Sources of coal are fairly remote (150 miles) from the main load centres. The location of fuel does not influence the siting of nuclear reactors which may therefore be located closer to the load centres.

The relative economics of conventional and nuclear generation will therefore depend on the availability of sites, the cost of transmission and the relative cost of the alternative fuels, all influenced by cost escalation factors which cannot be assumed to have equal influence on both alternatives. The prospect in general is that nuclear generation will achieve economic superiority sometime in the latter half of the 1970s decade.

Notwithstanding the above, the Commonwealth Government has decided to adopt a leading function in relation to introduction of nuclear power into Australia and has decided to construct a station of about 500 MW capacity. Although to be located on Commonwealth Territory, the station will feed its output into the New South Wales transmission system.

5.2. Victoria

This State has an electrical system of about 3000 MW and is interconnected with the even larger New South Wales system. The largest sets which are currently planned for installation are 350 MW. The Victorian system has now reached the stage where it would be large enough to accept 500-MW units by the time they could be planned, constructed and commissioned. This system will require the equivalent of about 9 such units by 1980 and about 40 by the end of the century.

Most generation depends on brown coal. As outlined before, the reserves are enormous and large-scale winning has resulted in low extraction costs. There are two practical disadvantages to the use of brown coal as a fuel; the expensive boiler maintenance and the possibility of an upper limit to the size of individual boilers. These limitations, together with lack of flexibility of siting, may eventually lead to the point where nuclear power or oil could compete with brown coal.

The effects of the introduction of natural gas on the electrical load growth and the availability of this fuel for electricity generation purposes (particularly for low-capacity factor operation) introduce further uncertainties into the Victorian energy situation. Until they are more fully appreciated their effects on the prospects for nuclear generation cannot be evaluated properly.

5.3. South Australia

The State system in South Australia is a much smaller system of 970 MW. On the other hand South Australia lacks local fuel resources. Discovery of natural gas has alleviated the position but this may be temporary; more valuable uses for the natural gas may be found. In any case the high cost of pipelines results in a fuel cost with which nuclear power might well compete if its costs can be decreased by technological developments.

The prospects for nuclear generation in South Australia are quite good; the only serious limitation is that the system is not yet large enough to be able to accept a plant in the 500-MW range. If the current expansion rate continues it may not be until the late 1990s that the South Australian system is large enough to accept such units.

5.4. Western Australia

This State also suffers from lack of high-quality low-cost indigenous fuel and its new generating stations are designed to burn fuel oil. Natural gas has been found but there have been no plans made yet for its use in base load power stations. Nor would such use be completely logical in view of the comparatively small size of the gas reserves at present established.

The electrical system is small (585 MW) but it is growing at a very rapid rate and it is expected that if this continues the system will be large enough to accept 500-MW units early in 1990s. This high growth-rate imposes a strain on capital resources which might be aggrevated if moves were made towards nuclear plants of higher specific capital cost. The system also suffers from another problem: that is, the system night load is growing at a rate much less than that for the peak load. Energy production from base load units is therefore restricted and this might upset the economics of any nuclear plant of reasonable rating.

Major mineral developments exist in the north of the State but are remote from the main electrical system. It is unlikely that nuclear generation could be used to provide power to these areas in the immediate or middle future. (On the other hand, in a long-term view, nuclear power could well be appropriate for development of this area in respect of greater processing of the mineral resources before export.)

Western Australia is not a good immediate prospect, in spite of a lack of indigenous fuel. The small size of the system should make oil-fired generation competitive for some time. The price levels of furnace fuel oil from the Middle East could be an important factor.

5.5. Tasmania

This State has a hydro-electric system but is installing an oil-fired thermal station to supplement the hydro potential. The low capital cost hydro sites have already been developed and there is no doubt that in time the capital intensive nature of hydro will find competition from nuclear power.

On an installed capacity basis (1000 MW) the system is not large and its growth-rate is less than those of the other systems. On a simple projection basis, the capacity will not reach 5000 MW until about 1995 and so early prospects for a nuclear reactor of 500 MW rating are slight.

5.6. Queensland

This State is divided into three separate electrical systems. Work is currently in hand to interconnect two of these systems and no doubt in time they will all be interconnected. If the interconnections are of sufficient strength the system might be able to accept 500-MW units by around 1985. Between that time and the end of the century such a system would require the equivalent of about 17 such units. However, the State is well endowed with cheap high-quality coal. In fact at several of the central Queensland coal fields, steaming coal is removed as overburden to permit export of underlying coking quality coal. The prospects for early introduction of nuclear generation in this State are therefore not good.

5.7. Cost of energy

At least in respect of the eastern States of Australia, the basic cost of energy is controlled by the availability of high-quality coal. Its price varies from mine to mine, but a mine mouth price as low as 20 ¢/10^6 Btu is not uncommon. In some locations the cost is even lower, down to about 15 ¢/10^6 Btu in the case of special-purpose development.

Transport costs increase the price of coal to consumers remote from high-grade deposits and in the States not endowed with such resources the price of fuel oil is often the controlling factor. A typical price for fuel oil at seaboard locations has been in the range 30 - 35 ¢/10^6 Btu, the actual price being determined according to quantity and precise location. There has, however, been a recent trend towards sharply increasing crude oil prices and this is expected to result in higher prices for fuel oil on the world market.

Natural gas is available in Brisbane, Melbourne and Adelaide. Prices vary from field to field but would be in the range 15 to 30 ¢/10^6 Btu ex treatment plant. Price to individual consumers will be particularly sensitive to quantity required and would include costs of transmission and distribution.

Uranium is available in ample quantities to cater for the prospective domestic requirement and to permit significant export. Prices are not publicized but some deposits are of particularly high grade and costs competitive on the world market are assured.

It is clear that some locations in Australia may be regarded as areas of basically low energy cost by world standards. Continuing future development is not prejudiced by any national scarcity of energy resources. That is not to say that problems do not exist in respect of energy. These problems, however, relate to geography, distribution of population, requirements for energy in particular forms and availability of capital.

PROJECTED ROLE OF NUCLEAR ENERGY IN MEETING FUTURE ENERGY NEEDS IN AUSTRALIA

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Abstract–Résumé–Аннотация–Resumen

PROJECTED ROLE OF NUCLEAR ENERGY IN MEETING FUTURE ENERGY NEEDS IN AUSTRALIA.

A summary is given of the fuel resources in Australia including the development of new deposits of oil, gas, and nuclear fuels over the last several years. Existing electricity generating arrangements are described for each State including the types of fuel used and the outlook for the use of black and brown coal, oil, hydro, and natural gas. Electricity demand and demand growth are summarized. The introduction of nuclear power into Australia is discussed. The proposed nuclear power station at Jervis Bay will be the first commercial nuclear plant installed and the station is expected to be in operation by 1976. Nuclear power should be competitive with conventional stations in the majority of States by the mid-1980s when additional nuclear power stations are expected to be in operation.

MESURE DANS LAQUELLE L'ENERGIE NUCLEAIRE POURRA REPONDRE AUX BESOINS FUTURS D'ENERGIE EN AUSTRALIE.

Le mémoire passe rapidement en revue les ressources australiennes en combustibles et décrit les recherches effectuées pendant ces dernières années concernant de nouveaux gisements de pétrole, de gaz et de combustibles nucléaires. Il décrit les méthodes adoptées par chaque Etat pour la génération d'électricité, les types de combustibles utilisés et les perspectives d'utilisation du charbon, du lignite, du pétrole, de la houille blanche et du gaz naturel. Il rend compte de la demande d'électricité et de sa progression. L'introduction de l'énergie nucléaire en Australie est discutée. L'usine de Jervis Bay sera la première centrale nucléaire commerciale installée; on prévoit qu'elle sera en service en 1976. Les centrales nucléaires devraient être en mesure de concurrencer les usines classiques dans la majorité des Etats vers le milieu des années quatre-vingts, date à laquelle on s'attend que d'autres centrales nucléaires encore seront en service.

РОЛЬ ЯДЕРНОЙ ЭНЕРГИИ В УДОВЛЕТВОРЕНИИ БУДУЩИХ ЭНЕРГЕТИЧЕСКИХ ПОТРЕБНОСТЕЙ АВСТРАЛИИ.

Дается краткое описание топливных ресурсов Австралии, включая разработку новых запасов нефти, газа и ядерных видов топлива за последние несколько лет. Описывается деятельность каждого штата в области производства электроэнергии, включая виды используемого топлива и перспективы использования каменного и бурого угля, энергии рек и природного газа. Суммируются потребности в электроэнергии и их рост. Рассматривается вопрос о развитии ядерной энергетики в Австралии. Атомная электростанция, которую планируют построить в Джервис-Бее, будет первой коммерческой АЭС в Австралии; полагают, что эта станция будет пущена в эксплуатацию к 1976 году. Атомные станции будут конкурентоспособными с обычными электростанциями в большинстве штатов страны к середине 80-х годов, когда, как ожидают, вступят в эксплуатацию новые АЭС.

UTILIZACION PROYECTADA DE LA ENERGIA NUCLEAR PARA SATISFACER LAS FUTURAS NECESIDADES ENERGETICAS DE AUSTRALIA.

Se describen brevemente los recursos de combustibles en Australia incluyendo los descubrimientos durante los últimos años de yacimientos de petróleo, gas y combustibles nucleares. Se describen las instalaciones existentes de generación de electricidad en cada Estado, incluyendo los tipos de combustibles utilizados y las perspectivas para el empleo de hulla, lignito, petróleo, recursos hidráulicos, y gas natural. Se resume la demanda de electricidad y el previsible crecimiento de esa demanda. La memoria describe la introducción de la energía nuclear en Australia. La central nucleoeléctrica proyectada en Jervis Bay será la primera planta nuclear comercial, y se espera que entre en funcionamiento antes de 1976. El costo de energía nucleoeléctrica deberá poder competir con el de las centrales convencionales en la mayoría de los Estados a mediados del decenio de 1980 en que se espera que estén ya en operación otras centrales nucleoeléctricas.

1. INTRODUCTION

Until the turn of the century it is unlikely that nuclear energy will be used to any significant extent in Australia for purposes other than electric power generation. In Australia thermal power stations (with an installed capacity of 10 190 MW(e)) at present provide over 80% of the electrical energy generated. The remainder is supplied by hydro plant with an installed capacity of 3760 MW(e). Generation and supply is largely under the control of central statutory bodies in each State; these produce 97% of the electricity consumed. The balance is provided mainly by diesel generating plant serving remote communities.

Coal is the main fuel used in New South Wales, Victoria and Queensland. In South Australia and Western Australia coal is at present the major fuel used, but plant under construction or planned in these States will use oil or natural gas. Tasmania up to the present has depended entirely on hydro-electric power, but in 1971 the first 120-MW(e) unit of an oil-fired thermal power station will come into operation. However, Tasmania still has considerable untapped hydro resources. The Snowy Mountains Hydro-electric Scheme serves New South Wales and Victoria, and by 1974 the final unit will be brought into operation.

The amount of electrical energy generated in Australia has increased at an average rate of 9.5% p.a. over the period 1950 to 1970, and the installed capacity of generating plant increased at the rate of 10% p.a. By the year 2000 the installed capacity in Australia will exceed 100 000 MW(e) based on present trends, and it is estimated that nuclear plant could account for 30% of this capacity.

2. ENERGY REQUIREMENTS AND RESOURCES

At present the major consumers of primary energy in Australia are industry (40%), transport (27%), electrical power generation (27%), with the remainder, (6%), made up of agricultural, domestic and commercial users. Consumption of primary energy in Australia is shown in Table I [1, 6] for the financial year 1968-69. Petroleum products represent the major source of energy consumed followed by black and brown coal. In the electrical generating industry about 90% of the primary energy consumed comes from black and brown coal, whilst consumption of petroleum products and natural gas is comparatively low.

The proven reserves of primary resources in Australia are shown summarized in Table II [1-5]. Proven reserves are considered here to represent the quantity of fuel which is economically recoverable from known deposits under existing conditions.

Recoverable black coal reserves in Australia are currently estimated at 5000 million tons, of which 60% are located in New South Wales and about 30% in Queensland. The remainder is mainly located in South Australia and Western Australia but economically recoverable reserves are largely committed to existing power stations. Brown coal reserves are mainly located in the Latrobe Valley, Victoria. Total reserves of brown coal would be about seven to eight times the proven reserves shown in Table I, but these resources have been extensively investigated and the figure for proven reserves (10 000 million tons) is the quantity believed to be economically recoverable by open-cut mining.

TABLE I. CONSUMPTION OF PRIMARY ENERGY FOR YEAR 1968-69 (10^{12} Btu)

	Black coal	Brown coal	Petroleum products	Natural gas	Wood bagasse	Hydro	Total
Electrical generation	278.9	165.0	27.2	0.1	2.6	28.2	502.0
Other	327.7	48.6	892.6	1.0	69.5	-	1339.4
Total	606.6	213.6	919.8	1.1	72.1	28.2	1841.4

TABLE II. PRIMARY RESOURCES OF AUSTRALIA
Proved reserves (10^{12} Btu)

	Black coal	Brown coal	Oil	Natural gas	Total
New South Wales	90 000	-	-	-	90 000
Victoria	-	89 000 [a]	9 660	10 000	108 660
Queensland	39 000	-	27	250	39 277
South Australia	1 340 [a]	-	-	1 460	2 800
Western Australia	5 380	-	1 050	630	7 060
Tasmania	-	-	-	-	-
Northern Territory	-	-	375	1 570	1 945
	135 720	89 000	11 112	13 910	249 742

[a] Economic recoverable reserves using the open-cut technique.

Uranium – Northern Territory· Approximately 130 000 tons U_3O_8 indicated.

Current proven reserves of oil at the end of 1969 were estimated to be about 1800 million barrels, and reserves of natural gas were estimated to be about 14 trillion (10^{12}) ft^3. The major portion of these reserves (95%) is located in Victoria, but significant reserves also exist in Western Australia, South Australia and the Northern Territory.

Known resources of uranium in Australia have increased significantly in recent years and indicated reserves are now in excess of 130 000 t. Most of this is located in the Northern Territory. The value of this material as a primary energy source will range between 70×10^{15} and 40×10^{17} Btu, depending on the type of reactor plant (e.g. thermal or breeders) in which it is used.

Hydro-electric resources are confined almost exclusively to the eastern States of Queensland, New South Wales, Victoria and Tasmania. Of these the largest scheme is located in the Snowy Mountains in New South Wales, and in 1974, when the final unit is scheduled for operation, the total installed capacity will be 3740 MW. No additional plant is planned for construction. In Tasmania only about one third of the hydro resources has been developed. Outside Tasmania there is little scope for further economic development.

From the foregoing it is apparent that, whilst Australia is relatively well endowed in terms of primary energy reserves, the distribution and balance of these reserves leave much to be desired in a continent of this size. For example, some 95% of the primary resources are located in the eastern States of Queensland, New South Wales and Victoria, and some 90% of the total resources are made up of black and brown coal, excluding uranium.

3. ELECTRICAL POWER GENERATION

The electricity supply industry in Australia is organized on a State basis with, at present, little transfer of energy between the various States other than Victoria and New South Wales. Power from the Snowy Mountains Hydro-electric Scheme, located in New South Wales, is fed to the New South Wales and Victorian systems. At some future time it can be expected that the Victorian and South Australian systems will be interconnected and likewise New South Wales and Southern Queensland. The Western Australian system is likely to remain isolated because of the vast distances between major load centres in the East and the West. A scheme to interconnect the Tasmanian and Victorian systems has been examined but is considered uneconomic at present.

The electrical power generation industry in Australia has expanded at a high and consistent rate. Table III shows the increase in installed plant capacity, electricity generated, and consumption per capita for the financial years 1949-50 to 1969-70. In this period the installed plant capacity has increased by an average of 10% p.a., electricity generated by 9.5% p.a., and consumption of electricity per capita by 7% p.a. There is reason to believe that a high rate of increase will continue for some time.

Some statistics for the Australian electrical power industry are shown in Table IV [7, 10]. Coal-fired plant predominates in the States of New South Wales, Victoria and Queensland, followed by hydro installations located mainly in New South Wales (Snowy Mountains Scheme) and Tasmania.

TABLE III. INSTALLED CAPACITY, GENERATION AND CONSUMPTION OF ELECTRICITY IN AUSTRALIA

	Year 1949-50	Year 1959-60	Year 1969-70
Installed capacity (MW)	2084	5618	13 954
Electricity generated (millions kWh)	8402	21 449	49 458
Consumption (kWh/capita)	1044	2111	3 974

Approximately 90% of the installed power plants in Australia are located on or near the eastern seaboard of the continent, leaving the very large areas of Western Australia, South Australia and the Northern Territory with the remaining 10%. Both Western Australia and South Australia have a large proportion of plant which utilizes indigenous coal, but the capacity of this plant is at present at or near the maximum for the reserves available. Future plant in these two States will be based on oil and/or natural gas, as will also be the case in the Northern Territory. Production of Australian crude oil will not be sufficient to satisfy power station requirements, and there will therefore be a continuing need to import residual oil or even crude for boiler use. Because Australia, in common with other countries, would have little control over the availability and price of imported oil there is some incentive to use natural gas rather than fuel oil if it is available. South Australia already uses a substantial amount of natural gas for power production. At a later stage it is expected that Victoria will install some natural-gas-fired plants.

In New South Wales, Victoria and Queensland the larger coal-fired plants are at present located on or near the coal fields where relatively low-cost fuel is available. Coal costs which were relatively stable for a number of years are now increasing in line with movements in general price levels [8]. Oil prices are usually negotiated on the basis of long-term bulk supply and the prices are not disclosed by the individual States. However, these are expected to be within the range of 35 to 40 ¢/10^6 Btu[1]

New power stations either under construction or committed for construction in the various States are listed in Table V. Unit sizes vary from 660 MW(e) in New South Wales to 120 MW(e) in Tasmania and down to 25 MW(e) in the Northern Territory. The largest brown-coal-fired unit boiler size at present being installed in Victoria is 350 MW(e), but it is expected that units of 500 MW(e) will be installed before 1980.

The completion of Tumut-3 hydro plant in 1974 will mark the final phase in the Snowy Mountains Hydro-electric Scheme. The output from the Snowy Mountains Authority stations is shared by New South Wales and Victoria in the proportion of 2 to 1 after allowing for the Australian Capital Territory's entitlement. The Tumut-3 station will incorporate pumped storage. With the completion of the Snowy Mountains Scheme in 1974,

[1] All currency expressed in US dollars.

TABLE IV. AUSTRALIAN ELECTRICITY STATISTICS 1969-70

	NSW	VIC.	QLD	SA	WA	TAS.	SMA	NT	Total
1. Generating plant installed (MW)									
Steam – Coal-fired	4 299	2 427	1 461	335	373	-	-	-	8 895
– Oil, natural gas (wood)	-	146	-	600 (22)	155	-	-	47	970
Hydro	140	334	136	-	2	992	2 160	-	3 764
Internal combustion	40	6	36	14	55	5	-	14	170
Gas turbine	-	-	115	-	-	40	-	-	155
	4 479	2 913	1 748	971	585	1 037	2 160	61	13 954
2. Electricity generated (10^6 kWh)	17 377	12 676	5 327	4 164	2 349	5 025	2 367	173	49 458
3. Average price to consumers (mills/kWh)	21.4	23.2	25.1	19.9	24.9	9.2[a]			
4. Fuel consumed									
Black coal (10^3 t)	7 200	-	2 405	2 124	1 017	-	-	-	12 746
Brown coal (10^3 t)	-	18 462	-	-	-	-	-	-	18 462
Petroleum products (10^3 t)	37	36	27	299	181	4	-	54	638
Natural gas (10^6 ft^3)	-	-	125	5 375	-	-	-	-	5 500
5. Average cost of fuel (¢ / 10^6 Btu)									
Black coal	19	-	31	24	27	-	-	-	
Brown coal	-	18	-	-	-	-	-	-	
Oil	-	-	-	-	-	-	-	-	
Natural gas	-	-	-	30	-	-	-	-	

[a] 70% of energy sales were in bulk and involved no distribution costs

TABLE V. NEW POWER STATIONS IN AUSTRALIA

State or Authority	Station	Capacity (MW(e))	Commissioning period	Estimated capital cost [a] (US $/kW)
New South Wales	Liddell	4 x 500	1973-76	
	Wallerawang	1 x 500	1974	
	Vales Point	2 x 660	1977-79	
	Shoalhaven	2 x 41)	1976	
	(Pumped storage)	2 x 82)		
Victoria	Hazelwood	8 x 200	8th 1971	168
	Yallourn W	2 x 350	1972-74	168
Queensland	Swanbank	4 x 120	1970-73	142
	Gladstone	4 x 275	1974-76	150
	Collinsville B	2 x 60	1974-77	206
South Australia	Torrens Island A	4 x 120	4th 1971	
	Torrens Island B	4 x 200	1975-1980	123
	Dry Creek	3 x 52	1972-74	73
		(Gas Turbine)		
Western Australia	Kwinana	4 x 120	1970-73	111
		2 x 200	1974-75	101
Tasmania	Mersey-Forth Hydro Scheme			
	(remaining 3 stages)	187	1971-72	437
	Gordon River Hydro Scheme	2 x 144	1976	336
	Bell Bay	2 x 120	1971-74	157
Snowy Mountains Authority	Blowering	1 x 80	1971	
	Tumut 3 – Hydro	6 x 250	1974	

[a] Based on 1970 dollars and excludes interest during construction.

TABLE VI. FORECAST OF MAXIMUM DEMAND (MW)

	June 30 1970 (actual)	June 30 1975	June 30 1980
New South Wales	4207	6000	10 000
Victoria	2536	3740	5 390
Queensland	1116	2240	3500
South Australia	820	1220	1800
Western Australia	540	890	1615
Tasmania	780	1180	1555
Northern Territory	52	120	250
	10 050	15 390	24 110

TABLE VII. FORECAST OF CONSUMPTION OF PRIMARY ENERGY FOR ELECTRICITY PRODUCTION IN YEAR 1979-80 (10^{12} Btu)

State or authority	Black coal	Brown coal	Oil/ natural gas	Hydro	Total
New South Wales	352.4	-	4.0	1.3	357.7
Victoria	-	261.9	44.0	1.8	307.7
Queensland	145.3	-	2.7	1.7	149.7
South Australia	28.5	-	74.0	-	102.5
Western Australia	19.4	-	65.4	-	84.8
Tasmania	-	-	15.0	27.0	42.0
Northern Territory	-	-	12.1	-	12.1
Snowy Mountains Authority	-	-	-	14.0	14.0
	545.6	261.9	217.2	45.8	1070.5

further peak load plant will be required in New South Wales and Victoria towards the latter end of the 1970s. In New South Wales a 240-MW(e) pumped storage scheme planned for 1976 operation is under construction; additional peak load requirements might be met with oil or gas-fired plant. In Victoria it is expected that natural gas or fuel oil will be used. The first thermal plant now under construction in Tasmania has been designed to operate on oil or natural gas.

A forecast of maximum power demand over the next 10 years is shown in Table VI for the various States. The average increase per annum for Australia is expected to be about 9%, but it is expected to be much higher in the States of Queensland and Western Australia.

A forecast of the primary energy requirements for electrical power generation in the year 1979-80 is shown on Table VII. Comparison with Table II for 1968-69 shows the significant increase expected in the use of fuel oil and natural gas.

4. NUCLEAR POWER

4.1. Electrical capacity to the year 2000

The demand for electrical energy in Australia has increased at the rate of 9.5% p.a. over the period 1949-50 to 1969-70 (Table III). The reasons for such a high rate of increase arise from the population growth including immigration, a rapid increase in industrial development, and a rise in general living standards.

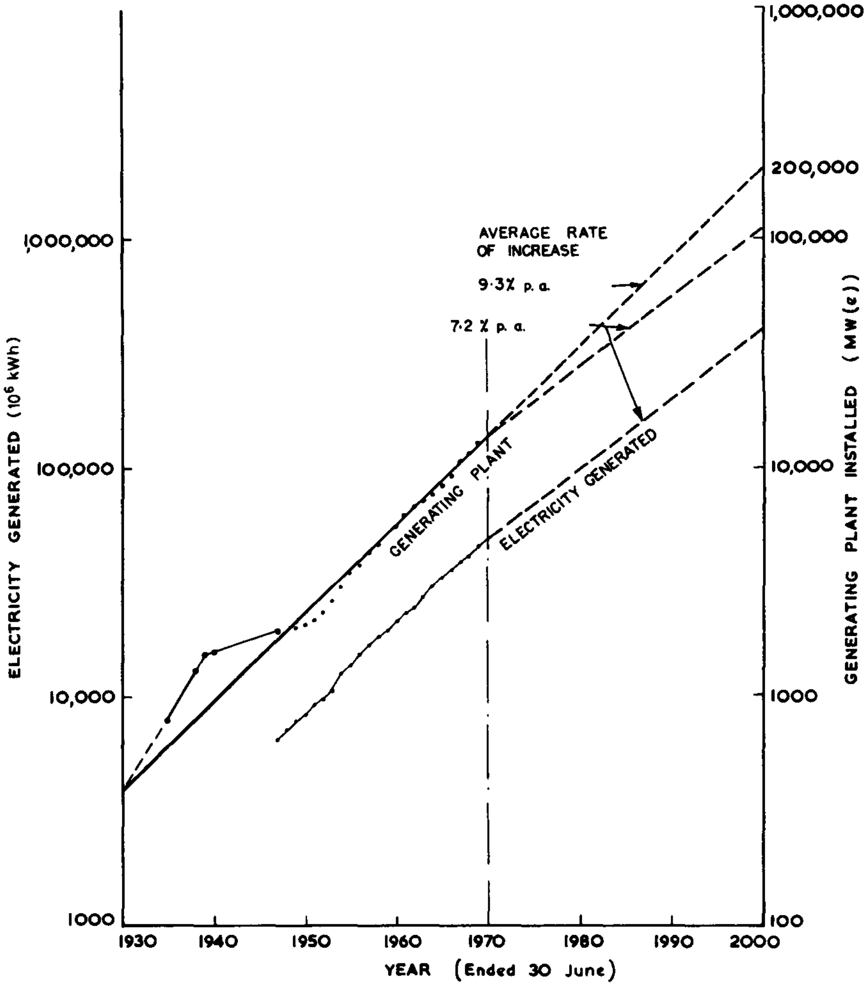

FIG. 1. Growth of electricity supply industry in Australia.

Figure 1 shows that the average rate of increase of installed generating capacity over the last 40 years or so has been 9.3% p.a. If this rate of increase continued to the year 2000 the installed capacity would be over 200 000 MW(e). However, it is highly unlikely that such a high growth-rate will continue until the turn of the century. If we accept the predictions of the various State Authorities to the year 1980 and assume a gradually reducing growth-rate over the following 20 years corresponding to an average rate of 7.2% p.a. we arrive at a combined peak demand (ignoring diversity) of 95 000 MW(e) in the year 2000, or a total installed capacity of about 112 000 MW(e) allowing 18% reserves. This reduced growth-rate of 7.2% p.a. corresponds to a doubling period of approximately 10 years and is used elsewhere [9] for a similar forecast of electricity growth in Australia over the same period.

4.2. Nuclear power prospects in Australia

Predictions have been made by the A.A.E.C. on the amount of nuclear power likely to be installed in Australia until the end of the century. In making such predictions a key question is the date when nuclear power will first become truly competitive in each State. This depends on many factors – the relative capital cost of nuclear stations and of alternative schemes, the cost and availability of nuclear and competing fuels, the cost and availability of money for new capital works – all of which vary with locality. Regarding relative capital cost, the size of the generating systems and growth-rate in demand which largely determine unit plant sizes are of particular importance.

Although Australian generating authorities have not yet acquired the competence to engineer a nuclear station completely we believe they will do so within the next 5 to 6 years, and built in the same way as conventional stations we see no reason why a 1000-MW LWR plant should cost more than $40 million over the cost of a 1000-MW coal-fired unit, inclusive of all clients' charges, but excluding the initial fuel charge. (Spinrad [9] expresses the opinion that, with a mature nuclear industry, the cost differential should not exceed $25 million). Provided escalation is kept within reasonable bounds we would not expect the above $40 million to be exceeded over the next decade or so. The cost of coal-fired stations can be expected to increase with the enforcement of anti-pollution measures and as more remote and more costly sites are developed, whereas the cost of nuclear stations should tend to decrease with greater competition and as the industry matures.

In comparing the economics of nuclear and conventional power the effect of escalation on fuel costs needs to be carefully considered as any such escalation will apply throughout the life of the station. In Australia the cost of coal, for a given scale of operations, can be expected to escalate at much the same rate as that applying to capital works, and likewise the price of alternative fuels (oil and gas) can be expected to keep in step. Although nuclear fuel costs have not shown the reductions earlier anticipated they have held fairly steady and, considering the present "mark-up" and the possibilities for cost reductions, there seems little reason why they should increase to any great extent over the next decade or so, despite recent increases in enrichment costs. However, even if one assumes the same rate of escalation for nuclear and conventional fuels, average annual savings based on unescalated prices will be considerably increased if escalation is taken into account. In the case of a 4% p.a. escalation the increase over a 25-year period would amount to approximately 50% for present worth discount factors of 6 to 8% p.a.

Studies carried out by the A.A.E.C. taking into account the many factors involved, but necessarily based on many assumptions, particularly those relating to fuel price movements, indicate that nuclear power should be competitive:

(a) In New South Wales in the early 1980s with plant unit sizes of 1000 MW;
(b) In Victoria by the mid-1980s with plant unit sizes of 750 MW;
(c) In Queensland, South Australia and Western Australia by about the mid-1980s, with unit plant sizes of 500 MW.

Tasmania would probably continue to exploit its hydro resources until the late 1980s and nuclear power units would not be installed before then unless they offered a substantial saving in capital cost.

In common with most other countries it seems unlikely that nuclear plants will prove competitive on any of the State systems for unit plant sizes smaller than 500 MW, and the mid-1980s is about the earliest date when units of this size could be accommodated on the Queensland, South Australian and Western Australian systems. If the cost of imported fuel oil became excessive over the next 10 years South Australia and Western Australia could import coal from New South Wales as an alternative. Once nuclear power stations become competitive on the State systems it can be expected that they will be built as a normal course for base load generation, and over the last decade about half of all new installations could be nuclear.

Table VIII sets out the predicted growth in installed generating plant and nuclear plant to the year 2000, when the total capacity is expected to reach approximately 112 000 MW, nuclear power accounting for 36 000 MW, or 32%.

TABLE VIII. ESTIMATED GROWTH OF CONVENTIONAL AND NUCLEAR POWER IN AUSTRALIA

Year (ended 30 June)	Total installed capacity (MW(e))	Conventional plant (MW(e))	Nuclear plant	
			MW(e)	(%) Total
1980	28 000	27 000	1 000	3.6
1985	42 000	38 000	4 000	9.5
1990	61 000	49 500	11 500	18.9
1995	83 000	60 500	22 500	27.1
2000	112 000	76 000	36 000	32.1

4.3. Nuclear fuel

Recent discoveries of new uranium deposits leads the Commission to believe that Australia could become one of the world's large producers. Present indicated reserves are of the order of 130 000 t but several years of additional exploration will be necessary to prove this. Undoubtedly further exploration by the numerous mining companies now engaged in the search will lead to further discoveries. By world standards the recently discovered ore reserves are very rich and they are amenable to open-cut mining which should lead to low production costs.

These reserves are likely to be far in excess of any foreseeable domestic requirements and should be sufficient to support a major nuclear fuel industry. Consideration is therefore being given to the establishment of such an industry, primarily for export purposes, although Australian power authorities would benefit from the lower costs that would result from large-scale operation. The benefits, particularly the increase in export income, that would derive from the sale of finished and semi-finished nuclear fuel rather than yellowcake are attractive. Studies are now in hand on the feasibility of installing industrial plants for UF_6 production, uranium enrichment and fuel fabrication.

4.4. Jervis Bay Nuclear Power Station

Although power generation in Australia is the responsibility of State-owned utilities, the Commonwealth Government announced in November 1969 that it proposed to build Australia's first nuclear power station at Jervis Bay, approximately 95 miles south of Sydney. The site for the proposed station is on Commonwealth territory, but surrounded by the State of New South Wales; the station will be constructed and owned by the Commonwealth through the Australian Atomic Energy Commission, but will be operated on a day-to-day basis by the Electricity Commission of New South Wales as part of the State grid.

This proposal arose from the Commonwealth Government's consideration of the need for it to establish a "lead station" in Australia in advance of the ordering of nuclear units by State utilities. It was considered that there would be many benefits arising from such a project, including the training of staff from the generating authorities in all aspects – engineering, construction and operation. Also, the development of licensing and regulatory procedures is a matter which concerns both the Commonwealth and the States and agreement must be reached and appropriate legislation enacted before States embark on their own nuclear power programs. The Jervis Bay project, in which the States will collaborate, will assist in this connection.

Tenders were called on a world-wide basis and closed in June 1970. At the time of submission of this paper the decision to proceed had not been announced; however, it is hoped that the station will be completed in time to obtain several years operating experience before the first State orders are placed for nuclear plant in the late 1970s.

5. CONCLUSIONS

The main role of nuclear energy in Australia for the immediate future is expected to be in the area of electrical power generation. Over the last 40 years or so there has been a high and consistent demand for electricity and there is no reason to believe that a high rate of increase will not continue for some time. Up to the present time this demand has been met by thermal stations using coal in the major areas of demand and by hydroelectric stations located mainly in New South Wales and Tasmania. Whilst it is expected that coal will continue to be the major primary source of energy in Queensland, New South Wales and Victoria in the next decade there is evidence to indicate that the electrical industry as a whole will undergo considerable development, in which natural gas, oil and nuclear power will each have important roles to play.

In the large areas of Western Australia and South Australia the indigenous reserves of coal are already inadequate to meet present requirements. These States will become increasingly dependent on imported fuel oil unless reserves of natural gas are substantially increased. Nuclear power will become more attractive as the respective electrical systems increase in size and larger unit sizes of plant can be accommodated.

In the eastern States of Australia, where presently 90% of the installed power plants are located, similar changes can be expected. There is limited scope for further development of hydro-electric installations, and natural gas and fuel oil consumption is expected to increase significantly by the year 1980.

Present studies on nuclear power indicate that nuclear plant could be competitive in New South Wales by the early 1980s, and in most other States several years later. Tasmania, because of its hydro resources and small system size, is unlikely to install nuclear power plant before the end of the 1980s.

With increasing power demands, the ability of the State systems to accept larger units, with rising fossil fuel costs, and with increased attention being given to atmospheric pollution, nuclear power stations must become increasingly attractive and will undoubtedly be built in rapidly increasing numbers, thus following the pattern overseas. From the present installed capacity of some 14 000 MW(e), to the conservative estimate of approximately 112 000 MW(e) by the year 2000, it is expected that about one-third of the total installed capacity of plant will be nuclear.

The recent discoveries of large reserves of uranium in Australia could result in a large fuel export industry being established, thus providing a further incentive to the power authorities to exploit nuclear power.

ACKNOWLEDGEMENT

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GROWTH OF DEMAND FOR ENERGY, AND PROJECTED ROLE OF NUCLEAR POWER IN TURKEY

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Abstract–Résumé–Аннотация–Resumen

GROWTH OF DEMAND FOR ENERGY, AND PROJECTED ROLE OF NUCLEAR POWER IN TURKEY.

In developing countries such as Turkey, a continually increasing demand for electric power stimulates extensive investigation into the most economical means of electricity generation. This paper reviews the existing power system, energy requirements up to year 2000 and power development in Turkey. Available conventional energy resources such as fossil fuels and hydro potential for meeting long-term energy requirements are considered. From the estimated costs, the competitiveness of nuclear power and the influence of local conditions on capital cost are discussed. It is shown that, in view of the limited amount of fossil fuel in Turkey, nuclear power would be a very promising source of electricity for sustaining and accelerating the country's economic development. The projected role that nuclear energy is expected to play in meeting near-term energy requirements for electric power and desalination is also summarized.

AUGMENTATION DE LA DEMANDE D'ENERGIE ET ROLE PREVU DE L'ENERGIE NUCLEAIRE EN TURQUIE.

Dans un pays en voie de développement comme la Turquie, la demande d'énergie électrique croît très vite; par conséquent il est nécessaire d'étudier sérieusement la rentabilité des moyens de production d'électricité. Les auteurs examinent l'état actuel des centrales de puissance, la demande d'énergie jusqu'à l'an 2000 et les prévisions concernant le développement de l'énergie électrique. Ils passent en revue les ressources d'énergie classiques comme les combustibles fossiles et l'énergie hydraulique et en évaluent la consommation probable en Turquie jusqu'à l'an 2000. La compétitivité de l'énergie nucléaire et les conséquences économiques des conditions locales sont étudiées sur la base d'une évaluation des coûts d'investissement. On en conclut que l'énergie nucléaire pourrait contribuer largement au développement économique de la Turquie, dont les ressources à long terme en combustibles sont insuffisantes. Les auteurs évaluent la mesure dans laquelle l'énergie nucléaire permettra de faire face aux besoins à court terme ainsi que la possibilité d'introduire le dessalement nucléaire en Turquie.

РОСТ ЭНЕРГЕТИЧЕСКИХ ПОТРЕБНОСТЕЙ И РОЛЬ ЯДЕРНОЙ ЭНЕРГЕТИКИ В ТУРЦИИ.

В развивающихся странах, таких,как Турция, непрерывный рост потребностей в электроэнергии способствует проведению широких исследований наиболее экономичных средств производства электроэнергии. В данном докладе рассматриваются существующие энергосистемы, энергетические потребности до 2000 года и проводимые в Турции разработки в области энергетики. Рассматриваются также имеющиеся в настоящее время обычные источники энергии – ископаемые виды топлива и потенциальные гидроресурсы с точки зрения удовлетворения потребностей на длительный период. На основе стоимостных оценок рассматриваются вопросы конкурентоспособности ядерной энергетики и влияния местных условий на капитальные затраты. Показано, что с учетом ограниченных запасов ископаемого топлива в Турции ядерная энергетика должна стать многообещающим источником электроэнергии для поддержания и ускорения экономического развития страны. Предполагается, что ядерная энергия будет играть заметную роль в удовлетворении ближайших потребностей в производстве электроэнергии и опреснении соленых вод.

CRECIMIENTO DE LA DEMANDA DE ENERGIA Y FUTURO PAPEL DE LA ENERGIA NUCLEOELECTRICA EN TURQUIA.

En los países en desarrollo como Turquía, la demanda constantemente creciente de energía eléctrica estimula la realización de amplios estudios sobre los medios más económicos para generar electricidad. La memoria describe la actual red eléctrica, la demanda de energía hasta el año 2000 y el desarrollo de la producción de electricidad en Turquía. Se presta consideración a los recursos energéticos clásicos, tales como los combustibles fósiles y el potencial hidroeléctrico con que se cuenta para satisfacer las necesidades energéticas a largo plazo. Partiendo de los costos estimados, se considera la rentabilidad de la energía nucleoeléctrica y la influencia que ejercen las circunstancias locales sobre la inversión de capital. Se demuestra que, en vista de las escasas reservas de combustibles fósiles existentes en Turquía, la energía nuclear ofrecerá excelentes perspectivas como fuente de electricidad para mantener y acelerar el desarrollo económico del país. Se resume asimismo el papel que se prevé desempeñará la energía nuclear para hacer frente a la demanda energética a corto plazo para la generación de electricidad y para la desalación del agua.

1. PRESENT POWER STATUS

Until 1955, about 70% of the population of Turkey was engaged in agriculture since there was very little industry. Therefore, until 1955, the energy demand was very low and was mostly met by thermal power plants. Between 1955 and 1965 a fraction of the population made the transition from illiterate subsistence farming to literate industrial-urban-farm patterns of life. By 1965 the power production per capita was 157 kWh which was still very low compared with European countries.

The electricity production since 1950 is shown in Table I. The result of switching over from coal to hydro is clearly shown in this table, which gives the relative importance of the various power supplies since 1950.

In 1950, 55.1% total power production was from high-grade coal, but by 1965 coal supplied only 10.3%. In 1960, power from hydro amounted only to 3.8% but in 1965 it reached 43.9%. The figures also show that liquid fuel was responsible for the fairly constant figure of 8% of the total power production.

However, the importance of liquid fuel has increased with the installation, in April 1967, of the second of the 110-MW units at the 220-MW Ambarlı fuel-oil plant near Istanbul.

In 1969 power generated from petroleum products amounted to 24.6% of total power production compared with 32.4% from coals and 57% from hydro-power.

The main coal plants are Silahtarağa, near Istanbul, which has a capacity of 120 MW; Çatalağzı, near Zonguldak, a capacity of 120 MW; and Tunçbilek, near Kütahyra, with a 129-MW capacity.

The main hydro plants are Sarıyar, 160 MW; Hirfanlı, 96 MW, and Kesikköprü, 76 MW. All these are in Ankara region.

Today the most important energy markets in Turkey are the North West Anatolia, West Anatolia and Çukurova. Because of the rapid development of the industrial centres between Istanbul and Adapazarı, and Istanbul being a big city, this part of Turkey has the largest power demand.

2. FUTURE ENERGY DEMAND

The population of Turkey was 20.9 million in 1950. In 1967 this increased to 32.9 million at an average growth-rate of 2.5%. If this

TABLE I. ENERGY PRODUCTION ACCORDING TO SOURCES

	1950		1955		1960		1965	
	(GWh)	(%)	(GWh)	(%)	(GWh)	(%)	(GWh)	(%)
High-grade coal	435	55.1	559	35.3	417	14.8	513	10.3
Low-grade coal	105	13.4	393	24.9	591	21.0	745	15.1
Lignite	137	17.4	339	21.4	532	18.9	998	20.2
Liquid fuel	60	7.5	158	10.0	233	8.3	430	8.7
Other fuels	28	2.8	40	2.6	40	1.4	88	1.8
Hydro	31	3.8	89	5.6	1001	35.6	2167	43.9
Total	789	100	1580	100	2815	100	4942	100

growth-rate is maintained for some time, the population of Turkey will be around 65 million by 1997.

The average growth-rate in the energy consumption per capita increased at about 9.3% p.a. during 1960-1967. During the same period, the average power production increased at the rate of 12%. At present 70% of the total electricity generated is consumed by industry. In the first five-year plan, 1962-1967, the average growth-rate in the industrial sector was 9.7%. During the same period, the growth-rate of energy consumption was 11.9%.

In the second five-year plan, 1967-1972, a constant growth-rate of 12% is expected as the probable average in industry. But growth-rates of 10 and 9.4% were reached in 1968 and 1969. Therefore, it is probable that the assumed growth-rate of 12% in industry will not be reached.

At present, more than half the population is unable to utilize the electricity; on the other hand, in the second five-year plan, emphasis is laid on the electrification of villages all over the country. Therefore, it is expected that during the second five-year plan, 1967-1972, the constant growth-rate of energy consumption will not be less than 12%.

Moreover it is expected that the 1240-MW Keban hydro-electric power plant will be in operation during the third five-year plan (1972-1977), when the expected growth-rate of energy consumption might exceed 12%.

Table II gives the estimates of energy demand up to the year 2000. But, at the National Power Conference held in November 1968, higher figures for growth-rates were proposed [1]. It was concluded that the electricity demand will reach about 180 000 GWh in 2000. In Table II, this figure is estimated as 153 000 GWh. According to these estimates the power demand per capita will reach 2200 kWh in 2000, which is equivalent to the power demand value of France in 1968.

From Fig. 1 it can be seen that during the period 1967-1982, the average growth-rate of energy production is about 11 or 12%, which is the similar to that in developing countries. The 1982-1987 interval is

TABLE II. ELECTRICITY ENERGY DEMAND ESTIMATES

Year	Population (millions)	Energy production per capita		Energy demand		
		(kWh)	Growth-rate (%)	(GWh)	Growth-rate (%)	Total installed power capacity (MW)
1967	32.9	187		6 167		
			9.7		12.3	
1972	37.2	296		11 000		2 670
			9.9		12.8	
1977	42.1	475		20 000		4 885
			9.8		12.5	
1982	47.4	760		36 000		8 135
			9.1		10.5	
1987	53.1	1130		60 000		12 160
			6.0		8.5	
1992	59.7	1511		90 250		17 440
			5.2		7	
1997	65.7	1926		126 600		23 920
			5.0		6.5	
2000	69.7	2200		153 000		28 660

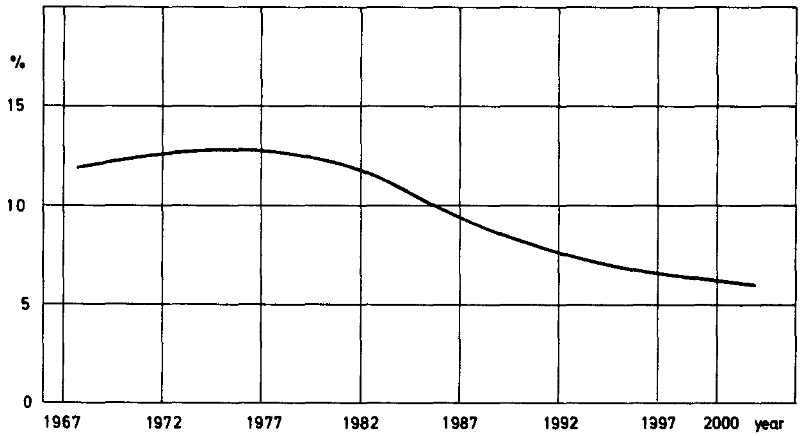

FIG. 1. Annual growth-rate of electricity production.

a transition period, after which the situation of the energy demand in Turkey will become similar in behaviour to that of the developed countries, i.e. the power consumption will only increase at about 5-6%, and the estimated total installed capacity of power plants and the demand for electric power will reach 28 660 MW(e) and 153 000 GWh, respectively. According to the above estimates, the possible trend of the electrical energy demand is shown in Fig. 2.

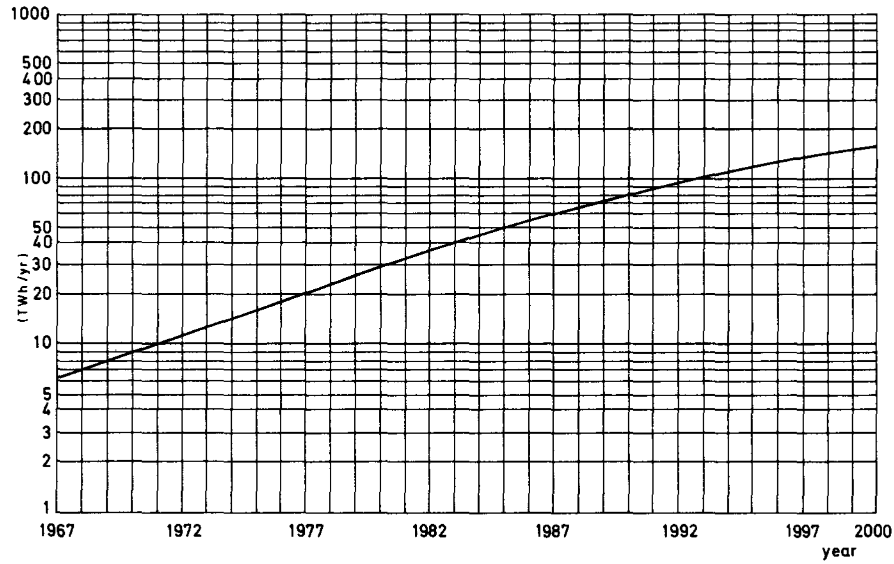

FIG. 2. Estimates of the electricity demand.

3. CONTRIBUTION OF VARIOUS ENERGY RESOURCES IN ENERGY PRODUCTION

In the Zonguldak region, bituminous coal, with a calorific value of 6000 to 7000/kg is found. In this region, the reserves are as follows:

Indicated	199 246 000 t
Inferred	261 485 000 t
Probable	892 369 000 t
Total reserves	1 313 100 000 t

In 1969, the production of bituminous coal was about 12 485 000 t. Of this amount 41.5% was used by big industries such as iron and steel works and railways. Only 18% of bituminous coal was used to produce electricity. After completion of the third iron and steel factories, most of the good quality coal will be used in these factories. For this reason, the contribution of bituminous coal in the production of electricity will be very small and will consist of largely low-grade coals.

The lignite reserves which are spread all over the country are as follows:

Indicated	370 081 654 t
Inferred	175 780 100 t
Probable	10 891 170 t
Total reserves	556 752 924 t

In 1969 the total production of brown coals and lignites was 5.77×10^6 t. Of this amount 14.5% was used by cement factories, sugar refineries, the nitrogen and other small industries. The main consumers of brown coals and lignites are domestic users and 32% is consumed in heating buildings, and only 11.8% of the lignite is used in the production of electricity.

It is believed that in future the bituminous coals will be used only by the heavy industries such as iron and steel works and the main consumers of lignites will be domestic users and small industries. Therefore, the contribution of lignite in the production of electrical power will be negligible.

The erection of a 2 × 150-MW(e) capacity lignite power plant at Seyitömer will be in operation at the end of 1973 and it will produce about 2100 GWh/yr. A newly discovered lignite area in the eastern part of Turkey at Elbistan has about 3×10^9 t of lignite in probable reserves.

According to the present analysis it is assumed that, during the period of 1982-1992, coal-fired thermal power plants with a total capacity of 2400 MW(e) can be installed at Elbistan.

According to the present economically recoverable oil reserves, it can be assumed that the potential contribution of fuel oil in the production of electricity is limited. It is estimated that the economically recoverable oil reserve of Turkey is around 65 or 70 million tons. But the consumption of petroleum products is increasing considerably in the country. The actual refinery capacity was 9 million tons of crude oil in 1970, and it is expected that this capacity will increase to 14.6 million tons in 1972. The total domestic crude oil production was 3.6 million tons in 1969, and 4.2 million tons of crude oil were imported in the same year. It is expected that the domestic crude oil production will increase to 5.8 million tons and the imported crude oil will increase considerably amounting to 5.92 million tons in 1972.

As can be seen from Table III, the present economically recoverable oil reserves of Turkey will be used up by 1982, after which Turkey will import all the crude oil needed, and crude oil imports will reach the order of 100 million tons in 2000. It is clear that, owing to difficulties in importing about 50 to 60 million tons of crude oil annually after 1987, the contribution of fuel oil to power production will be rather small.

According to this analysis, and considering the future necessity to erect fuel-oil-fired thermo-electric power plants, apart from Ambarlı power plant with a total capacity of 630 MW(e), it is assumed that it would be necessary to introduce further fuel-oil-fired thermo-electric power plants with a total capacity of 10 800 MW during the period 1982-2000.

TABLE III. FUTURE PRODUCTION AND IMPORT OF CRUDE OIL IN TURKEY (1000 tons)

Year	1972	1977	1982	1987	1992	2000
Production	5800	11 200	-	-	-	-
Cumulative			65 000			
Import	5920	8380	32400	46 770	66 840	103 600

Turkey has a large hydro potential whose total realizable output is about 69 500 GWh/yr.

Turkey lies fourth in Europe in its hydro potential following Norway, Sweden, and Italy. But up to 1967 the actual recovered percentage of the hydro-electric potential was about 3.4%, and installed capacity was 650 MW. Because of some delays in the operation of the Keban hydro-power station, it is expected that after 1972, which is the end of the second five-year plan, any substantial increase in the installed capacity of hydro-plants would not take place. However, during 1973-1975, the Keban hydro-power station with a capacity of 1240 MW, and several

TABLE IV. ESTIMATED POTENTIAL CONTRIBUTION OF HYDRO-POWER

Year	Hydro energy production (GWh)	Recovered percentage of hydro potential (%)	Average utilization (h/yr)	Installed hydro power capacity) (MW)	Annual growth-rate (%)
1967	2370	3.4	3650	650	4.5
1972	3850	5.5	4750	850	25.8
1977	11350	16.3	4300	2540	14.4
1982	21 140	30.4	4250	4970	5.5
1987	28 900	41.5	4450	6510	3.4
1992	36 300	52.3	4700	7710	1.7
1997	38 360	55.5	4600	8333	1.3
2000	39 425	56.7	4550	8660	

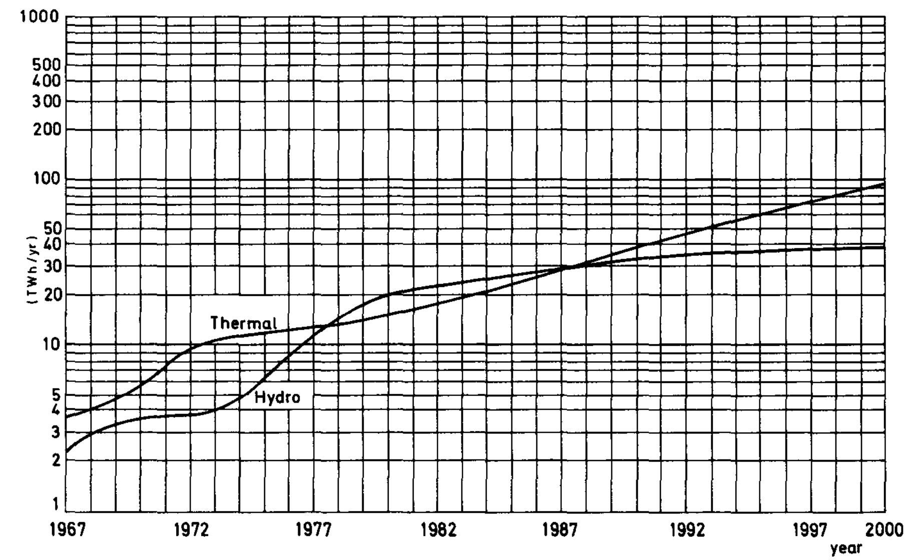

FIG. 3. Comparison of hydro and thermal energy developments.

TABLE V. ESTIMATED POTENTIAL CONTRIBUTION OF VARIOUS ENERGY RESOURCES IN ENERGY PRODUCTION

Energy resources		1969	1972	1977	1982	1987	1992	1997	2000
Coals and other fuels	(MW)	670	670	1 000	1500	1955	2435	2375	2375
	(GWh)	2590	2590	4750	7100	10 000	12 500	12 300	12 000
	(%)	32.4	23.5	23.8	19.7	16.6	13.8	9.6	7.8
Petroleum products	(MW)	585	1095	1095	1545	2445	4445	8215	10 225
	(GWh)	1971	4560	3900	5660	11 700	26 750	41 000	60 000
	(%)	24.6	41.5	19.5	15.7	19.6	29.7	32.5	39.2
Total thermal	(MW)	1255	1765	2095	3045	4400	6880	10 590	12 600
	(GWh)	4561	7150	8650	12 760	12 760	39 250	53 300	72 000
	(%)	57	65	43.3	35.4	36.2	43.5	42.1	47
Hydro	(MW)	725	805	2540	4950	6510	7710	8336	8660
	(GWh)	3439	3852	11 350	21 000	28 900	33 500	38 300	39 000
	(%)	43	35	56.7	58.3	48.1	37.1	30.3	25.5
Nuclear	(MW)			350	350	1350	2860	5000	6000
	(GWh)			Under	2260	9400	17 500	35 000	42 000
	(%)			construction	6.3	15.7	19.4	27.6	27.5
Total energy production	(MW)	2080	2570	4635	8365	12 260	17 440	23 921	27 260
	Production (GWh)	8000	11 002	20 000	36 020	60 000	90 250	126 600	153 000
	Production capacity (GWh)	9270	12 942	23 642	42 525	68 120	103 300	146 360	179 425
	load factor (%)	51.5	58.5	59.5	59	64	68	70	76
Energy demand	(GWh)	8000	11 000	20 000	36 000	60 000	90 250	126 600	153 000
Reserve	(MW)	280	380	715	1280	1600	2530	3500	4200
	(%)	13.5	14.3	14.4	15.7	13.2	14.5	15	15.4

other projects under construction will increase the recovered hydro-potential to 16. 3%. The erection of Karakaya and Karababa hydro-power stations, with a total capacity of 3100 MW on the Fırat River, are in the planning stages.

It is expected that erection of Karababa hydro-power station which will be larger than Keban, will start around 1973. Then it appears that during 1977-1987 a considerable amount of hydro potential will be recovered. Thus, the recovered percentage will reach about 41. 5 and 56. 7% in the years 1987 and 2000, respectively. This is also shown in Table IV. It is estimated that the growth-rate of the development of hydro-electric power will slow down considerably after 1987.

A comparison of hydro and thermal power developments is given in Fig. 3. The behaviour of the hydro power curve around 1972 is due to the delay of completion of the Keban hydro power station. The steep increase in the thermal power curve around 1967-1972 is due to the introduction of the Ambarlı fuel-oil-fired thermo-electric power plants. After 1977, hydro-power plants will increase until 1987, beyond which the most important hydro plants will be completed and in turn the growth-rate of thermal power development will increase. The estimated potential contribution of the various energy resources in power production up to 2000 is summarized in Table V. It can be seen from Table V that the contribution of coal in the total energy production will decrease from 32. 4% to 7. 8% during 1969-2000. On the other hand, fuel-oil-fired thermo-electric power plants will gain importance and they will contribute 39% to the total electric energy generation in 2000. When the natural gas and geothermal energy potential of the country is realized, then the energy generation would be shared by fuel-oil, geothermal and natural gas resources. Otherwise Turkey will have to spend much foreign exchange to import fuel oil.

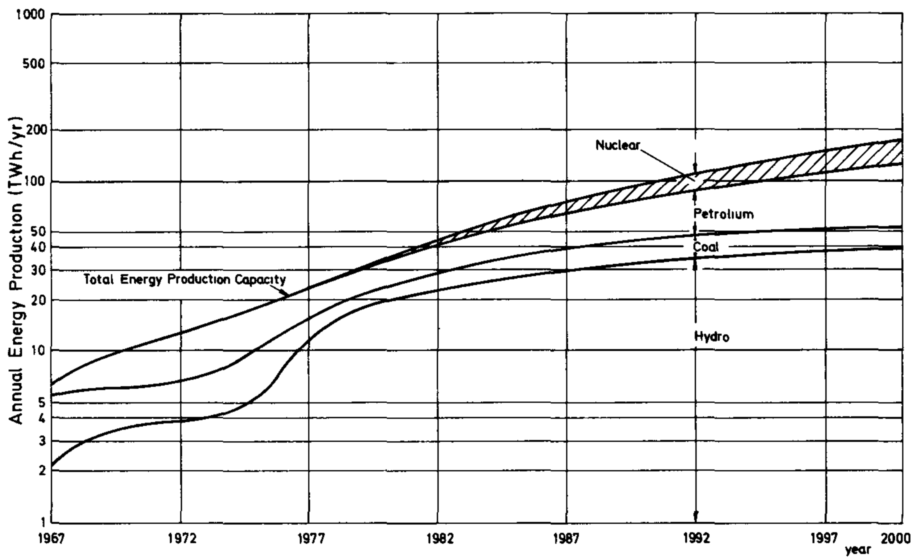

FIG. 4. Estimated potential contribution of the various energy resources in energy production.

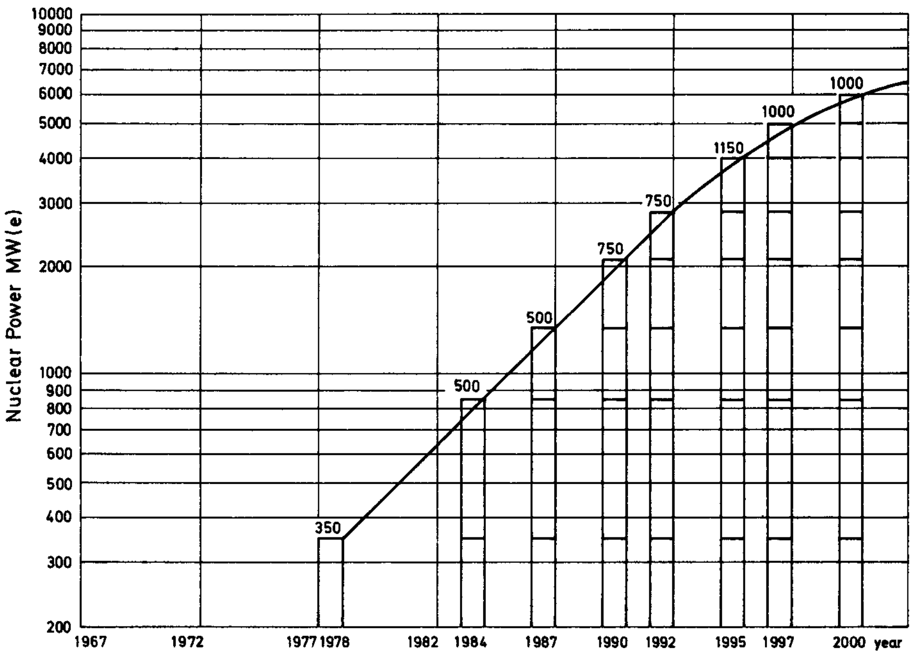

FIG. 5. Projected role of nuclear power in Turkey.

Hydro power will contribute about 58.3% in 1982 in the total electric energy generation, but beyond 1982 its importance will decrease and it will contribute 25.5% around 2000.

According to the present analysis, despite the fact that the contribution of thermal power in the production of electric energy is calculated at 47% under the above assumptions, it appears that it would be necessary for Turkey to introduce nuclear power stations from the year 1980 onwards. This situation can be seen very clearly in Fig. 4.

4. POTENTIAL CONTRIBUTION OF NUCLEAR POWER

It appears that the first Turkish nuclear power plant with a capacity of 350 MW(e) (gross), which was planned to be commissioned in 1977, might be delayed, and for this reason this station is not included in the energy balance calculations for 1977. As is shown in Fig. 5, it is assumed that the first Turkish nuclear power plant will start operation in 1978.

It is calculated that it would be necessary to introduce nuclear power with a capacity of 1350 MW(e) up to 1987. For this reason, it would be suitable to introduce a twin reactor with a capacity of 2 × 500 MW(e), the first unit in 1984 and the second in 1987. In the fifth five-year plan, (i.e. from 1987 to 1992) two further nuclear power stations, each with a capacity of 750 MW(e), would be needed to meet the rapidly increasing energy demand.

The forecast of the energy demand shows that Turkey should probably introduce nuclear power stations with a total capacity of 5000 or 6000 MW(e) in 2000. Thus nuclear power is expected to have a major role in the energy growth around the year 2000.

5. NUCLEAR ENERGY FOR SEA-WATER DESALINATION

In general, there is no water shortage in the regions near the sea coasts of Turkey. Main sources of fresh water are the rainfall on the sea coasts and the rivers joining the sea. Therefore, water is available in these regions, and no extra provision is needed. At present, economic considerations do not permit the use of desalted water from dual-purpose nuclear power stations in agriculture or even in industry.

In Turkey the arid zones are in central Anatolia which is away from the sea coast. Therefore, the utilization of the desalted water in those areas is impossible.

But in some of the big cities such as Istanbul and Ankara, the alarming increase in population necessitates that some measures be taken in order to prevent the exhaustion of existing fresh water. For this reason, a study on the desalination of sea-water for the city of Istanbul has been made. The present population of Istanbul is about 2.7 million and it is expected that this population will increase to 6 million around 2000. In Istanbul, water consumption per person is approximately 0.025 m^3/d. It is estimated that water consumption will increase to 0.250 m^3/d around the year 2000. Water requirements in Istanbul were 246.5 million m^3/yr in 1970 and by 2000 are expected to be 814 million m^3/yr. At present fresh water is supplied to Istanbul from Lake Terkos, the Elmali and Kirkçeşme dams and from some wells. In the near future, the Alibey and Ömerli reservoirs, and Çekmece lakes will be used as fresh-water suppliers to Istanbul. It is also expected that from the dams near Ağva, fresh water with a capacity of 236 millions m^3/yr will be obtained. It appears that there will be no water shortage in Istanbul between 1985 and 1990. After then, it has been planned that fresh water would be transported from Lake Sapanca, 160 km away from Istanbul, and the Sakarya River. The cost of supplying water to Istanbul from Lake Terkos and the Alibey and Ömerli dams is about 25 krş/m^3 (= \$0.0166/m^3). But the cost of water supplied from the Ağva stream is 40 krş/m^3 (= \$0.0266/m^3).

It is estimated that cost of the water pumped from further distances would be 60 to 70 krş/m^3. With the present prices, it is predicted that by the use of a dual-purpose nuclear plant, $4 \times 10^5 m^3/d$ water could be produced at a cost of 100 krş/m^3 (= \$0.066/m^3) and saleable power of 200 MW(e) will be available. The prospects of the nuclear production of fresh water will improve and in coming years the cost of water produced will decrease owing to further technical developments in reactor technology.

It is most probable that the water of the Sakarya river will be used only for irrigation purposes and, therefore, the use of its waters for Istanbul will not be possible. Because of the long distance, the costs would be quite high if water was pumped from Sapanca Lake to Istanbul. Under these circumstances it is predicted that, by erecting a dual-purpose complex with a high capacity near Istanbul it could safely compete with the costs of pumping water from Sapanca Lake.

6. NUCLEAR AND THERMAL ENERGY GENERATION COSTS IN TURKEY

The breakdown of the capital investment, and operating and maintenance costs for a nuclear power station consisting of a 311-MW(e) net CANDU-PHW single-unit steam supply system is shown in Table VI. The estimates are based upon the economic conditions that were prevalent at the end of 1969. The breakdown for the nuclear power stations generally agrees with costs given in the feasibility study for the Turkish First Nuclear Power Project [2]. But the salaries in the operating and maintenance cost breakdown have been corrected according to the new labour rates that prevailed at the beginning of 1970. It will be seen from this table that

TABLE VI. COST ESTIMATE FOR 311 MW(e) NET NUCLEAR POWER PLANT IN TURKEY

A. Capital investment costs

Description	Local (10^6 Tl.)	Foreign (10^6 Tl.)	Total (10^6 Tl.)
1. Total civil works	82.5	90.0	172.5
2. Total nuclear steam supply system	-	814.2	814.2
3. Total conventional plant	6.1	251.7	257.8
4. Transportation, insurance, erection and contingencies	51.4	309.6	361.0
(a) Cost of plant:	140.0	1465.5	1605.5
5. Customer costs	27.0	54.5	81.5
(b) Cost of investment:	167.0	1520.0 (US \$101 × 10^6)	1687.0
6. Interest during construction	39.0	304.0	343.0
(c) Total cost of investment:	206.0	1824.0 (US \$123 × 10^6)	2030.0 (US \$135 × 10^6)

B. Operating and maintenance

Description	10^6 Tl./yr	krş/kWh
Salaries	7.000	0.32
Materials and services	13.08	0.61
D_2O losses	2.12	0.09
Total	22.20	1.02

the Turkish Government will need about 120 million dollars for the foreign exchange part of the capital.

Customs duties on investment are exempted, the total cost of investment includes interest during construction, but excludes cost of the operators' settlement and the energy used during construction. All costs are converted to equivalent Turkish liras at the new exchange rate of 15 Tl. ≃ US $1.

Interest during construction is based on 8% simple interest and a $4\frac{1}{2}$-year construction cycle. The investments required for a nuclear power station depend on location and vary widely from one country to another.

A possible location for the nuclear plant site was found at Yalı on the Mediterranean coast, 28 km west of Alanya within the Antalya bay. The site permits the construction of intake and outfall structures of simple design and represents an especially stable seismic region.

The costs given in Table VI were estimated according to local conditions at the selected site. Costs required for site investigation and purchase, land expropriation administrative costs, engineering services, training and commissioning costs are included in item 5 in Table VI.

According to estimates of Table VI the total investment required for this nuclear power station would be about 2030 million Tl. ($135 million); thus the investment cost per kilowatt installed will be 6540 Tl/kW(e) ($435/kW(e)). The investment cost per kilowatt installed for the plant above including transportation, insurance, erection and contingencies is about 5150 Tl/kW(e) ($344/kW(e)).

To evaluate the competitiveness of nuclear power in Turkey, the capital investment, fuel and generating costs of a thermal power plant

TABLE VII. COST ESTIMATE FOR THE EXTENSION OF AMBARLI OIL-FIRED THERMAL POWER PLANT
Net power: 285 MW (2 × 142.5)

A. Capital investment costs:	Local, 10^6 Tl.	125
Including interest during construction; excluding costs of operators' village and energy during construction	Foreign, 10^6 Tl.	550 (= US $36.7 × 10^6)
	Total, 10^6 Tl.	675
B. Operating and maintenance cost:	Fixed charges	8.4 × 10^6 Tl./yr
	Variable charges	3.0 × 10^6 Tl./yr
	Total	11.4 × 10^6 Tl./yr
C. Fuel costs:	Without taxes 260 Tl./t	124.5 × 10^6 Tl./yr
	With taxes 420 Tl./t	202 × 10^6 Tl./yr
	Imported fuel oil with taxes 600 Tl./t	288 × 10^6 Tl./yr

TABLE VIII. GENERATING COSTS OF NUCLEAR POWER PLANT AND OIL-FIRED POWER PLANTS (krş/kWh)

Type of plant	Nuclear power plant		Oil-fired thermal power plant		
Annual energy generation	2.179 × 10⁹ kWh/yr		2 × 10⁹ kWh/yr		
Custom duties on investment	Exempt		Exempt		
Taxes and duties on fuel	Exempt	67%	Exempt	With taxes	Imported fuel oil with taxes and duties
Annual fixed capital charges	9.29	9.29	3.05	3.05	3.05
Operating and maintenance	1.01	1.01	0.57	0.57	0.57
Fueling costs	1.83	3.06	6.20	10.10	14.43
Generating costs: (krş/kWh)	12.13	13.36	9.82	13.72	18.05
Generating costs: (mills/kWh)	8.10	8.90	6.55	9.16	12.02

burning fuel oil have been compared with those of the reference nuclear power plant. The extension of the 4th and 5th units of the Ambarlı thermal station have been selected for this comparison. This station is located on the Marmara Sea 30 km west of Istanbul. Ambarlı power plant has been in operation since 1967, equipped in the first stage with two 110-MW units. The third unit with the same capacity was added in 1969. The setting up of the 4th and 5th extensions of 2 × 150-MW(gross) power was programmed for 1970 in order to raise the effective capacity to 630 MW(gross). This plant is now almost ready.

According to the costs provided by Etibank, the total investment cost of the extension of 4th and 5th units of the Ambarlı thermal power station amounts to about 600 million Tl.

To facilitate the comparison with the nuclear power station on the basis of a common scope, the capital investment figure of the Ambarlı extension of the 4th and 5th units was increased to 675 million Tl. as shown in Table VII. The costs of the land, access and fuel discharge facility, circulating water system, water supply, administration building etc. were estimated and added to costs provided by Etibank. The civil engineering work and erection costs were increased by about 5% to comply with labour costs at the end of 1970. Thus it is estimated that the investment cost per kilowatt of a 2 × 150-MW(gross) oil-fired thermal power station in Turkey will be about $157/kW(net).

The compution of annual fuel costs was accomplished by assuming a heat rate of 2400 kcal/net kWh. The unit cost per ton for Bunker-C oil delivered to Ambarlı is at present 387. 5 Tl/t including all taxes. But it is expected that beyond 15 February, 1971 this price will be about 420 Tl/t with taxes and 260 Tl/t without. According to the cost estimate provided by TEK (Turkish Electricity Board), the cost of imported fuel oil including taxes and duties would be about 600 Tl/t delivered to Ambarlı. Thus the cost of a thermie (1 thermie = 1000 kcal) would be, in Turkey, 2. 6 krş/thermie without taxes and 4. 2 krş/thermie with taxes on fuel for domestic fuel-oil and about 6 krş/thermie for imported fuel oil with all taxes and duties.

To calculate the generating costs per kWh for each plant, an 80% capacity factor, an interest rate of 8% and a 35-yr lifetime have been used as ground rules and the annual fixed costs were calculated for each plant according to the following factors:

	Nuclear plant	Thermal plant
Capital recovery factor	0. 0858	0. 0858
Interim replacement	0. 0035	0. 0035
Insurance	0. 0075	0. 0020
	0. 0968	0. 0913

Table VIII shows the generating costs calculated on the basis of the above ground rules and with an exchange rate of 15 Tl = $1.

It may be seen from the comparison of Table VIII that the generating costs of a nuclear power plant are in the same range as the generating costs of oil-fired power plants when one includes appropriate taxes on fuel for both plants. For fuel tax exemptions, the generating costs of oil-fired plants appear to be about 20% lower than for a natural-uranium heavy-water-moderated nuclear power plant.

The generating costs of the heavy-water nuclear power plants that range from 12.13 krş/kWh (8.10 mills/kWh) to 13.36 krş/kWh (8.90 mills/kWh) would be about 30% lower than for a thermal power station burning imported fuel oil.

Therefore, in view of the limited amount of fossil fuel in Turkey, it is concluded that nuclear power would be a very promising source of electricity to sustain and accelerate the country's economic development.

7. CONCLUSIONS

In developing countries such as Turkey, a continually increasing demand for electric power stimulates extensive investigation into the most economical means of electricity generation.

The introduction of nuclear power must, however, proceed step by step as the electricity system, looked at in its entirety, is developed The first nuclear power plant is planned to be commissioned in 1978. It is calculated that, by 1987, it would be necessary to introduce nuclear power with a capacity of 1350 MW(e).

The forecast of the energy demand shows that Turkey should probably introduce nuclear power stations with a total capacity of 5000 to 6000 MW(e) by 2000. It is shown that the generating costs of a nuclear power plant are in the same range as those of oil-fired thermal power plants when the appropriate taxes on fuel are included.

With fuel tax exemption, the generating cost of oil-fired plants appear to be about 20% lower than for a natural-uranium heavy-water-moderated nuclear power plant. But the generating costs of the heavy-water nuclear power plant would be lower than for a thermal power station burning imported fuel-oil.

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EGYPT
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POSSIBILITIES OF INTRODUCING AND INTEGRATING NUCLEAR POWER IN THE EGYPTIAN POWER SYSTEM

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Abstract–Résumé–Аннотация–Resumen

POSSIBILITIES OF INTRODUCING AND INTEGRATING NUCLEAR POWER IN THE EGYPTIAN POWER SYSTEM.

In Egypt the electric energy demand has increased in the last two decades at an average rate of 12.8% annually and it is expected that this trend will continue but with a slightly lower rate to meet the growing needs of electric energy required for industry, agriculture and social development. The consumption per capita increased from 43.4 kWh in 1952 to 188 kWh in 1969. It is anticipated that the doubling period for development of electric energy demand will be less than the 10-year period which is the average for the highly industrialized countries. In the light of the prospects of development of the electric demands on the Egyptian power system, a program for the additional generating capacity is developed. The present installed capacity in the unified national power system amounts to approximately 4000 MW, out of which 60% is hydroelectric and the rest is thermal. It is anticipated that the existing thermal and hydroelectric power stations and those under construction could meet the demand up to around 1975. Starting from that date, new generating capacity will be needed to meet the future requirements. In this paper, the different possible energy resources in Egypt are reviewed taking into consideration the possibility of the utilization of nuclear energy as a source for the production of electricity. The size and timing of introducing nuclear power plants are discussed together with the problems of their integration in the Egyptian network. The comparison between the technical and economic merits of nuclear stations with alternative sources under local conditions is undertaken. Various alternatives of the integration of nuclear plants are examined at different load levels for the cases of single-purpose electricity-only plants or dual-purpose plants for the combined production of electricity and water, with the eventual possibility of their association with high-energy consuming industrial projects. In the light of this study, the initial steps of introducing nuclear power in Egypt are reviewed. The effects of financing terms, particularly of the rate of interest, on the competitive size and the timing of introducing nuclear plants, are discussed.

POSSIBILITES D'INTRODUCTION ET D'INTEGRATION DE L'ENERGIE D'ORIGINE NUCLEAIRE DANS LE RESEAU ELECTRIQUE EGYPTIEN.

L'augmentation annuelle moyenne de la consommation d'énergie électrique en Egypte a été de 12,8% au cours des deux dernières décennies; il est prévu que cette tendance continuera à se manifester, bien qu'à une cadence un peu inférieure, pour satisfaire aux besoins croissants du développement industriel, agricole et social. La consommation par habitant a passé de 43,4 kWh en 1952 à 188 kWh en 1969. Il est prévu que le temps de doublement de la demande d'électricité sera de loin inférieur à celui de dix ans constaté dans les pays hautement industrialisés. A la lumière de ces prévisions, l'expansion de la puissance installée est envisagée. Cette puissance s'élève actuellement à 4000 MW, dont 60% sont d'origine hydro-électrique et le reste, soit 40%, d'origine thermique. On estime que les centrales actuelles (thermiques et hydro-électriques) et les nouvelles unités en cours de construction suffiront à couvrir les besoins jusqu'en 1975. Au-delà de cette date il faudra recourir à d'autres ressources pour répondre aux besoins. Le mémoire passe en revue les possibilités qui s'offrent à l'Egypte dans ce domaine, y compris l'utilisation de l'énergie nucléaire. La puissance des centrales nucléaires et le moment le plus propice à leur introduction et à leur intégration dans le réseau électrique égyptien font l'objet d'une étude détaillée. Une comparaison technico-économique des centrales nucléaires et conventionnelles est faite dans le contexte local. Plusieurs alternatives sont examinées en ce qui concerne l'intégration de centrales nucléaires dans le réseau électrique égyptien, et ceci pour différents niveaux de consommation: utilisation d'une centrale en vue de la seule production d'énergie électrique;

centrales à double fin pour la production d'énergie électrique et le dessalement de l'eau de mer, compte tenu de la possibilité d'utiliser la totalité ou une partie de l'énergie électrique dans un ou plusieurs centres industriels gros consommateurs et situés à proximité de la centrale. A la lumière de cette étude les premières étapes de l'introduction de l'énergie nucléaire en Egypte sont examinées. L'influence des modalités de financement et, en particulier, du taux d'intérêt, sur la puissance optimale des centrales nucléaires et le moment de leur introduction est aussi discutée.

ВОЗМОЖНОСТИ РАЗВИТИЯ ЯДЕРНОЙ ЭНЕРГЕТИКИ И ВКЛЮЧЕНИЯ АТОМНЫХ ЭЛЕКТРОСТАНЦИЙ В ЭНЕРГЕТИЧЕСКУЮ СИСТЕМУ АРАБСКОЙ РЕСПУБЛИКИ ЕГИПЕТ.

За последние два десятилетия потребность в электроэнергии в Египте увеличивалась ежегодно в среднем на 12,8%. Ожидается, что эта тенденция будет развиваться, но уже более низкими темпами, с тем чтобы удовлетворить растущие потребности в электроэнергии, необходимой для промышленности, сельского хозяйства и социального развития. Потребление электроэнергии на душу населения возросло с 43,4 кВт-ч в 1952 году до 188 кВт-ч в 1969 году. Предполагается, что период удвоения потребностей в электроэнергии составит менее 10 лет, что является средним значением для высокоиндустриальных стран. В свете перспективного влияния растущих потребностей в электроэнергии на энергетическую систему Египта, разрабатывается программа введения в строй дополнительных мощностей. Настоящая установленная мощность в объединенной национальной энергосистеме составляет примерно 4000 МВт, из которых 60% падает на гидростанции и остальная часть на тепловые. Предполагается, что существующие, а также находящиеся в стадии строительства тепловые и гидроэлектростанции смогли бы удовлетворить потребности в электроэнергии приблизительно до 1975 года. С этого времени будут необходимы новые мощности по производству электроэнергии для удовлетворения будущих потребностей. В настоящем докладе дается обзор различных возможных энергетических ресурсов в Египте с учетом возможности использования ядерной энергии как источника для производства электроэнергии. Размер атомных электростанций и время их включения рассматриваются наряду с вопросами их объединения в энергосистеме Египта. Проводится сравнение технических и экономических характеристик ядерных станций с обычными источниками энергии с учетом местных условий. Рассматриваются различные альтернативы объединения атомных электростанций при различных уровнях нагрузки в случае одноцелевых или двухцелевых установок для одновременного производства электроэнергии и опреснения воды с учетом возможности их объединения с энергоемкими промышленными объектами. В свете этой работы дается обзор первых шагов Египта в области внедрения ядерной энергетики. Рассматривается влияние финансовых условий, особенно касающихся процентных ставок, на конкурентоспособный размер и определение времени ввода в эксплуатацию атомных электростанций.

LAS POSIBILIDADES DE INTRODUCCION E INTEGRACION DE ENERGIA NUCLEAR EN EL SISTEMA DE ENERGIA ELECTRICA DE EGIPTO.

En Egipto la demanda de energía eléctrica ha experimentado en los dos últimos decenios un incremento cuyo índice promedio anual ha sido del 12,8% y se prevé que esta tendencia se mantendrá, si bien con un índice ligeramente inferior, para satisfacer las crecientes necesidades de energía eléctrica en el desarrollo de la industria, de la agricultura y social. El consumo por habitante aumentó desde 43,4 kWh en 1952 hasta 188 kWh en 1969. Se puede predecir que el período de duplicación de la demanda de energía eléctrica será inferior a 10 años, que es el promedio para los países altamente industrializados. A la luz de las previsiones de desarrollo de la demanda de electricidad en Egipto se ha elaborado un programa para conseguir una capacidad adicional de generación de energía. La potencia instalada actual en el sistema nacional unificado asciende, aproximadamente, a 4000 MW, de los cuales el 60% es hidroeléctrica y el resto térmica. Se estima que la demanda podrá ser atendida por las centrales hidroeléctricas y térmicas existentes y por las que se hallan en construcción hasta, aproximadamente, el año 1975. A partir de esta fecha será necesaria nueva capacidad de generación para satisfacer las necesidades futuras. En la presente memoria se examinan los diferentes recursos energéticos de posible existencia en Egipto tomándose en consideración la posibilidad de la utilización de la energía nuclear como medio para producir electricidad. En el informe se estudian el tamaño y las fechas propicias para la introducción de centrales nucleares así como los problemas que plantea su integración en la red eléctrica de Egipto. También se comparan las ventajas técnicas y económicas de las centrales nucleares y de las centrales convencionales teniendo en cuenta las condiciones locales. Se examinan varias alternativas para la integración de centrales nucleares en el sistema eléctrico egipcio, en correspondencia con diferentes niveles de consumo, tanto para los casos de centrales de uso único generadoras de electricidad como para los de centrales de doble uso productoras de electricidad y desaladoras de agua, con la posibilidad eventual de asociarlas a proyectos industriales con un consumo de electricidad muy elevado. A la vista de este estudio se examinan las etapas iniciales de la introducción de la energía nuclear en Egipto. Los efectos que dependen de las modalidades de financiación, en particular del tipo de interés, del tamaño de las centrales y de las fechas de introducción de las mismas son asimismo debatidos.

1. INTRODUCTION

The development programs for industrializing Egypt and the expanded land reclamation schemes have resulted in greatly increased demands for a dependable electric power supply. Consequently the expansion of the electric power system during the past 20 years has been very extensive. From an installed capacity of 384 MW(e) in 1952, the capacity of the system grew to 4100 MW(e) by 1970 upon the completion of the High Dam Project and its associated 2100-MW(e) installed hydro-electric station.

Estimates of the new generation capacity required, and the choice of the type of plants are governed to a large extent by comparative economic considerations between the remaining hydro potential and the construction of thermal stations with the possibilities of integrating nuclear power plants in the grid system. In the light of power system considerations and of comparative economic studies of nuclear power plants with alternative conventional thermal plants, the prospects of integrating nuclear plants in the system are discussed.

TABLE I. TENTATIVE DIVISION OF ENERGY PRODUCTION BETWEEN THERMAL AND HYDRO STATIONS AND EXPECTED POWER DEFICIT

(A) Energy balance:

Energy consumption level (10^9 kWh)		12.0	13.72	15.0	16.56	18.51
Maximum hydro energy production (10^9 kWh)	low flow	8.55	8.56	9.2	9.2	9.2
	high flow	9.63	10.21	10.7	10.7	10.7
Contribution of hydro stations (10^9 kWh)	low flow	7.96	8.35	9.0	9.15	9.2
	high flow	8.57	9.36	10.0	10.09	10.26
Contribution of thermal stations (10^9 kWh)	high flow	3.43	4.36	5.0	6.47	8.26
	low flow	4.04	5.37	6.0	7.41	9.31
Possible year of occurrence		1973	1974	1975	1976	1980

(B) Power balance:

	(MW)	(MW)	(MW)	(MW)	(MW)
Design peak load	2470	2625	2700	2770	2850
Max. contribution of hydro stations	1020	1020	1030	1060	1100
Necessary contribution of thermal stations	1450	1605	1670	1710	1750
Peak power deficit (including its reserve)	95	280	355	395	470
Possible year of occurrence	1976	1977	1978	1979	1980

TABLE II. ANNUAL OPERATING CONDITIONS OF HYDRO AND THERMAL STATIONS[a] (at a load level 2850 MW)

Items	July	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June
UPS peak load (MW)	2740	2763	2784	2810	2830	2850	2850	2847	2840	2835	2830	2825
A. Low-water conditions:												
Average daily power of the Aswan and High Dam HEPS[b] (MW)	1414	1170	960	920	940	1020	625	910	940	927	1006	1376
Contribution of the HEPS in meeting the peak load (MW)	1715	1475	1258	1258	1300	1390	1100	1270	1310	1272	1346	1700
Contribution of existing TEPS[c] and a new station in meeting the peak load (MW)	1025	1288	1504	1552	1530	1460	1750	1577	1530	1563	1484	1125
Utilization of the total power of the TEPS and of the new station (%)	65	82	95	98	97	93	99	100	97	99	94	71
B. High-water conditions:												
Average daily power of the Aswan and High Dam HEPS (MW)	1827	1741	1276	1120	1173	1320	723	1120	1202	1182	1644	1852
Contribution of the HEPS in meeting the peak load (MW)	1900	1900	1590	1450	1450	1523	1690	1476	1552	1527	1900	1900
Contribution of existing TEPS and a new station in meeting the peak load (MW)	840	863	1194	1360	1307	1160	1374	1370	1288	1308	930	925
Utilization of the total power of the TEPS and of the new station (%)	53	55	75	86	83	73	78	87	82	83	59	59

[a] Total available thermal power will be 1772 MW in January and 1577 MW (for remaining months), taking into consideration planned maintenance. Including a new station of 500 MW.

[b] HEPS = hydro-electric power stations.

[c] TEPS = thermal electric power stations.

2. POWER SYSTEM CONSIDERATIONS

At present, electricity is produced in Egypt mainly by eleven thermal stations in the Cairo area and Lower Egypt with an installed capacity totalling 1351 MW, and two hydro-electric stations in the Aswan area, namely the Aswan and the High Dam stations with an installed capacity of 2445 MW. The upstream level of the High Dam reservoir is at present lower than projected and hence also the available power. As the water discharge through the stations undergoes fluctuations to meet the irrigation requirements, the available power from the hydro-block varies from a minimum of 500-600 MW in January to a maximum of 1500-1600 MW in July. The thermal stations are connected together by means of a 220-kV network, which is in turn interconnected with the hydro-electric complex through a 500-kV transmission system to form a Unified Power System (UPS). Another small thermal unit not connected to the UPS brings the total installed capacity up to about 4100 MW(e). With the completion of a new thermal station which is now under construction, the installed capacity of the interconnected thermal stations on the UPS will reach 1560 MW in 1974. Also, the available hydro-electric power and energy will increase gradually with the filling of the reservoir. Tables I and II show the estimated annual energy production and the monthly variation of the output of the hydro-block under low and high water flow conditions.

2.1. Optimum utilization of the UPS

The thermal stations and the hydro-electric block are now operated in full co-ordination so as to obtain the maximum utilization of the hydro-electric energy. The High Dam station is regulated to cope with the peak demand and the schedules of maintenance and repair of thermal stations are co-ordinated with the water-discharge conditions.

The commissioning of the High Dam power station and its co-ordinated mode of operation have resulted in the reduction of the utilization of the thermal stations. However, with the increase of the load on the UPS, the utilization of the thermal energy will gradually increase up to the highest allowable limits. At the same time, hydro-energy utilization will also increase to cope with the future increase of the energy demand. Table I shows a tentative estimation of the division of energy between thermal and hydro-electric stations for successive levels of total energy consumption. From the table it can be seen that the utilization of the hydro energy will increase with the growth of the energy consumption level and will approach the full utilization by 1980.

2.2. Potential hydro-power resources of Egypt

2.2.1. Potential resources of the Nile

Preliminary studies show that the utilization of the slopes between Aswan and Delta Barrages for power production (about 600 MW) may be realized by building seven new barrages in addition to the three existing ones. The available annual energy will amount to about 4677 million kWh.

2.2.2. The Qattara project

The Qattara project, named after a deep depression in the Western Desert near El-Alamain presents a unique large-scale hydro-electric potential. The idea is based on spilling the Mediterranean sea water in this depression to produce electricity.

Extensive geological, topographical and hydrological investigations have shown so far that the most economical scheme can be realized by a complex project including a high storage pumping scheme, using a natural basin on a plateau with a capacity of 50 million m^3 at 285 m level. Further investigations are being carried out.

During off-peak hours the water is used for the continuous generation of electricity, which is utilized in addition to electric energy from the grid in pumping water to a high-level reservoir; then at peak load periods this water at a head of 285 m can cover the peak demands up to 4000 MW. The project is visualized to be executed in three stages to meet peak loads of 625, 1500, 2100 and ultimately 4000 MW.

2.3. Projected growth of consumption

The economic development programs are aimed at realizing the equilibrium between the various sectors of production within the State (industry and agriculture) and at gearing the development of the public service to the welfare of the people, with the ultimate aim of raising the levels of the standard of living. It is therefore important to predict the probable evolution of the demand of electric energy to project the incidence of the future consumption on the electricity sector itself.

Estimates of the future development of electricity consumption for the period extending from 1970-1980, are based on two main assumptions:

(a) The first assumption is that the development of the actual consumption of the different categories of electric energy demands are to increase at an annual average of 6.5% – with the exception of the consumption by heavy industries and the irrigation and drainage pumping stations.

(b) The second assumption is based on estimates of the loads required by the new large industrial projects, as well as the loads required by the projected expansion of the existing heavy industries, in addition to the loads necessary to meet the requirements of the rapidly expanding agricultural sector. Combination of these two assumptions will give an average annual increase of about 10.5%.

2.4. Industrial demands

The expected energy consumption of the new industrial projects, (electro-metallurgical, electro-chemical and petro-chemical) will reach 5.7 milliard kWh before the end of the present decade, and the consumption of the projected expansion of the already existing large industrial plants will reach 1.5 milliard kWh.

2.5. Agricultural demands

The loads required for the agricultural sector represent a great leap forward in the field of irrigation and drainage. A considerable increase in energy consumption is necessitated by the fact that large areas of new land have been reclaimed for agriculture. The average annual increase of the energy consumption is expected to be about 16.5% (from 1970 to 1980). It is to be noted that the annual increase will be very high at the beginning of the said decade but will, however, decrease gradually to reach about 6.2% by the end of the decade.

On the basis of the two assumptions outlined above and taking into consideration the industrial and agricultural demands, the anticipated total energy consumption for the period (1970-1980) is estimated.

The energy consumption of new industrial projects as well as that due to the expansion of the existing industries and the agricultural sector, represents about 51.6% of the total energy consumption by all consumers.

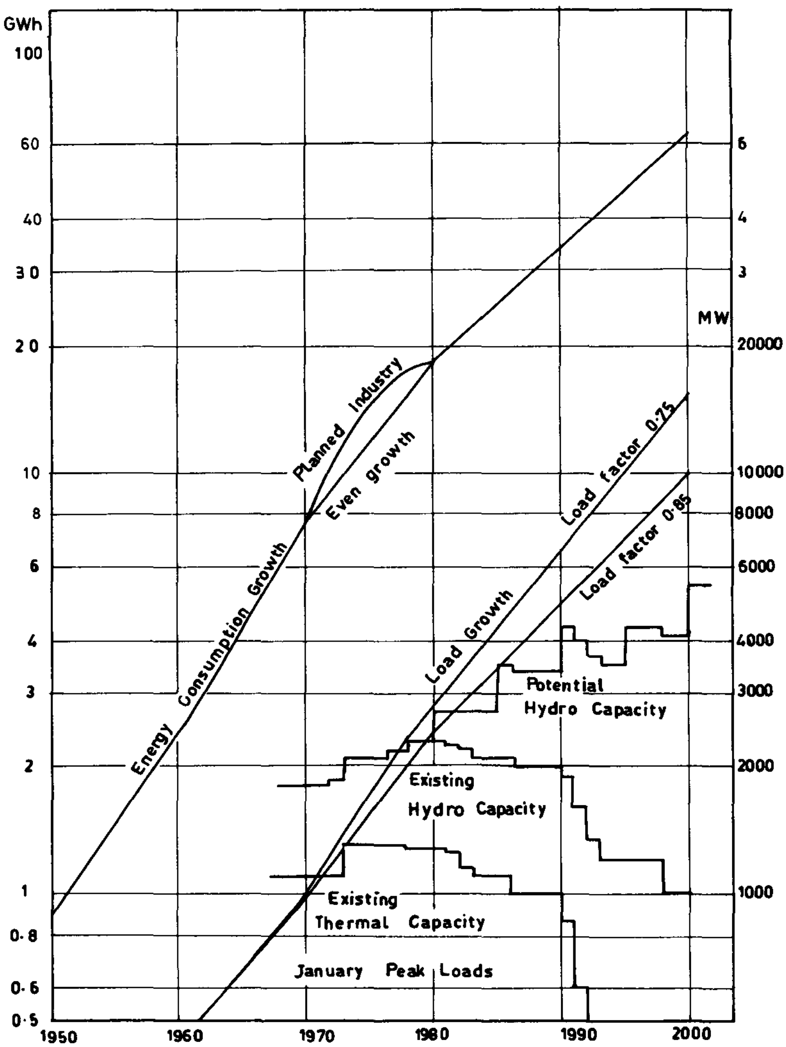

FIG. 1. Energy consumption and peak load growth.

Figure 1 shows the evolution of energy consumption and corresponding load from 1950 to the year 2000. From 1950 to 1970 the curves represent actual data. Estimates from 1971 to 1980 are based on the two assumptions referred to above. Further projections up to the year 2000 are based on 7.5% development rate. This represents a total energy consumption of 65 milliard kWh in the year 2000. The corresponding load level will vary between 10 000 and 16 000 MW according to the load factor in each case with an average of 13 000 MW.

3. OPTIMUM PATTERN OF THE DEVELOPMENT OF GENERATING CAPACITY

3.1. Future generating capacity requirements

It is anticipated that the existing thermal stations will retire successively, starting from 1980 and the whole capacity of these stations will be out of use by 1998. The present hydro power would still be in service and would contribute about 1000 MW during minimum water flow conditions (January).

Taking into account the remaining unexploited hydro potential resources, namely the Nile Barrages and the Qattara depression schemes, which would contribute about 4400-MW peak load, this will leave 7500 MW in the year 2000 to be progressively covered by additional thermal power to be installed, starting from the year 1976. It can be assumed that about half this new capacity would work under base load conditions.

On the other hand, as indicated in the paper on desalination submitted to this conference [1], the projected water deficit, which is anticipated to be covered by desalination, is estimated as 4-5 milliard m^3 by the year 2000. This will require thermal energy equivalent to about 8000-10 000 MW(e).

3.2. Time of addition of new generating capacity

Examination of power balance shows that the existing thermal and hydro-electric stations (under low-water conditions) can meet the rising demands of the system until the total consumption level reaches 16 milliard kWh, corresponding to a peak load of 2400 MW.

In accordance with the development plans available at the time of writing this paper, the system maximum demand may rise to about 2000 MW by 1975.

It is clear that the maximum load of the system in 1975 will be considerably lower than the capacity of the generating stations in operation. This means that up to 1975 the system will not need any additional generating capacity other than the thermal station now under construction.

The magnitude of the additional generating capacity and the optimum time of its operation beyond that period depends mainly upon the growth-rate of energy consumption and maximum demand on the system. Table II shows the mode of operation for different levels of load development up to 2850 MW expected in 1980, due consideration being given to the best utilization of hydro energy.

It is thus clear that with a peak load of 2625 MW the system would have a power deficit of about 280 MW, which rises progressively with the peak load to about 470 MW at a load level of 2850 MW. A tentative estimate of 100 MW to cover part of the load requirements of the recent extensive rural electrification plan is assumed.

3.3. Expected operating conditions and requirements for a new generating station (about 500 MW)

The existing High Dam hydro-electric station can cover the entire daily irregularities of the system consumption during the period up till 1980. Thus, the thermal power stations will work mainly as base load stations to supply part of the daily base load energy requirements.

However, in order to absorb the high energy output of the High Dam during the period from June to August, while high irrigation requirements are needed, the hydro power stations should share more energy in the daily base load energy requirements, and consequently the share of base load energy to be supplied by the thermal power stations will be uneven around the year.

Calculations show that during high-water flow, in the summer period, the actual utilization of the available hydro-electric power depends on the minimum permissible loading of the thermal units which should be in operation to satisfy the stability conditions of the system.

Accordingly, when planning for a new thermal station, due consideration should be given to the loading range to allow for the minimum possible load on such a station in order to secure the maximum utilization of the hydro stations during high-water discharge. Consideration should also be given to the quick response when sudden loading is required of such a station in order to secure the spinning reserve capacity necessary to meet the emergency outages of the 500-kV transmission system.

It is clear that if a new station is not available by 1980, the system will suffer a power deficit of around 480 MW during nine months of the year. Thus a new station added in the system to cover the power and energy deficit will be intensely utilized during the major part of the year. Under high-water conditions there would be practically no power deficit owing to the higher generation of the hydro stations. However, this condition cannot be assumed when planning for new generating capacity to cover a deficit in the system.

The utilization factor of both – the existing thermal power stations and a new thermal station with a rating of 500 MW (with the system load of 2850 MW) – is shown in Table II, which is calculated for the conditions of low- and high-water flow at the High Dam hydro station.

It is clearly seen that the total power of the existing thermal stations and the new station will be completely and uniformly utilized during nine months under both low- and high-water flow conditions. However, in the period of the higher hydro generation (June-August) it will be required to unload thermal stations by 35-40% under low-water conditions and by 40-45% under high-water conditions.

3.4. Unit sizes

The largest unit size available in the present system is 175 MW(e) of the High Dam station and 110 MW(e) in thermal stations. Further unit sizes acceptable in the unified power system have been estimated on the basis of 10-5% of the connected load. Accordingly, the following unit sizes could be readily integrated in the system:

Period	Load level (MW)	Unit size (MW(e))
1977-1980	2850	285
1985	3750	375
1990	5000	500
1995	8000	600
2000	13 000	650

4. INTEGRATION OF NUCLEAR POWER PLANTS

4.1. Comparative study

During the past few years there has been a trend towards steady increase in unit sizes of nuclear plants whereby they would be economically competitive with conventional thermal plants. The break-even size of nuclear and conventional plants is, however, dependant upon local conditions and is particularly sensitive to the economic parameters used in cost analysis. Wide variations are therefore expected and a careful examination should be made for the specific conditions of the situation under consideration.

In considering the possibilities of nuclear power integration in the Egyptian electric grid system, a comparative study has been made for the possible variations in the break-even sizes, for light-water reactor plants and oil-fired stations. The light-water reactor system was chosen for the purpose of this study solely because more reasonably consistent data are at present readily available for light-water than for any other reactor system. This choice however should not imply any prejudgement or preferance for this particular system.

The economic comparison between nuclear and conventional thermal plants was carried out for the conditions of a manufacturing country and under the conditions pertaining to developing countries in which nuclear plants may be installed. The main economic parameters which have been considered in the analysis are:

(a) Capital charges on investment costs;
(b) Fuel oil and nuclear fuel prices and future trends;
(c) Capital cost variations due to escalation in manufacturing countries;
(d) Capital cost adjustments for the conditions of developing countries according to their level of development.

Cost data for light-water reactors and oil-fired plants for unit sizes ranging from 100-1000 MW(e) were obtained from published literature by various authors and IAEA reports [2-4]. The capital investment cost data obtained were considered to represent the conditions in the manufacturing country at the price levels of 1970. Cost adjustments for developing countries were based on an estimated increase in costs of 30 and 40% [5-7] according to the level of development. The differences between the total annual charges for capital investment (including fuel inventory), operation

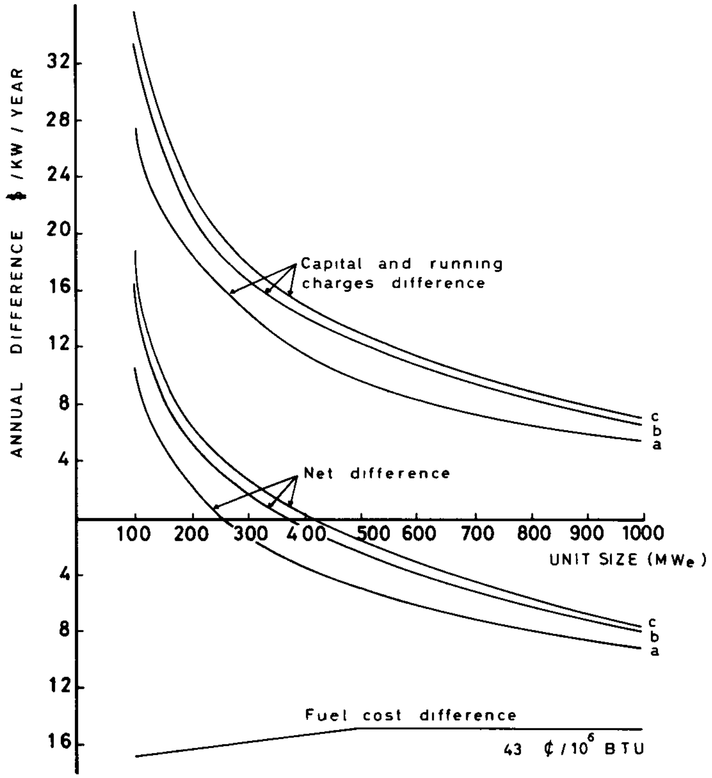

FIG.2. Break-even sizes between nuclear and oil-fired plants (7% fixed-charge rate).
a. Manufacturing countries; b. Developing countries, 30% increase (1980 price levels);
c. Developing countries, 40% increase (1980 price levels).

and maintenance and insurance, between nuclear and oil-fired plants over the unit-size range considered, were calculated from published data. The difference between the annual nuclear fuel replacement costs and fuel-oil costs was similarly calculated. The net differential annual costs were plotted and the break-even sizes were obtained from the corresponding curves for the conditions of the manufacturing country and for the two assumed adjustments of 30 and 40% for developing countries' conditions. Figure 2 shows a typical set of curves for a fixed charge-rate of 7% and fuel-oil price of 43 $¢/10^6$ Btu.

Break-even sizes were obtained for different interest rates representing different conditions of financing corresponding to fixed-charge rates of 5, 7, 10 and 14%; and for different escalation in prices due to rising costs of labour and materials in manufacturing countries as estimated from appropriate extrapolated reactor cost index numbers [6, 8] for 1975 and 1980 price levels, as well as for fuel-oil and nuclear fuel prices. The results are presented in Table III.

Although these results are based on published data and estimates involving various economic assumptions, they can be taken as a useful guide upon which some tentative but nevertheless important conclusions may

TABLE III. VARIATION OF BREAK-EVEN SIZE BETWEEN NUCLEAR AND OIL-FIRED PLANTS

A. Manufacturing countries

Fuel prices (¢/10⁶ Btu)			Break-even size (MW(e))			
Year	Nuclear	Oil-fired	5% FCR[c]	7% FCR	10% FCR	14% FCR
1970	15	30	260	435	590	765
		35	135	235	380	575
		40	100	150	260	435
1975	17	36	190	315	505	750
		42	105	155	315	500
		50	100	100	205	340
1980	19	43	125	255	415	635
		50	100	145	255	445

B. Developing countries

Fuel prices (¢/10⁶ Btu)			Break-even size (MW(e))			
Year	Nuclear	Oil-fired	5% FCR	7% FCR	10% FCR	14% FCR
1970	15	30	355[a]—400[b]	545[a]—600[b]	800[a]—865[b]	> 1000
		35	200 —230	360 —400	580 —645	835[a]— 900[b]
		40	143 —155	230 —260	400 —450	650 — 710
1975	17	36	290 —320	460 —515	700 —790	960 —1000
		42	145 —160	265 —315	460 —515	700 — 755
		50	105 —110	150 —170	300 —335	505 — 560
1980	19	43	200 —235	370 —415	560 —630	890 — 960
		50	120 —140	215 —245	375 —430	640 — 720

[a] For 30% increase.
[b] For 40% increase.
[c] FCR = fixed-charge rate.

be drawn. First, the pronounced effect of the financing terms is clearly seen by the wide variations of the break-even size with the fixed-charge rate, and its particular sensitivity to fuel-oil prices. The recent increase in international market oil prices according to the agreements concluded, in February and March of this year, between the oil firms and the producing countries, will result in an immediate price increase of about 20%, and a further increase of 3% annually until 1975. This increase will have a marked effect on the energy costs from conventional plants where the fuel cost component of the generating cost is rather high, representing about 70%.

From Table III a 20% increase in fuel-oil price results in a decrease in the break-even size of about 160 MW(e) in favour of the nuclear plants. Predictions in nuclear fuel price increase for the period 1970-1980 were obtained from published data [4]. Secondly, the financing terms are clearly seen to affect appreciably the break-even size. A change of the fixed-charge rate from 10 to 7% results in a marked decrease of the break-even size of the order of 150-200 MW(e).

The above considerations indicate that for developing countries, under appropriate conditions and favourable terms of financing, nuclear power plants of intermediate unit sizes acceptable in their grid system capacity, may economically compete with alternative conventional plants.

In Egypt, the financing of the main recent electricity generating stations has been obtained on rather favourable terms ranging from the special AID loan from the United States of America of $\frac{3}{4}$% over 40 years for the Cairo West power plant, to the loan from the USSR of $2\frac{1}{2}$% over 12 years after commissioning for the High Dam hydro-electric station. For nuclear plants, although similar or better terms are expected, an interest rate of 5% corresponding to a fixed-charge rate of 7%, for a nuclear station life of 25 years, has been used in determining the break-even size. This value is the fixed-charge rate generally used in Egypt for the economic analysis of conventional stations.

Fuel-oil prices in Egypt have been established by the Government at a uniform price of 7.5 LE/t, which corresponds to about 43 ¢/10^6 Btu. This price is considered to be rather conservative to use for 1980, in view of higher oil prices anticipated in the future owing to the recent price increases.

Accordingly, for 1975-1980 a fixed-charge rate of 7% and a fuel-oil price at 43 ¢/10^6 Btu have been assumed. The corresponding break-even sizes of nuclear plants from Table III are 265-315 MW(e) for 1975 and 370-415 MW(e) for 1980. It has therefore been assumed that during this period the size range of 300-400 MW(e) could be considered in any economic comparison between nuclear and conventional new thermal generating plant to be installed during the period up to 1980.

5. PROSPECTS OF NUCLEAR POWER

From the previous considerations of the electric power system projected future requirements, and the comparative study of the competitiveness of nuclear and alternative thermal plants, the long-range prospects of nuclear power, as well as the timing and size for the first nuclear power plant, have been considered in the light of the following points:

(a) Anticipated energy and power requirements for electricity demands will grow progressively from the year 1980 reaching 65 milliard kWh with a corresponding load level of 13 000 MW(e) by the year 2000. Assuming full exploitation of the potential hydro energy from the Nile Barrages and Qattara depression during this period, the remaining power to be covered by new generating thermal plants will be about 7500 MW(e), out of which 3500 MW(e) have been considered to operate as base-load stations. The annual growth of demand is estimated at a rate of 200 MW(e) at the beginning of the period and about 500 MW(e) near the end of the same period.

(b) During the same period, the electric grid system will accept unit sizes ranging from 300 MW(e) around 1980 up to 600 MW(e) near the year 2000.

(c) Projections of long-range water requirements have shown that, after exploitation of conventional water resources, the remaining water deficit to be covered progressively by desalting sea-water from 1980 to 2000, will amount to about 4-5 milliards m^3 in the year 2000 [1]. Additional power requirements necessary to produce the heat energy required are estimated to be equivalent to about 8000-10 000 MW(e).

(d) During 1976-1980 there will be a power deficit in the system, under assumed low-water conditions, amounting to about 100 MW(e) in 1976 and reaching about 500 MW(e) in 1980.

(e) The economic comparison between nuclear and alternative thermal plants, show that at a fixed-charge rate of 7% and fuel-oil price of 43 ¢/10^6 Btu, which are the conditions assumed to prevail in Egypt, the break-even size in this period ranges from 300 to 400 MW(e).

In the light of the above conditions and considerations, the future prospects of nuclear power in Egypt are visualized as follows.

5.1. Long-range prospects

It is anticipated that the period 1980-2000 will be characterized by an intensive and expanding program of nuclear power involving electricity generating units of 300-600 MW(e) to cover a major part of the previously mentioned estimated base-load power deficit of 3500 MW(e). The exact timing, choice of size and type of plant to be installed will be governed mainly by pure economic considerations, by the commercial availability of suitable sizes from manufacturers, and the basic requirement of obtaining favourable financing terms.

For electricity generation only, it is estimated that from five to seven nuclear plants in the size range mentioned above could be installed during this period.

Consideration of additional power requirements, to cover the predicted water deficit, leads to the possibility and necessity of dual-purpose plants for the combined production of electricity and desalted water instead of the aforementioned electricity-only plants. Optimized dual-purpose nuclear plants are considered to provide the most economical means for meeting these requirements. However, since for such plants a water-to-power ratio of about 2 MW(e)/MGD[1] is required [9] and, assuming that about 2 MW(e) are needed to produce 1 MGD water [10] and that all the previously mentioned electricity base-load requirements from thermal plants are covered by nuclear stations, the maximum electric power equivalent for water production from optimized dual-purpose plants will be 3500 MW(e).

For these dual-purpose plants, reactor unit sizes would be increased to 600-1200 MW(e) equivalent, which will have the added economic advantages of the economy of scale resulting in a reduction in both electricity and water costs.

The remaining power requirements for water production of 4500-6500 MW(e) equivalent will be in excess of the total capacity of optimized dual-

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[1] MGD = 10^6 gal/day.

purpose plants. These could be covered by nuclear or conventional single-purpose water-only plants or by the installation of the dual-purpose plants with water-to-power ratio much higher than that required for optimization.

Under such conditions it is visualized that single-purpose nuclear water-only plants could play an increasingly important role. Attention has been drawn to this fact in another paper submitted to this conference [1], particularly that similar situations will undoubtedly prevail in various other arid developing countries, and hence the necessity for concentrated efforts to develop such plants. It should be pointed out that, in such cases, the choice of water-only plants will depend on economic comparison with either unoptimized dual-purpose plants or conventional single-purpose water-only plants, as well as on other factors such as the flexibility in overall planning, technical advances etc.

The promotion of intensive energy consuming industrial projects could further improve the overall economics of the UPS by improving the conditions of base-load operation with its implications of better utilization of nuclear power plants.

5.2. First nuclear power project

For meeting the power deficit of about 500 MW(e) expected to occur during 1976-1980, it is considered that a nuclear plant could be introduced in the system as a base-load station with a unit size of 300-400 MW(e). Such plant could be economically competitive with the conventional thermal alternative of smaller unit sizes compatible with the size of 285 MW(e) acceptable to the system at that time. The temporary increase incurred in the operational cost during the first few years of the UPS, to furnish the reserve capacity required to meet the larger unit size of the nuclear plant, could be compensated by better financing terms.

The early installation of the first nuclear power plant around 1978 is required to introduce necessary experience in nuclear power technology and to train engineers, scientists and skilled technicians to meet the needs of the expanding long-range nuclear power program in the subsequent two decades. The exact size and choice of nuclear plant type will be the subject of further detailed studies.

It is also considered that the inclusion with this plant of a pilot desalination unit of 5-10 MGD to provide water for a pilot experimental agricultural scheme will be of great advantage for the assessment of the future potential use of nuclear desalted water in agriculture.

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ПЕРСПЕКТИВЫ РАЗВИТИЯ ЯДЕРНОЙ ЭНЕРГЕТИКИ НАРОДНОЙ РЕСПУБЛИКИ БОЛГАРИИ

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Abstract–Résumé–Аннотация–Resumen

PROSPECTS FOR NUCLEAR POWER DEVELOPMENT IN THE PEOPLE'S REPUBLIC OF BULGARIA.

The reserves of organic fuel (coal, gas and oil) and hydro power in Bulgaria are limited. To fill the gap in its energy balance, Bulgaria will have to concentrate on nuclear power. Construction of the first Bulgarian nuclear power station near the town of Kozlodui on the Danube was begun in 1970. The station will have an output of 880 MW(e) from two water-moderated reactors each producing 440 MW(e). In 1972 work will begin on stepping up the output of the power station by another 880 MW(e), making a total output of 1760 MW(e). Since the steam condensation system has been designed for a 2000-MW(e) nuclear power station, it will be possible to increase the output still more at some time in the future. Another nuclear power station with an output of 1000 MW(e) is due for construction in 1980. Revision of the preliminary calculations will make it possible to increase the station's output to 2000 MW(e). It has not been finally decided, however, on what type of reactor further development of this power station system is to be based. The consumption of power in Bulgaria by the year 2000 is expected to be approximately 200 billion kW/h. Nuclear sources are expected to account for 60% of this power.

PERSPECTIVES DE DEVELOPPEMENT DE LA PRODUCTION D'ENERGIE NUCLEO-ELECTRIQUE EN REPUBLIQUE POPULAIRE DE BULGARIE.

Les réserves de la République populaire de Bulgarie de combustibles organiques (houille, gaz, mazout) et d'énergie hydraulique sont limitées. Pour combler le déficit de sa balance énergétique, elle doit recourir à l'utilisation de l'énergie d'origine nucléaire. La construction de la première centrale nucléo-électrique a commencé en Bulgarie en 1970. Située aux environs de Kozlodoui, petite ville riveraine du Danube, elle aura une puissance de 880 MW(e) et sera équipée de deux réacteurs ralentis à l'eau de 440 MW(e) chacun. Dès 1972 on commencera à l'agrandir et sa puissance sera portée à 1760 MW(e). Etant donné que le système de condensation de la vapeur est prévu pour satisfaire les besoins d'une station de 2000 MW(e) la puissance pourra encore être accrue plus tard. La construction d'une deuxième centrale nucléaire, d'une puissance de 1000 MW(e), est prévue pour 1980. Une revision des calculs permettra d'en faire passer la puissance à 2000 MW(e). Il n'a pas encore été définitivement décidé quelle filière devrait être adoptée pour le développement de cette centrale. On estime que la consommation d'énergie électrique en Bulgarie s'élèvera à 200 milliards de kWh en l'an 2000 et que plus de 60% de cette énergie devra être d'origine nucléaire.

ПЕРСПЕКТИВЫ РАЗВИТИЯ ЯДЕРНОЙ ЭНЕРГЕТИКИ НАРОДНОЙ РЕСПУБЛИКИ БОЛГАРИИ.

Запасы органического топлива (уголь, газ, нефть) и гидроэнергии в Болгарии ограничены. Чтобы восполнить дефицит в своем энергетическом балансе, наша страна должна сосредоточить свое внимание на ядерной энергетике. Строительство первой атомной электростанции Болгарии около небольшого придунайского городка Козлодуй началось в 1970 году. Мощность станции составит 880 МВт(эл). Она будет состоять из двух реакторов с водой в качестве замедлителя, каждый мощностью 440 МВт(эл). В 1972 году начнется наращивание мощности станции еще на 880 МВт(эл), что увеличит ее общую мощность до 1760 МВт(эл). Поскольку система конденсации пара предусмотрена для атомной электростанции мощностью в 2000 МВт(эл), в будущем возможно дальнейшее увеличение мощности станции. В 1980 году должна быть построена еще одна атомная электростанция мощностью 1000 МВт(эл). Изучение предварительных расчетов позволит увеличить мощность станции до 2000 МВт(эл). Однако еще не принято окончательное решение относительно типа реактора, на основе которого в дальнейшем должна развиваться система этой атомной электростанции. Предполагается, что потребление электроэнергии в Болгарии к 2000 году составит примерно 200 биллионов кВт-ч. Ожидается, что 60% этой энергии будет поступать из ядерного источника.

PERSPECTIVAS DE DESARROLLO DE LA ELECTRICIDAD NUCLEAR EN LA REPUBLICA POPULAR DE BULGARIA.

Las reservas de combustible orgánico (hulla, gas y petróleo) y de energía hidroeléctrica en Bulgaria son limitadas. A fin de colmar esta laguna de su inventario energético, Bulgaria tendrá que concentrarse en la energía nucleoeléctrica. En 1970 se empezó a construir la primera central nuclear del país cerca de la ciudad de Kozlodui, a orillas del Danubio. Tendrá una capacidad de 880 MW(e) y constará de dos reactores moderados con agua, de 440 MW(e) cada uno. En 1972 empezará a incrementarse su potencia en otros 880 MW(e), con lo que la capacidad total será de 1760 MW(e). Como el sistema de condensación de vapor ha sido diseñado para una central nuclear de 2000 MW(e), en lo sucesivo será posible aumentar todavía más la potencia. En 1980 empezará a construirse otra central nuclear de 1000 MW(e) de capacidad. Una revisión de los cálculos preliminares permitirá aumentar su capacidad hasta 2000 MW(e). No se ha decidido todavía qué tipo de reactor se utilizará para el ulterior desarrollo de esta central. Se calcula que el consumo de electricidad en Bulgaria en el año 2000 será de unos 200 mil millones de kW/h. Se confía en que el 60% de esta electricidad sea de origen nuclear.

В конце 1944 года общая мощность электростанций Народной Республики Болгарии (НРБ) составляла 130,5 МВт(эл), т.е. на душу населения приходилось лишь 45 кВт-ч. К 31 декабря 1970 года установленная мощность электростанций в НРБ достигла 4073 МВт(эл), а выработка электроэнергии – 19,5 млрд.кВт-ч, т.е. 2 213 кВт-ч на душу населения. За последние 15 лет выработка электроэнергии в НРБ удваивалась примерно за 4,5 года (или со средним годовым приростом – около 16%). В НРБ составлен прогноз развития энергетики с учетом возможных путей и будущих изменений в структуре топливно-энергетического хозяйства страны на период до 2000 года. Предварительные материалы прогноза свидетельствуют о непрерывном росте потребления электроэнергии до 2000 года, как это показано в табл.I.

Потребление электроэнергии на душу населения от 6400 кВт-ч в 1980 году повысится к 2000 году до 17 000-19 000 кВт-ч. В соответствии с ожидаемым ростом потребления электроэнергии ее выработка должна увеличиться приблизительно от 54 млрд.кВт-ч в 1980 году до 110 – 120 млрд.кВт-ч в 1990 году и до 200 млрд.кВт-ч в 2000 году.

В целях обеспечения производства такого количества электроэнергии установленные электроэнергетические производственные мощности должны быть увеличены приблизительно от 11 000 МВт в 1980 году до 40 000 МВт в 2000 году. При разработке прогноза развития энергетики особое внимание было уделено вопросу об установлении энергетических ресурсов, которые должны удовлетворять потребностям производства электроэнергии.

НРБ не располагает в достаточном количестве собственными энергоисточниками – около 140 т условного топлива на душу населения, т.е. меньше, чем 1/10 средних ресурсов мира. Из этих источников можно

ТАБЛИЦА I. ДАННЫЕ ПРЕДВАРИТЕЛЬНОГО ПРОГНОЗА

Данные прогноза	1960 г	1970 г	1980 г	1990 г	2000 г
Потребности в электроэнергии, млрд.кВт-ч	4,6	19,1	55-60	110-120	~200
Прирост за 10 лет, млрд.кВт-ч	3,2	14,5	36-40	50-60	80-100
Среднегодовой рост, %	18,9	15,3	11,2-11,6	6,4 -6,7	5-5,7

получить примерно 35-36 млрд.кВт-ч электроэнергии. Основная часть открывающихся в будущем органических энергетических ресурсов в нашей стране пойдет на удовлетворение потребностей других отраслей экономики.

Для нужд действующих в настоящий момент и намеченных к строительству до 1980 года теплоэлектрических станций будут использованы почти все известные, более или менее эффективные виды местного угля.

Из органического топлива будет использовано преимущественно жидкое и газообразное топливо для газотурбинных агрегатов и для непосредственного преобразования топлива в электроэнергию путем магнитно-гидродинамического метода.

Гидроэнергетические ресурсы страны, несмотря на их ограниченное количество, тоже в дальнейшем займут свое место в покрытии энергетического баланса. Максимальное экономически выгодное и целесообразное количество энергии, которое может быть получено на базе этих ресурсов (включая р. Дунай), составляет примерно 14 млрд.кВт-ч/г электроэнергии. К 1980 году гидроэлектростанции(ГЭС) будут вырабатывать 5–6 млрд.кВт-ч, а остальные мощности будут освоены до 2000 года. Общая мощность ГЭС к 2000 году возрастет приблизительно до 4000 МВт и будет удовлетворять лишь 5% общих потребностей.

Надо подчеркнуть, что ГЭС, намеченные к строительству, в особенности после 1980 года, требуют крупных капиталовложений, и по этой причине они будут сооружаться по мере необходимости.

Как было подчеркнуто выше, НРБ не располагает достаточным количеством классических энергетических ресурсов, и этот дефицит мы будем восстанавливать за счет импорта электроэнергии. В то же время на основании научно-технических и экономических исследований и разработок становится все более очевидным, что с точки зрения экономики нефть и природный газ лучше использовать не для добычи электроэнергии, а в качестве сырья в различных отраслях химической промышленности. Необходимо также учитывать и прогнозы конъюнктуры цен на мировом рынке, а также возможные трудности, имеющие место при импорте жидкого топлива и газа. В связи с этим надо прежде всего стремиться к их экономному и эффективному использованию. Отсюда следует, что тип и топливную базу электростанций, намечаемых к строительству в будущем, необходимо определять с учетом их эффективности, а также возможностей поставки импортных энергоресурсов. Зависимость производства электроэнергии в НРБ от импортных ресурсов и ограниченность классических национальных источников требует развития в Болгарии ядерной энергетики. Это является основным выводом, который был сделан у нас на основании прогноза развития энергетики на период до 2000 года.

Руководствуясь этим выводом, наша страна оказывает полную поддержку работам по выполнению программы строительства атомных электростанций не только в настоящей, VI-ой пятилетке, но и в течение долгосрочного плана развития страны до 2000 года.

На период 1971-1980 гг. в НРБ намечаются к строительству атомные электростанции общей мощностью примерно 2800 МВт(эл). По всей вероятности, на основании дополнительной переоценки эта цифра будет скорректирована до 3800 МВт(эл). Доля прироста выработки электроэнергии ядерного происхождения на период 1976-1980 гг. будет составлять не менее 50% общего прироста.

Мы считаем, что развитие ядерной энергетики до 1980 года должно способствовать созданию базы для накопления опыта в связи с ее широким развитием в дальнейшем.

Путем последовательного проведения линии систематического сооружения атомных электростанций их общая мощность к 1990 году возрастет примерно до 8000 МВт(эл). В период 1990-2000 гг. доля ядерной энергетики в общем приросте электроэнергетических мощностей будет составлять 75—85%. В тот же период атомные электростанции будут вырабатывать 60—65% общего количества электроэнергии.

Программа развития ядерной энергетики в НРБ до 1980 года основывается на атомных электростанциях с реакторами на тепловых нейтронах, водо-водяных реакторах с корпусами под давлением, поскольку на сегодняшнем этапе они являются в техническом отношении полностью освоенными и опробованными в эксплуатационных условиях. Учитывая мировой технический прогресс, мы считаем, что после 1980 года можно будет располагать атомными электростанциями с реакторами на быстрых нейтронах, которые будут опробованы в эксплуатационных условиях. В более отдаленной перспективе развитие нашей ядерной энергетики будет осуществляться преимущественно на базе реакторов на быстрых нейтронах.

Программа развития ядерной энергетики в нашей стране уже выполняется. Во втором квартале 1970 года в северо-западной Болгарии, где не хватает электрической энергии, началось строительство первой в НРБ атомной электростанции. Оборудование станции поставляется из Советского Союза. Мощность станции будет 880 МВт(эл). На станции смонтировано два водо-водяных реактора с корпусами под давлением (типа ВВЭР-440), каждый мощностью по 440 МВт(эл). На каждом реакторе установлено по две турбогенераторных группы мощностью по 220 МВт. Для охлаждения конденсата турбин будут использованы воды р.Дунай. Пуск первого реактора в эксплуатацию намечается в 1974 году, а второго — в 1975 году. В 1972 году начнутся работы по расширению станции еще на 880 МВт (эл). Таким образом, ее общая мощность достигнет 1760 МВт.

Строительство первой болгарской атомной станции осуществляется совместными усилиями наших и советских специалистов. В соответствии с условиями контракта о поставке станции, наши специалисты принимают участие в проектировании, строительстве, монтаже и наладке.

Наши проектировщики участвуют частично в разработке генерального плана главного корпуса. Они полностью проектируют: гидротехнические сооружения, пристань на р. Дунай, вспомогательный корпус с мастерскими и лабораториями станции, открытое электрораспределительное устройство, цех химводоочистки и некоторые другие вспомогательные сооружения. Все изыскательские работы (геологические, гидрогеологические и др.) выполнены нашими специалистами.

Строительные работы осуществляются болгарскими строителями при консультации, для особых видов строительных работ, с советскими специалистами. Проект организации строительства также разрабатывается у нас. Следует отметить, что возведение главного корпуса станции (машинный зал и реакторное отделение) выполняется методом "скользящей опалубки". При помощи этого метода значительно сокращаются сроки выполнения большей части основных строительных работ. Машинный зал будет построен за четыре этапа (длительность каждого этапа —

24 суток), а реакторный зал – за два этапа. Как видно, строительство нашей первой атомной станции осуществляется на современном техническом уровне, при высокой степени механизации. В настоящий момент на стройке используется 20 кранов различного типа, 18 экскаваторов, 55 бульдозеров и скреперов, сотни автосамосвалов, ряд автоматических бетонных центров, бетонных насосов и других механизмов. Инертные материалы добываются из р. Дунай, причем для этой цели на реке построена специальная пристань и моечно-сортировочная установка. Оборудование станции из СССР будет транспортироваться по р. Дунай. В связи с этим в ближайшее время будет закончено строительство искусственного лимана с эстакадой, на которой будет установлен 275-тонный мостовой кран для разгрузки тяжелого и крупногабаритного оборудования. Для более легких элементов эстакада оборудуется также 32-тонным краном. По своим возможностям разгрузки единичных тяжелых грузов пристань атомной электростанции занимает первое место в Болгарии.

В целях использования воды р. Дунай для конденсации пара за турбинами сооружается 6—километровый двойной канал(для холодной и теплой воды) максимальной пропускной способностью до 120 $м^3$/сек.

Как было отмечено, основное оборудование поставляется из Советского Союза, а часть вспомогательного оборудования изготовляется в Болгарии. В процессе строительства будущих атомных электростанций доля изготовляемого в нашей стране оборудования будет непрерывно увеличиваться.

Расширенная программа развития ядерной энергетики остро ставит вопрос и о подготовке необходимых специалистов. В специальной программе подготовки кадров предусматривается несколько форм обучения.

Значительная часть наших первоочередных нужд в кадрах будет удовлетворяться за счет дополнительной специализации в области ядерной энергетики специалистов с подходящим высшим образованием. Эта специализация начинается на 4-месячных курсах с 5-ю учебными предметами: физика ядерных реакторов, конструкция и технология ядерных реакторов, управление ядерными реакторами, дозиметрия и электропитание. Обучение будет сопровождаться соответствующими упражнениями и практикой на нашем исследовательском атомном реакторе. В качестве следующего этапа обучения предусматривается проведение в течении примерно 5 месяцев теоретической и практической подготовки на Нововоронежской атомной электростанции в СССР, где имеются реакторы того же типа.

Наряду с этим идет подготовка специалистов и в высших учебных заведениях. В болгарских высших учебных заведениях сейчас формируются новые профили, где на базе подходящей общей специальности (напр. теплоэнергетика, электроника, физика) в конце обучения студент получает соответствующую специализацию. Каждый год определенное число молодых людей направляется в зарубежные учебные заведения в соответствии с нашей программой.

Для подготовки специалистов предусматриваются и долгосрочные командировки за границу. Часть этих командировок предоставляется нашей стране в виде стипендий Международным агентством по атомной энергии. Мы будем благодарны Международному агентству по атомной энергии, если число стипендий будет увеличено.

Кадры со средним техническим образованием подготавливаются в техникумах с 4-летним курсом обучения. Здесь также применяется система дополнительной специализации на базе подходящей основной специальности.

Большое значение в подготовке специалистов для эксплуатации станции имеет их непосредственное участие в строительстве и монтаже атомной станции. По этой причине уже сейчас они назначаются на работу, по окончании первоначальной специализации приходят на стройку и активно включаются в работу по выполнению строительных операций.

В 1944 году Болгария занимала одно из последних мест в мире по выработке электроэнергии на душу населения. За 26 лет, в результате ускоренного экономического и научно-технического развития, к 1970 году она уже достигла уровня многих других промышленно развитых стран мира. Мы надеемся, что, осуществив эту большую для наших условий программу развития ядерной энергетики, к 2000 году Болгария станет одной из ведущих стран мира по производству электроэнергии на душу населения.

FUNDAMENTAL ECONOMIC AND NATIONAL ENERGY BALANCE UNDERLYING FUTURE DEVELOPMENT OF NUCLEAR POWER IN POLAND

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Abstract–Résumé–Аннотация–Resumen

FUNDAMENTAL ECONOMIC AND NATIONAL ENERGY BALANCE UNDERLYING FUTURE DEVELOPMENT OF NUCLEAR POWER IN POLAND.

Poland possesses large and favourably deposited resources of hard and brown coal and, with her present production of hard coal occupies fifth place in the world as a coal mining country, and as an exporting country, the third place. Cheap coal resources justify a delay in developing the nuclear power in comparison with countries with a deficiency of conventional fuels. However, the high rate of industrial development in the steel, copper, sulphur, machine, chemical and textile industries, means a considerable increase of power demand which, in the near future, will not be possible to cover even by the growing coal production. If the rate of increase of the total power demand is to be maintained until the end of the century and beyond at the level of 2.2 each 20 years, the rich Polish coal deposits would only last until the year 2070. The above premises and the unavoidable barriers connected with both site planning and obtaining the manpower for underground works, limit the increase of coal mining in Poland to 205×10^6 t in 1985 and 310×10^6t in 2000. Forecasts of complex power balances up to the year 2000, taking into account the above-mentioned circumstances, indicate the necessity to develop nuclear power during the last 20 years of this century at an average rate of 1000 MW installed per annum. Thus, the capacity of nuclear power plants in 2000 could amount to 20 000 MW, which would constitute 20% of the total capacity installed in the Polish power industry and a 30% contribution in the total energy production. The competitivity of nuclear power plants in comparison with thermal ones with coal combustion are essential for the development of nuclear power. A preliminary analysis indicates that, by 1980, when the first nuclear power plant is to be started, such a competitivity can only be afforded by power plants equipped with large power reactors ensuring a high availability. Therefore, the application of pressurized-water reactors (PWR) rated at 1000 MW(e) is foreseen for the first nuclear electric power plant. The 400-kV supergrid allows, without any difficulty, the integration of blocks of this capacity. At the next stage, based on the fuel cycle, a proportional development of electric power plants equipped with fast-breeder reactors and thermal reactors should follow.

FAITS ECONOMIQUES ESSENTIELS ET BILAN ENERGETIQUE NATIONAL A LA BASE DU DEVELOPPEMENT FUTUR DE L'UTILISATION DE L'ENERGIE NUCLEAIRE EN POLOGNE.

La Pologne possède de grandes réserves de charbon favorablement situées et occupe de par sa production actuelle la cinquième place dans le monde parmi les pays miniers et, de par ses exportations, la troisième place dans le monde. Ces ressources en charbon bon marché justifient un certain retard dans le développement des centrales nucléo-électriques en Pologne par rapport aux pays manquant de combustibles conventionnels. Cependant, la rapidité du développement industriel dans les domaines de l'acier, du cuivre, du soufre, des machines, des industries chimiques et textiles, entraîne une augmentation considérable de la demande énergétique qu'il ne sera plus possible, dans un avenir proche, de couvrir par une augmentation de la production de charbon. Si la demande énergétique augmente jusqu'à la fin du siècle et au-delà au même rythme de 2,2 pour 20 ans, les réserves de charbon polonais ne suffiront que jusqu'en 2070. Ces prémisses, ainsi que les difficultés inévitables liées au planning des sites et à l'obtention de main-d'œuvre pour les travaux souterrains, limitent l'augmentation de la production des mines de charbon en Pologne à 205 millions de tonnes en 1985 et 310 millions en l'an 2000. Les prévisions concernant l'équilibre des complexes énergétiques du pays au-delà de l'an 2000, compte tenu de ces circonstances, font ressortir la nécessité d'un développement de l'industrie nucléo-électrique durant les 20 dernières années du siècle à une vitesse moyenne de 1000 MW installés par an. Ainsi la capacité nucléaire installée en l'an 2000 s'élèverait à 20 000 MW, ce qui représenterait 20% de la capacité totale installée et une contribution de 30% dans la production totale d'énergie. La compétitivité des centrales nucléaires par rapport aux centrales thermiques à combustion de charbon est naturellement essentielle pour le développement de l'industrie nucléo-électrique. Une analyse préliminaire

indique qu'en 1980, quand la première installation nucléaire sera mise en service, la compétitivité pourra seulement être assurée par des centrales équipées de réacteurs de grande puissance et à disponibilité élevée. L'utilisation de réacteurs à eau sous pression produisant 1000 MW(e) est envisagée pour la première centrale nucléaire. La haute tension de 400 kV permet sans difficulté l'intégration d'unités de cette capacité. Au stade suivant, compte tenu du cycle du combustible, un développement proportionnel de centrales à réacteurs surgénérateurs et thermiques devrait suivre.

ОСНОВНЫЕ ЭКОНОМИЧЕСКИЕ И НАЦИОНАЛЬНЫЕ ЭНЕРГЕТИЧЕСКИЕ ПРЕДПОСЫЛКИ, ОПРЕДЕЛЯЮЩИЕ БУДУЩЕЕ РАЗВИТИЕ ЯДЕРНОЙ ЭНЕРГЕТИКИ В ПОЛЬШЕ.

Польша обладает большими ресурсами открытых залежей каменного и бурого угля, занимает пятое место в мире среди стран, добывающих каменный уголь, и третье место среди экспортирующих его стран. Запасы дешевого угля являются причиной замедленного развития ядерной энергетики Польши по сравнению со странами с дефицитом ископаемого топлива. Однако высокие темпы развития сталелитейной, медной, серной, машиностроительной, химической и текстильной промышленности влекут за собой значительное увеличение спроса на энергию, который не сможет в недалеком будущем удовлетворяться за счет роста добычи угля. Даже если увеличение спроса на электроэнергию к концу текущего и к началу следующего столетия будет по-прежнему составлять 2,2% на протяжении каждых 20 лет, то и тогда имеющихся в Польше угольных ресурсов хватит лишь до 2070 года. Указанные предпосылки, неизбежные трудности, связанные с планированием места добычи, и возможность получения рабочей силы для подземных работ ограничивают добычу угля в Польше: $205 \cdot 10^6$ тонн в 1985 году и $310 \cdot 10^6$ тонн в 2000 году. Прогнозы в отношении всех энергетических ресурсов до 2000 года с учетом упомянутых обстоятельств указывают на необходимость развития ядерной энергетики в Польше в течение последних 20 лет этого столетия темпами, обеспечивающими в среднем создание установленных мощностей в 1000 МВт в год. Таким образом, мощность ядерных электростанций в 2000 году могла бы достигнуть 20 000 МВт, что составило бы 20% от общей установленной энергомощности страны и 30% от общего производства электроэнергии. Очень существенным для развития ядерной энергетики Польши является конкурентоспособность атомных станций по сравнению с тепловыми электростанциями, работающими на угле. Предварительные анализы показывают, что к 1980 году, когда должна быть пущена первая атомная электростанция, такой конкурентоспособностью могут обладать лишь электростанции, имеющие крупные энергетические реакторы с высоким коэффициентом использования. Поэтому для первой атомной электростанции предусматривается реактор с водой под давлением мощностью 1000 МВт(эл). Сеть электропередач с напряжением в 400 киловольт позволяет без каких-либо трудностей подключать блоки такой мощности. На следующем этапе должны появиться на основе топливного цикла электростанции с быстрыми реакторами-размножителями и реакторами на тепловых нейтронах.

PREMISAS FUNDAMENTALES ECONOMICAS Y COMERCIALES, DETERMINANTES DEL DESARROLLO FUTURO DE LA ENERGIA NUCLEOELECTRICA EN POLONIA.

Polonia dispone de grandes recursos de hulla y lignito en yacimientos favorablemente situados; con su producción de hulla ocupa el 5º lugar en el mundo y en su exportación ocupa el 3er lugar. Las reservas de carbón barato justifican el que la energía nucleoeléctrica se desarrolle en Polonia con retraso respecto a países deficitarios en combustible fósil. Sin embargo, su elevado grado de desarrollo industrial, con una gran industria en las ramas del acero, cobre, azufre, construcción de maquinaria, química y textil, provoca un crecimiento rápido de la demanda de energía que, en plazo breve, no se podrá cubrir ni siquiera incrementando la extracción de carbón. Si el ritmo de crecimiento actual del consumo de energía se mantuviese hasta el final del presente siglo y a principios del próximo, es decir, si dicho ritmo se sigue multiplicando por 2,2 cada 20 años, se agotarían las reservas de carbón polacas para el año 2070. Las premisas citadas, las limitaciones inevitables en los planes relativos a los emplazamientos y la disponibilidad de personal para trabajos subterráneos, limitan el desarrollo de la minería del carbón, en Polonia, a 205×10^6 t en 1985 y a 310×10^6 t en el año 2000. La previsión de todos los recursos energéticos del país en el año 2000, teniendo en cuenta lo dicho anteriormente, señala la necesidad de desarrollar la energía nucleoeléctrica en Polonia en los 20 últimos años del presente siglo, con la instalación anual de 1000 MW por término medio. Por tanto, la potencia instalada de las centrales nucleares en el año 2000 puede llegar a 20 000 MW, es decir, el 20% de toda la capacidad del sistema energético del país, y el 30% de la producción de energía eléctrica. La competitividad de las centrales nucleares en comparación con las térmicas que queman carbón es, naturalmente, esencial para el desarrollo de la energía nuclear en Polonia. Estudios preliminares muestran que, en 1980, año en que se prevé entrará en funcionamiento la primera central nuclear, sólo estarán en condiciones de competir las centrales eléctricas que tengan reactores de gran potencia y cuyo grado de disponibilidad sea grande. Por esta razón, se prevé que

la primera central nuclear tendrá un reactor del tipo de agua ligera de 1000 MW(e). La red de 400 kV permite la incorporación de grupos de esta potencia sin dificultad. En el período siguiente, teniendo en cuenta los ciclos de combustible, deberán desarrollarse las centrales con reactores rápidos y térmicos, que regeneren el combustible nuclear.

1. INTRODUCTION

At the end of 1970 the capacity of all Poland's electricity stations was 14 000 MW and the annual production of electricity amounted to 64.5 TWh, approximately 98% of this arising from coal-fired stations.

The largest and most efficient generating units are 125- and 200-MW, single reheat (24 and 15 units, respectively). The capacity of the largest power station recently reached 1600 MW and new coal-fired stations of 2000 to 3000 MW capacity are under construction.

All electricity plants and electricity consumption centres are interconnected with 220- and 400-kV lines into an integrated national power system. Distribution voltages are 110 and 30 kV.

Poland's great resources of bituminous coal amount to 85×10^9 t (deposited at a depth of less than 1000 m) and lignite resources are evaluated at 40×10^9 t. Bituminous coal is obtained by underground mining, and lignite by surface mining. The annual bituminous coal production of 140×10^6 t puts Poland at present into seventh place in the world. In the future development of the country's electricity, coal will remain as basic fuel.

During the consecutive decades from 1970 to 2000, the average annual growth-rates of the electricity demand are expected to be 7.9, 7.0 and 6.4%, respectively. To cover the rising energy demand, the country's installed capacity in the year 2000 should be around 100 000 MW. A new range of 500-MW generating units is to be introduced in coal-fired thermal stations (the first unit of this type will be put into operation in 1976). The super-grid will be developed mainly as a 400/110 kV system. Automation of the operation of the national integrated electricity system, as well as the introduction of computer techniques for the optimization of its operation and for programming its expansion, will be continuously intensified. At the same time, the role and the significance of central dispatching will increase. This will require suitable equipment for its central and regional boards as well as the development of separate telecommunication interconnections for the electricity industry applying h.f. trunk lines running along high-voltage power lines.

Besides the electricity industry, the Power Board runs central-heating systems for 35 towns. The heat demand in these systems is met by combined electricity and district-heating stations, there being three or more in some towns. The total amount of thermal energy distributed by these systems to industrial, municipal and domestic consumers at present equals 20 000 Tcal and, owing to a further expansion program of heating systems, will rise to 32 000 Tcal in 1975. All combined power stations are coal fired. Thus the heat industry of the country, with limited liquid fuels and natural gas, supplies consumers with an equivalent high-ranging energy source convenient for utilization, i.e. with hot water and steam generated from coal. This creates important centres of fuel consumption for process and district heating.

2. BALANCE OF RAW MATERIALS FOR POWER AFFECTING THE DEVELOPMENT RATE OF NUCLEAR POWER

In the analysis of the prospective electricity demand two periods were taken into account:

(a) Up to 1980, where advantage could be taken of a detailed analysis of industrial development, the rate of urbanization of the country, the final stage of railway electrification and, in general, of the possible growth of electricity consumption.
(b) After 1980, a period that lacks data on the development of particular categories of consumers. Here, some assumptions were made concerning the rate of national income rise and its correlation with the increase of electricity demand (the so-called "flexibility factor").

As a result, the following figures of the necessary electricity production were obtained for the consecutive 10-year stages: 1980: 138 TWh; 1990: 270 TWh; 2000: 500 TWh. These electricity production figures may be treated as reliable. The considerable development of the consumption of electricity for domestic and social purposes notwithstanding, a great increase of energy demand will be caused by the development of the steel, chemical machinery and textile industries exploiting the rich home resources of coal, sulphur, copper and other raw materials.

Unfortunately, Poland possesses very poor hydro resources, evaluated at 6 TWh of economically accessible energy. These resources, which can be economically accessible only through complex projects, are smaller than the annual growth of the electricity demand around 1980. Moreover, because of the restricted national resources of crude oil and natural gas, which cannot even cover the demands of industry, automobile fuel production and most indispensable living and municipal purposes, the basic development of the electric power and central heating industries must be based on coal.

The required average annual increments of the electricity production for 1981 - 1990 amount to about 13 TWh/yr, and for 1991 - 2000 to about 23 TWh/yr. Thus, the average annual growth of coal consumption (of 6000 kcal/kg calorific value), if new capacities consist exclusively of coal-fired units, would amount to, respectively:

(1) 5 million t/yr and 8.5 million t/yr (excluding central heating). Whereas, the evolution of bituminous coal production, even considering the expected high development costs to the national economy, can be evaluated at the levels: 1980: 180 million t/yr; 1990: 235 t/yr; and 2000: 310 million t/yr.
(2) For the consecutive decades 1981 - 1990 and 1991 - 2000, the average annual growth of coal production would thus amount to 5.5 million t/yr and 7.5 million t/yr, respectively.

Comparing the data (1) and (2) and taking into account that the increments of coal production will not only be consumed by the electricity industry but also by the central heating industry and metallurgy (coking coal), it is necessary to develop nuclear power after 1980, due to fuel balance considerations even in a country as rich in coal as Poland.

TABLE I. POSSIBLE EXHAUSTION RATE OF BITUMINOUS COAL RESOURCES IN POLAND

Years	Average annual production (10^6 t/yr)	Production over a 20-year period (10^9 t)	Exhaustion of resources after the year 2000 (10^9 t)
2000-2020	500	10	10
2021-2040	1100	22	32
2041-2060	2400	48	80
2061-2080	5300	106	186
2081-2100	11700	234	340

The situation cannot be changed by a possible further, though limited, expansion of the electricity industry based on lignite. The greatest lignite reserve enables the construction of a power station of 35 TWh annual electric energy production. It follows from the energy production growth-rates forecasted above that the construction of the power station, using lignite deposits of such a value, would mean only a shift of the problems of nuclear power by two to three years.

Moreover, when forecasting the exploitation of bituminous coal resources, the following essential facts must be considered:

(a) Probable limitations owing to site planning
(b) Prospective access to labour force for mining
(c) The possible revaluation of coal as a precious raw material for attractive processes in the production of liquid fuels and high methane content gases.

It should finally be realized that the significance of the extensive coal resources in Poland becomes rather doubtful in the light of the progressive increase of the total national energy demand. If we assume, that the total energy demand and the coal demand of the country would grow linearly, involving a 2.2-fold increase every 20 years during the next century, then coal resources would be exhausted at a rate indicated in Table I.

It is clear that even geological resources deposited down to a depth of 1200 m (130×10^9 t) would be exhausted by about 2070.

3. CONDITIONS OF ECONOMIC COMPETITIVITY OF NUCLEAR AND CONVENTIONAL ELECTRICITY INDUSTRIES IN POLAND

In the following, the main conditions of the competitivity of conventional fuel-fired and nuclear power plants are investigated. If we assume that the total cost of electricity production (t) consists of fixed charges (S) and fuel costs (C), related as follows:

For coal-fired power stations fuel costs constitute about 60% of the total cost, i.e.

$$t_c = S_c + C_c \text{ or, otherwise } t_c = 2.5\ S_c \qquad (1)$$

For nuclear power stations, fuel costs constitute about 1/3 of the total cost, i.e.

$$t_n = S_n + C_n, \text{ or otherwise } t_n = 1.5\ S_n \qquad (2)$$

The competitivity condition of a nuclear power station acquires the form:

$$t_n < t_c, \text{ or otherwise } S_n < 1.67\ S_c$$

In other words, a nuclear power station will be competitive in the circumstances assumed above when its specific capital costs do not exceed those of a conventional power station by more than 67%. The above condition is, in principle, possible to fulfil when choosing a type of reactor intended for enriched nuclear fuel.

The availability of a nuclear power station equal to that of a conventional one, is vital for its competitivity. Until now, no large nuclear reactor has passed a long-term test reliable enough to confirm its guaranteed availability. However, it can be expected that the condition of a sufficient availability might be fulfilled by light-water reactors (LWR) in their present state of development.

The generating capacity of a nuclear unit affects the competitivity of nuclear power stations in a similar way. In Poland's electric power system, with a total installed capacity of 30 000 MW expected for 1980 (i.e. at the expected time of putting the first nuclear station into operation) the unit capacity of 1000 MW(e) would constitute only 3.3%, hence it would easily be assimilated by the system. The situation is made even easier because the Polish electricity system is connected with other CMEA countries systems into a large international system with a capacity four times greater.

The 1000-MW(e) unit should be characterized by specific capital costs more than 15% lower than in the 500-MW(e) unit. For a cost structure in accordance with expression (2), assuming that technical parameters are unchanged, a decrease in specific cost of electricity production by over 10% can be expected. This constitutes a considerable difference, which should predispose units of around 1000 MW(e), technologically feasible at the time, as a basis for the first program for the development of nuclear power stations.

Though Poland is relatively small (an average of 1000 × 1000 km), problems associated with fuel transport play an essential role in the siting of electric power plants. Bituminous coal deposits are in the south-west regions (Upper Silesian basin). On the other hand, a considerable energy demand increase is foreseen in the northern regions, which are connected with overseas trade and have industrial ports. Railway and water routes leading from Upper Silesia to the coast are overcharged by the transports of coal (exports) and of iron ore (imports) and by a wide assortment of other goods meant for foreign trade. Therefore, the siting of the first nuclear power plants in the coastal part of the country creates the most advantageous conditions for competitivity.

A very important problem presenting obstacles to the competitivity of nuclear power stations is their great demand for cooling water. For instance, if a conventional coal-fired power station needs (in the case of an open cooling-water cycle) 35 m^3/sec for every 1000 MW and warms the water up to 8°C, a nuclear power station needs about 40-80% more cooling water (depending on the type of reactor).

The adoption of an open cooling water cycle solution, avoiding the construction of costly and additional area cooling appliances, requires consideration in site planning. On the other hand, the question of covering the water losses in the cooling cycle (irreclaimable loss of up to 2% of circulating water) constitutes an important problem in regions scanty in water. All these factors are less acute when the plant is located either at the seaside or at the mouth of a large river. Thus, in the conditions prevailing in Poland, the planned location of the first nuclear power stations in the coast region are even more advantageous.

In addition, such arguments as the almost total harmlessness of nuclear power stations for their environment (except for the water heating) speaks in their favour, especially when one takes into account the noxious influence (air pollution) of conventional coal-fired stations. Basing on the up-to-date experience, it may be stated that the radioactivity of nuclear power stations affecting their environment is no worse than that of normal industrial installations. The methods of storage and transport of radioactive wastes seem to have reached the state of maturity. All restrictions existing in this field are to a great extent psychological.

4. PROBABLE TECHNOLOGY OF THE FIRST NUCLEAR POWER STATIONS IN POLAND

Basing on the optimization analysis of the constitution of electric power station types in the year 2000 (coal-fired, nuclear, hydro and pumped-storage power stations) a minimum capacity installed in nuclear power stations of 20 000 MW is obtained. It would constitute 20% of the total installed capacity of the country at that time. This result is obtained when assuming for nuclear and conventional electric power stations, respectively: the ratio of fixed costs of 1.6:1.0; and the ratio of fuel costs of 0.43:1.0.

To minimize capital outlays, pressurized-water reactors (PWR), considered in Poland as better proven, were already chosen for the initial development of nuclear power stations. This choice coincides with high availability, proved (though still over a short time period) by a large number of PWR reactors operating in the world today.

It can be assumed that the supply of slightly enriched (2 - 4%) nuclear fuel needed for the operation of PWR reactors is ensured for many years.

Since the practical possibility of introducing some intermediate type of reactor is today difficult to forecast, the fast-breeder reactors are envisaged for the consecutive development program of the nuclear power industry in this country. When analysing the progress of world technology in this field, one estimates 1990 as the possible time of putting into operation in Poland the first electricity plant based on large fast-breeder reactors. Assuming the closed plutonium cycle, the relative capacity installed in FBR nuclear power stations (with respect to the total nuclear power capacity) in the year 2000 can reach 40 to 60%.

It is possible to locate the nuclear power stations production of 20 000-MW capacity on the basis of the load curve for the year 2000.

This will constitute 20% of the total installed capacity of the country, the load valley amounting to 50% of the annual load peak. It might be only necessary to shift a certain number of conventional power stations to the sub-peak operation. Large coal-fired generating units rated at 125 MW, 250 MW and, in the future, 500 MW, are designed for sub-critical steam parameters. This fact makes it easy to facilitate a change of the operation regime from the technical and economic points of view. Advantageous conditions for the evolution of the nuclear power industry are also due to the ample program for developing pumped-storage power plants, which is to be realized in Poland. Economic sitings for this type of station offer a total capacity of nearly 6000 MW. The most advantageous pumped-storage power plants of this program are already either in operation or under construction.

The problem to be promptly solved is the choice of sizes of generating units with PWR reactors and the schedule of construction of the first nuclear power station. It is possible that, in spite of the reactor capacity of 1000 MW(e) fixed as most advantageous for the first program of the development of the nuclear power industry, the initially built units will be rated at about half this capacity. Such a decision may be dictated by a list of competent references only for reactors of lower power at disposal at present and especially by a competent guarantee regarding their operation availability. Such a decision might also be due to the strategy of gradual training of designers, and building, mounting and servicing personnel in nuclear power technology.

5. CONCLUSIONS

5.1. The high degree of industrialization and the long-term trends of the evolution of industry and urbanization in Poland will give rise to an increased demand of electricity, impossible to be covered exclusively by coal – in spite of the abundant resources – even in the near future. In the conditions prevailing in a country with little crude oil, natural gas and hydro-power resources, only nuclear fuel may be envisaged as a supplementary power source.

5.2. To ensure the required availability and reduce the capital outlays when introducing this new technology of electricity production – evaluated at about 20 000 MW in the year 2000 – PWR reactors will be chosen for the first development program of nuclear power stations. In 1990-2000, the development of power stations equipped with fast-breeder reactors is foreseen, their share in the total capacity corresponding to the plutonium balance in the fuel cycle.

5.3. Economic premises suggested the choice of a basic reactor capacity of about 1000 MW(e) in the first program of the development of nuclear power stations. However, it is admitted that several initially built reactors might be rated at about half this capacity, this being justified by the necessity to gradually train the design staff as well as the building, mounting and servicing personnel for nuclear power technology.

5.4. The structure of development of the conventional electricity industry realized in Poland can be acknowledged as very favourable for the future introduction of nuclear power technology. The most advantageous circumstances are: the far-reaching integration of the national electric power system owing to its saturation with 400-kV networks; the installation of sub-critical generating units in conventional electric power plants; the ample program of development of pumped-storage power stations under realization.

5.5. Because of insufficient resources of crude oil and natural gas in Poland, urban central-heating systems, where steam or hot water serve as heat carriers, are widely used. The thermal energy is economically produced in large combined electric and heat power stations. The stringent requirements concerning clean air may in the future either impose the construction of combined nuclear electric and heat power stations, or a wide utilization of electric heating that would create additional growth of the electricity demand.

EL PROGRAMA NUCLEAR ESPAÑOL

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Abstract–Résumé–Аннотация–Resumen

THE SPANISH NUCLEAR PROGRAM.

The Spanish electricity system at present includes two nuclear units in operation and one under advanced construction. Experience obtained thus far enables planners to program the economic integration of nuclear power plants into the Spanish grid in the near future. The National Electric Plan, approved by the Government in 1969, was prepared following the optimization of the peninsular system. It covers a span of ten years and includes, by 31 December 1981, a nuclear component of 8.5 GW, representing 21.8% of the installed power. Present plans of the utilities account for a substantial part of this figure. A study of the years between 1981 and 2000 has been made: it is estimated that 71 GW of nuclear plant will be installed at the end of the period, accounting for 60.7% of the total installed power. Light-water reactors are expected to be the main contributors, with fast breeders being progressively introduced, as far as plutonium availability permits, and depending on their commercial availability. Present availability of fuels and projections for the future are studied, as well as the mutual interaction of nuclear energy and regulated hydro energy, including pumped storage, which will permit base operation of nuclear plants during the early part of the period. Industrial activities relating to nuclear constructions are then analysed, from equipment manufacturing to nuclear fuel facilities. A rapid development of this industry is foreseen, in view of the accelerating growth of nuclear plant commitments.

LE PROGRAMME NUCLEAIRE ESPAGNOL.

Actuellement, le système électrique espagnol comprend deux centrales nucléaires en exploitation et une dont la construction est avancée. On dispose en ce moment d'une expérience suffisante pour programmer l'intégration économique de ce type de centrale dans le réseau espagnol au cours des prochaines années. Le Plan électrique national, approuvé par le Gouvernement au cours de l'année 1969 et établi grâce à une optimisation du système péninsulaire, couvre une période de dix années et fait état, pour le 31 décembre 1981, d'une puissance nucléaire de 8,5 GW, ce qui représentera 21,8% de la puissance totale installée. Les prévisions actuelles des entreprises électriques couvrent déjà une grande partie du chiffre avancé. Les auteurs ont étudié la période comprise entre 1981 et la fin du siècle en cours; ils estiment qu'en fonction des disponibilités énergétiques du pays on disposera, à la fin de la période indiquée, de 71 GW nucléaires, soit 60,7% de la puissance totale installée. On prévoit une majorité de réacteurs thermiques à eau légère avec incorporation progressive, à partir de leur commercialisation, de surgénérateurs rapides au rythme que permettront les disponibilités en plutonium. Les auteurs examinent également les disponibilités en combustible de l'Espagne et leur évolution future, ainsi que l'influence mutuelle de l'énergie nucléaire et de l'énergie hydro-électrique régulée, y compris le pompage, compte tenu de l'introduction de centrales nucléaires de base au cours des premières années. Ils passent enfin en revue les activités industrielles en rapport avec l'énergie nucléaire, depuis les industries de biens d'équipement jusqu'à celles qui sont liées au cycle des combustibles nucléaires. Il y a lieu de prévoir un développement rapide de ces industries vu l'accroissement considérable envisagé en ce qui concerne les centrales nucléaires.

АТОМНЫЕ ЭЛЕКТРОСТАНЦИИ В ЭЛЕКТРОЭНЕРГЕТИЧЕСКОЙ СИСТЕМЕ ИСПАНИИ.

В настоящее время энергосистема Испании включает две действующих АЭС, еще одна АЭС находится в стадии активного строительства. Полученный опыт позволяет планировать работы по экономичному вводу АЭС в испанскую энергосистему в ближайшем будущем. Национальный план электрификации, одобренный правительством в 1969 году, был составлен после оптимизации энергосистемы всего полуострова. План рассчитан на 10 лет и предусматривает к 31 декабря 1981 года строительство АЭС общей мощностью 8,5 ГВт, что составит 21,8% общей установленной мощности. Значительная доля этой мощности предусмотрена нынешними планами предприятий энергоснабжения. Проведено исследование, охватывающее период между 1981 и 2000 гг; подсчитано, что к концу рассматриваемого периода общая мощность АЭС составит 71 ГВт, что будет эквивалентно 60,7% общей установленной мощности. Предполагается, что основная нагрузка ляжет на легководные реакторы, причем постепенно будут использоваться реакторы-размножители на быстрых нейтронах в зависимости от их пригодности в коммерческом отношении; темпы внедрения быстрых реакторов будут зависеть от наличия плутония. В докладе рассматриваются имеющиеся в настоящее время виды топлива и планы на будущее, а также взаимосвязь ядерной энергии и гидроэнергии, включая гидроаккумулирующие станции, что позволит эксплуатировать АЭС с базовой нагрузкой на начальном этапе. Анализируется деятельность промышленных кругов в области строительства АЭС, начиная от изготовления оборудования и кончая установками по производству ядерного топлива. Предполагается быстрое развитие этой отрасли промышленности, ввиду растущего числа заявок на строительство АЭС.

EL PROGRAMA NUCLEAR ESPAÑOL.

El sistema eléctrico español cuenta en la actualidad con dos centrales nucleares en explotación y una en construcción adelantada. En el momento presente se cuenta con experiencia suficiente para programar la integración económica de este tipo de central en la red española en los próximos años. El Plan Eléctrico Nacional, aprobado por el Gobierno durante el año 1969 y redactado mediante una optimación del sistema peninsular, cubre un período de diez años e incluye, para el 31 de diciembre de 1981, una potencia nuclear de 8,5 GW, lo que representará un 21,8% de la potencia total instalada. Las previsiones actuales de las empresas eléctricas cubren ya una gran proporción de esta cifra. Los autores examinan el período comprendido entre 1981 y el fin del siglo actual, y estiman, en función de las disponibilidades energéticas del país, que al final del período señalado se dispondrá de 71 GW nucleares, o un 60,7% de la potencia total instalada. Prevén una mayoría de reactores térmicos de agua ligera con la incorporación progresiva de reproductores rápidos, a partir de su comercialización, al ritmo que permitan las disponibilidades de plutonio. Examinan además las disponibilidades de combustibles en España y su evolución futura, así como la influencia mutua de la energía nuclear y la hidroeléctrica regulada, incluyendo bombeo, que facilite la inclusión en base de la energía nuclear en los primeros años. Por último, estudian las actividades industriales relacionadas con la energía nuclear, desde las industrias de bienes de equipo a las relacionadas con el ciclo de los combustibles nucleares. Es de prever un desarrollo rápido de estas industrias, en vistas del fuerte incremento previsto en las nuevas instalaciones de centrales nucleares.

1. INTRODUCCION

En esta memoria se presenta un esquema del desarrollo de la energía nuclear en España como fuente generadora de energía eléctrica y de las brillantes perspectivas que a ella se abren en el presente decenio y más allá de 1980.

España es un país que tiene un inventario energético deficitario; más del 50% de las necesidades de energía primaria deben ser importadas en forma de petróleo crudo. Por ello se tiene un gran interés en diversificar las fuentes de abastecimiento y en incrementar, en lo posible, el patrimonio de recursos básicos.

Desde 1950 se ha dedicado una creciente atención al estudio del potencial nacional en minerales radiactivos, particularmente en uranio. Los trabajos iniciales evidencian las favorables perspectivas de la geología española a este respecto y la posibilidad de incorporar al inventario nacional un potencial de energía mucho más significativo e importante que todo el conjunto anterior, representado por los carbones.

Cuando todavía queda por explorar con detalle más del 50% del territorio nacional de geología favorable, el inventario español de uranio se resume en las cifras provisionales de la Tabla I.

TABLA I. RESERVAS TOTALES DE URANIO (Unidad: t de U_3O_8)

En minerales de primera categoría	9 000
En minerales de segunda categoría	22 500
En minerales de tercera categoría	225 000

En la primera categoría se incluyen aquellos minerales que originan un concentrado a un precio hasta 10 dólares/libra. En la segunda categoría se incluyen los que corresponden a precios entre 10-15 dólares la libra. Y en la tercera los superiores a 15 dólares.

A la vista de estos resultados positivos, y de las perspectivas de encontrar mayores reservas, el interés por la energía nuclear quedó plenamente justificado y motivó la preparación de un primer programa de potencia constituido por tres centrales nucleares, dos de las cuales han entrado en servicio y la tercera tiene prevista su conexión a la red eléctrica nacional a final de 1972.

En esta primera fase, iniciada en 1964, se pretendió ganar experiencia en las técnicas nucleares más desarrolladas y con mejores perspectivas de alcanzar un precio del kWh competitivo.

La primera central nuclear española entró en servicio en 1968; es de tipo de agua a presión, tiene una potencia de 150 MWe, y está enclavada a 90 km de Madrid. Viene funcionando con una gran regularidad y con un factor de disponibilidad muy alto. Actualmente se procede al recambio de la primera región de combustible y a la primera revisión de sus componentes internos.

La segunda central ha entrado en servicio muy recientemente; del tipo de agua en ebullición tiene una potencia de 460 MWe (la mayor de Europa, en el momento presente, en esta clase de reactores). Está emplazada a orillas del río Ebro, a unos 60 km de Bilbao. Ha tenido una puesta en marcha muy sencilla y en un tiempo muy corto ha alcanzado la plena carga. Durante los ensayos realizados en la fase de puesta en marcha, y posteriormente durante su explotación, ha demostrado poseer unas condiciones excelentes de agilidad operativa y respuesta a las fluctuaciones de la carga.

La tercera central nuclear incluída en esta fase del programa nuclear español es de tipo grafito-gas-uranio natural con una potencia de 500 MWe, situada en la provincia de Tarragona a orillas del mar Mediterráneo. Se trata en este caso de un proyecto de cooperación técnica franco-española y el 25% de la potencia de régimen quedará a disposición del sistema eléctrico francés.

La experiencia alcanzada con la construcción y explotación de estas centrales nucleares permite proyectarse hacia el futuro con una participación mayor de la energía nuclear. En consecuencia el Plan Eléctrico

Español, durante el período 1972-81, prevé que las centrales nucleares participen de una manera progresiva, y muy rápidamente a partir de 1976. Vamos a referirnos al futuro nuclear de España en los próximos 12 años.

2. PLAN ELECTRICO NACIONAL

En el mes de Julio de 1969 el Ministerio de Industria publicó el Plan Eléctrico Nacional (P.E.N.) para el período 1972-81 con el fín de promover el crecimiento coordinado de la industria productora distribuidora de electricidad, atendiendo las directrices del II Plan de Desarrollo Económico y Social, y la exigencia de una óptima explotación del Sistema Eléctrico Español.

El P.E.N. contempla la evolución del mercado de energía eléctrica y las curvas de demanda del sistema español, la previsión de las centrales eléctricas a construir durante el período 1972-1975 y los balances energéticos en los años 1975, 1978 y 1981. Considera también las necesidades de combustibles para centrales generadoras durante el período, la previsión del sistema primario de interconexiones, así como una estimación general de las inversiones exigidas, a moneda constante.

Como objetivo principal aparece el aumento de la utilización de las instalaciones eléctricas de producción y distribución, por medio de un programa coordinado de las nuevas centrales, aplicando paulatinamente medidas conducentes a la amortiguación de las oscilaciones de la demanda horaria.

Se introduce el principio de normalizar el tamaño de los grupos generadores térmicos, que serán los mayores compatibles con las características del mercado, con objeto de facilitar a la industria española constructora de equipo eléctrico su adaptación a las futuras demandas de dicho equipo y su participación creciente en el desarrollo del Plan.

Dentro de los condicionamientos geográficos, técnicos y económicos de los emplazamientos en relación con el mercado eléctrico, se establece que las nuevas centrales se sitúen próximas a los centros de gravedad de los consumos principales. De acuerdo con los estudios realizados sobre la evolución de la demanda y análisis de los costes, se deduce la estructura óptima de la potencia generadora, el tamaño de los grupos de producción, el factor de cobertura resultante y los balances de la energía a lo largo del período.

El P.E.N. debe ser revisado cada dos años, para adaptarlo a las circunstancias. En el momento de redactar esta memoria se trabaja en ello y las últimas cifras disponibles, todavía de carácter provisional, son las que se resumen en la Tabla II.

Cabe destacar el objetivo señalado de reducir el factor de cobertura, aunque en 1974 por razones de adaptación a los programas anteriormente establecidos por las diferentes empresas se obtenga un valor superior al correspondiente a 1971.

TABLA II. PARAMETROS DEL MERCADO ESPAÑOL

	1971	1974	1977	1980	1983
Demanda de energía (TWh)	62,1	77,5	118,7	163,1	220,3
Demanda de potencia (GW)	11,4	14,3	21,9	30,1	40,3
Potencia instalada (GW)	18,8	24,2	32,3	41,6	54,5
Factor de cobertura [a]	1,65	1,75	1,48	1,39	1,35

[a] El factor de cobertura se define por el cociente de la potencia total instalada y la demanda máxima de potencia de cada año.

TABLA III. ESTRUCTURA DE LA POTENCIA ELECTRICA INSTALADA (GW[e])

	1971	1974	1977	1980	1983
Hidráulica ordinaria y de bombeo	10,7	13,0	14,7	17,0	20,0
Carbón	3,7	4,3	5,2	6,1	7,1
Fuel-oil	3,8	5,8	7,9	10,0	12,0
Nuclear	0,6	1,1	4,5	8,0	14,0
Turbina de gas	---	---	---	0,5	1,4
Totales	18,8	24,2	32,3	41,6	54,5

Se prevé la instalación de nuevas unidades de producción, conforme a la estructura de la potencia que aparece en la Tabla III.

3. INSTALACION DE NUEVA POTENCIA NUCLEAR

La potencia nuclear instalada, que sólo representa el 3,2% de la potencia eléctrica total en 1971, alcanzará el 25,7% en 1983, lo que supone una incorporación muy rápida a partir de 1975.

En la Fig. 1 se ha representado el diagrama anual de cargas del sistema español extrapolado a los parámetros previstos para el año 1980. El área del diagrama representa la demanda total de energía del sistema y las ordenadas las demandas de potencia en porcentajes de la demanda máxima.

El diagrama está dividido por líneas horizontales que delimitan la superficie total en regiones, cada una de ellas correspondiente a las diversas formas de generación que participan en la producción.

En la base del diagrama se sitúa la energía hidráulica fluyente estimada en unos 3 800 GWh, mientras que en el vértice superior se ha de colocar la energía hidráulica regulada, 34 200 GWh encargada de hacer frente a las variaciones de carga y a los períodos de punta.

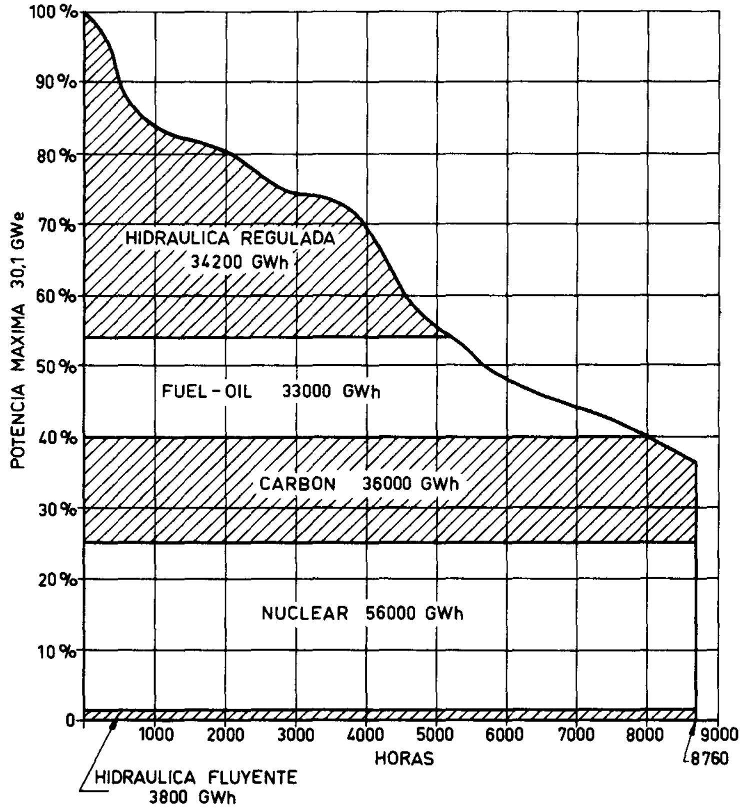

FIG. 1. Previsión del diagrama de carga español para 1981. Demanda de energía: 163 100 GWh. Demanda máxima de potencia: 30,1 GW(e).

La energía nuclear cubre también la base del diagrama con una producción de 56 000 GWh. Inmediatamente, en la parte superior, aparece la generación térmica con carbones nacionales, prevista para generar 36 000 GWh. El resto del diagrama habrá de ser abastecido por generación termoeléctrica con centrales de fuel-oil y por un total de 33 000 GWh.

Esta Fig. 1 resume el esquema de la explotación anual del sistema español, con claro predominio de la energía térmica (nuclear, carbón y petróleo) y una participación de la energía nuclear superior al 30% del total.

Los proyectos nucleares estudiados por las empresas eléctricas españolas cubren ya una parte sustancial de estas previsiones. Existen los siguientes proyectos, en distinta fase de gestión:

i) Instalación de una central nuclear en el término municipal de Lemóniz, provincia de Vizcaya, con dos unidades de 850 MWe para entrar en servicio en el período 1976-1978.

ii) Instalación de una central nuclear en el término municipal de Almaraz, provincia de Cáceres, con dos unidades de 850 MWe para entrar en servicio en el período 1976-1978.

Tanto la central de Lemóniz como la de Almaraz están muy próximas, en el momento de redactar esta memoria, a la fase de decisión, habiéndose evaluado las ofertas de equipo nuclear.

iii) Instalación de un segundo grupo de unos 500 MWe (Zorita II) en el mismo emplazamiento de la Central José Cabrera (Zorita I), para empezar a funcionar entre 1976 y 1977.

iv) Instalación de una central nuclear en el término municipal de Ascó, provincia de Tarragona, con dos unidades de 850 MWe, para entrar en servicio en el período 1977-1980.

Las empresas interesadas han presentado la solicitud de estas centrales ante el Ministerio de Industria.

v) Instalación de una central en Irta (Castellón) con una potencia de 500 MWe, autorizada en principio hace algún tiempo y detenido su trámite por un recurso. Este proyecto posiblemente será revisado y ampliada su potencia de generación.

Estos proyectos suman 6100 MWe que junto a las previsibles ampliaciones de Santa María de Garoña y Vandellós, con grupos de 850 MWe, y una nueva central en el Sur, elevará la potencia nuclear atribuible a proyectos concretos a 9500 MWe.

El P.E.N. se aplica hasta 1983 pero se han hecho estimaciones a más largo plazo. Se ha tenido en cuenta una disminución gradual del ritmo de aumento de la demanda, para llegar a fines del siglo a un 5,5% anual. La componente nuclear de la potencia instalada resulta ser, para 1990, 1995 y 2000, de 29500, 46500 y 71000 MWe, respectivamente. Estas cifras se han de considerar como las mínimas previsibles, y señalan la significación del programa nuclear español.

4. TECNICAS ELEGIDAS Y JUSTIFICACION ECONOMICA

El orden de prioridad en la satisfacción de la demanda expuesta en los apartados anteriores es función de los condicionamientos técnicos y económicos de los distintos tipos de central. A continuación se exponen estos condicionamientos, en las circunstancias españolas de los próximos años.

4.1. Parámetros básicos

a) Costes del dinero

La demanda de capital en España es muy acusada. La industria eléctrica es, en un 80%, privada y las necesidades de capital para inversiones nuevas se satisfacen por autofinanciación (23%), créditos y aportación de capital propio. En los proyectos nucleares se suele disponer de una buena financiación, con participación de créditos exteriores y puede estimarse que las cargas fijas financieras resultan de un 14% anual, aproximadamente.

b) Factor de carga

Gracias al importante desarrollo de los programas hidráulicos del país, la energía hidroeléctrica regulada permite atender al suministro de las penetraciones horarias y estaciones del consumo. Como ya se ha dicho, se estima que en 1980 la energía hidroeléctrica en año medio podrá suministrar 34 200 GWh (21% del total) cubriendo holgadamente las puntas en año normal. La base quedará repartida entre energía hidráulica fluyente, carbón y centrales nucleares. Por consiguiente, durante la vigencia del P.E.N. puede garantizarse el funcionamiento en base de las centrales nucleares. Después se habrán de ir sacando de la base las centrales de costes marginales mayores, a medida que se van poniendo en funcionamiento otras más económicas.

c) Costes fijos

Para los cálculos económicos se han tomado como costes fijos de instalación y de explotación los vigentes en España en las condiciones actuales (ptas. de 1970 y costes actuales de explotación). Estos costes aparecen en la Tabla IV.

d) Costes proporcionales

Los costes proporcionales se exponen en la Tabla V e incluyen el coste de los combustibles y materiales fungibles. En el caso del fuel-oil se consideran los precios actuales, incluidos los impuestos que cargan a las distintas fases de producción. Es de notar que estos costes incluyen los últimos aumentos en los precios de los crudos, que, en España, han repercutido muy escasamente en el precio del fuel-oil. La tonelada de este combustible se vende para la generación termoeléctrica a 1400 ptas. (20$). Los costes del combustible nuclear corresponden a centrales modernas con reactores de agua ligera.

TABLA IV. COSTES ACTUALES DE EXPLOTACION

Tipo de central	Costes instalación (Pts./kW[e])	Costes fijos explotación (Pts./kW-año)
Térmica de carbón	8 500-9 500	180
Térmica de lignito	8 500-10 000	180
Nuclear	13 500-15 000	220
Térmica fuel-oil	7 300-8 500	140
1 $ = 70 ptas.		

TABLA V. COSTES PROPORCIONALES DE LOS COMBUSTIBLES

Tipo de combustible	Costes del combustible (cts./kWh)
Hulla y antracita	33
Lignito	12-33
Nuclear	12-14
Fuel-Oil	34

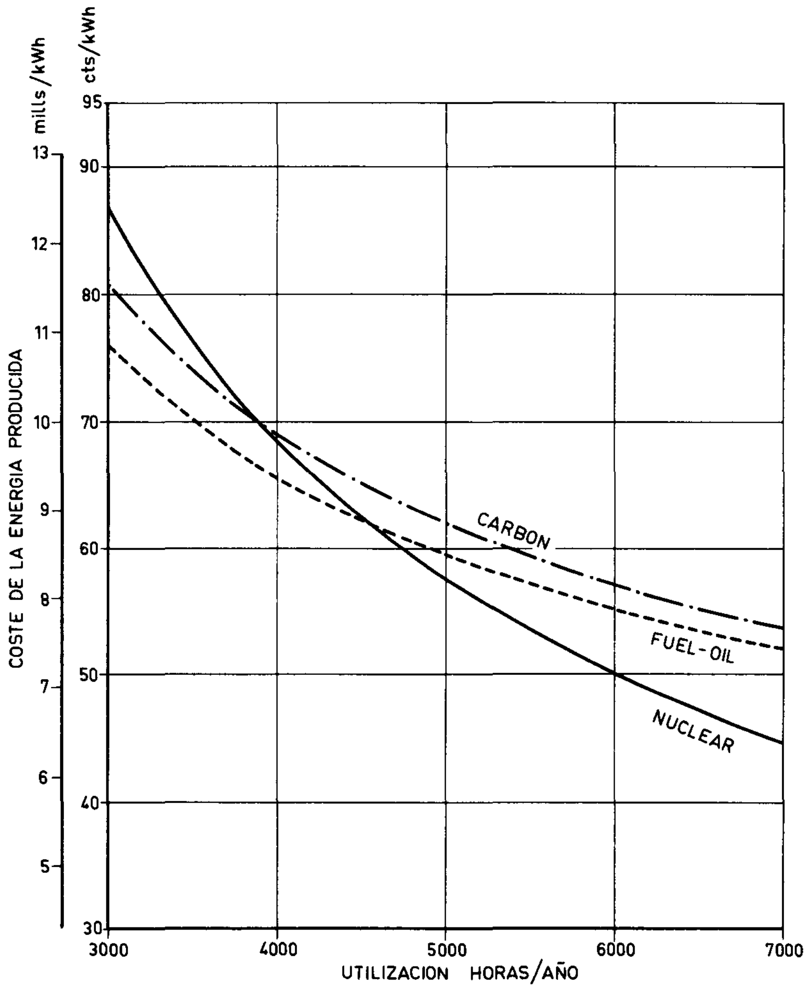

FIG. 2. Coste de la energía.

4.2. Tipos de central a instalar

En la Fig. 2 pueden verse los costes resultantes de la energía, para utilizaciones intermedias y altas. Se han excluído las centrales de lignito explotado a cielo abierto, puesto que este combustible tiene disponibilidad limitada. Las centrales térmicas de hulla son más caras, pero este combustible es el que más abunda en el país y por ello interesa su aprovechamiento. Las centrales hidráulicas irán reservándose para el suministro de las puntas y, por tanto, no entran en esta comparación. Las centrales nucleares compiten ventajosamente con las de fuel-oil por encima de las 4 500 horas anuales. En estos dos tipos de central se basará la mayoría de los aprovechamientos futuros. La Tabla III nos ha dado la distribución de la potencia resultante de estos criterios.

Es de prever que al final del período considerado lleguen a comercializarse otros tipos de reactor, tales como los reproductores rápidos y los convertidores avanzados. Los costes de combustible probables para estos reactores son de 7-8 cts/kWh (reproductores rápidos iniciales) y 5-6 cts/kWh (convertidores avanzados de agua pesada). Estas ventajas justifican, en las condiciones financieras españolas, para funcionamiento en base, unos sobrecostes del orden de 2 750 y 3 750 ptas/kW instalado, respectivamente. Su instalación dependerá de la inversión necesaria y del grado de comercialización que hayan alcanzado.

En las estimaciones mencionadas en el punto 3 aparecen potencias nucleares en reactores rápidos en los años 1990, 1995 y 2000, de 9000, 19000 y 36000 MWe que corresponden a 33, 41 y 51 % de las potencias nucleares totales para estos años. Esta solución corresponde a la instalación de reactores rápidos al máximo ritmo que permiten las disponibilidades de plutonio nacional obtenido sin adquisiciones en el mercado internacional. En estas condiciones, la instalación de reactores térmicos continuaría hasta el fin de siglo, a tenor de unos 1 500 MWe al año.

4.3. Incidencia de las centrales nucleares sobre la balanza de pagos

Las necesidades crecientes de energía, la insuficiencia de los recursos nacionales y el alto nivel de investigaciones exigidos por este sector hace que su incidencia en la balanza de pagos sea muy seria. Con base en las cifras expuestas anteriormente, y en las consideraciones del punto 9, puede calcularse el ahorro en divisas que representaría la construcción de centrales nucleares en lugar de térmicas de fuel-oil. Este ahorro se ha estimado en unos 560 millones de ptas. anuales (8 millones de $) por cada 1 000 MWe instalados, y podrá incrementarse sustancialmente a medida que aumente la participación nacional en la construcción de los reactores.

5. TAMAÑO Y NORMALIZACION DE LAS UNIDADES

El crecimiento del mercado español en los últimos años ha sido muy rápido y las perspectivas de que este ritmo de crecimiento continúe por algún tiempo permiten prever el acoplamiento de unidades de gran tamaño a la red para aprovechar las ventajas que ofrecen desde el punto de vista económico. Como existen ciertos desequilibrios geográficos en la localización de las centrales productoras con respecto al consumo y la interconexión entre zonas suele estar cargada preferentemente en un solo sentido y puede resultar aconsejable limitar el tamaño de las unidades nucleares a potencias del orden de 800 MWe. En zonas de menor densidad de consumo y en las áreas insulares resultarán más convenientes unidades del orden de 500 a 600 MWe.

Por otra parte resulta obvia la necesidad de normalizar los tamaños, con lo que se favorecerá el lanzamiento de la industria nuclear del país, se dispondrá de mayor flexibilidad en los repuestos y se reducirán los costes. Una idea particularmente interesante y de la que España ha sido iniciadora, es la contratación conjunta de centrales casi idénticas, con lo que se consiguen grandes ventajas económicas y logísticas.

6. CRITERIOS PARA LA LOCALIZACIÓN DE LAS CENTRALES

El problema de la disponibilidad de lugares donde situar las grandes centrales eléctricas debe ser objeto de especial consideración porque en el futuro pueden presentarse dificultades, si no se establecen las oportunas previsiones.

Es bien sabido que desde el punto de vista de la economía energética, la central generadora debe situarse lo más próxima posible a los centros de consumo. Las centrales nucleares, para las que no existe ninguna vinculación por razones de aprovisionamiento del combustible, pueden jugar un papel complementario de las clásicas, situándolas en zonas no servidas directamente por éstas.

Por otro lado, la opinión competente se inclina a afirmar que, desde el punto de vista de la seguridad nuclear, no existe inconveniente en acercarlas a los centros de consumo, si bien a cambio de un encarecimiento de las instalaciones para cumplir las exigencias, cada vez más estrictas, en cuanto a la seguridad nuclear y protecciones adoptadas.

Las principales limitaciones se derivarán tal vez de la necesidad de usar un importante caudal de agua para su refrigeración. Desde este punto de vista la geografía peninsular ofrece cierta facilidad de encontrar lugares adecuados en su extenso litoral marítimo y en las grandes reservas de agua embalsada en las cuencas de sus principales ríos. Las centrales de Zorita y Santa María de Garoña están situadas en sendos embalses de los ríos Tajo y Ebro, mientras que la central de Vandellós está localizada en el litoral mediterráneo. Sin embargo las futuras centrales sufrirán competencia en la elección de emplazamientos derivadas de la expansión demográfica, del crecimiento de otras industrias, de las necesidades portuarias del gran transporte y del importante desarrollo turístico que se apoya en el mar. Esta competencia hará cada vez más difícil encontrar sitios que reúnan las condiciones requeridas, por lo que se estima aconsejable estudiar, desde ahora, un esquema jurídico de reserva de zonas para estos fines.

7. DESARROLLO ADMINISTRATIVO DEL PROGRAMA

En España la instalación de una central nuclear requiere la concesión del Ministerio de Industria de las siguientes Autorizaciones: Previa, de Construcción y de Puesta en Marcha.

Las empresas eléctricas interesadas en llevar a cabo un proyecto nuclear, deben justificar técnica y económicamente la instalación, en puntos tales como necesidades del mercado propio, coste previsible de la energía producida, elección del emplazamiento, seguridad nuclear de la instalación, participación de la industria nacional en el suministro de equipo, conservación del medio ambiental y del paisaje local, etc.

La Administración por medio de sus servicios técnicos analiza estos factores aisladamente y en relación con las líneas establecidas en el PEN, tiene en cuenta las necesidades de uranio y de inversiones exigidas por la central, y atiende las alegaciones formuladas por los sectores público y privado afectados en sus intereses. Desde el punto de vista de la seguridad nuclear es siempre preceptivo el informe de la Junta de Energía Nuclear.

Con objeto de facilitar la contrucción y puesta en marcha de la central, y de vigilar el cumplimiento de las cláusulas contenidas en las Autorizaciones, se han instrumentado órganos de consulta permanente denominados Comité de Coordinación, uno por central, constituidos por representantes de la Administración y de la Empresa Concesionaria, a cuyas sesiones de trabajo asisten especialistas invitados por las partes interesadas.

Los resultados de la actuación de estos Comités pueden calificarse como muy positivos. De sus gestiones se han derivado una gran fluidez y rapidez en los trámites administrativos, y se han evitado demoras en la construcción y puesta en servicio, merced al estudio y solución anticipada de problemas que no hubiesen sido previstos sin esta clase de consultas. Por otra parte, las empresas se benefician de las orientaciones que les facilita en relación con los compromisos adquiridos con la Administración.

8. POLITICA EN EL CICLO DE LOS COMBUSTIBLES

Las necesidades de combustible para atender al programa nuclear español se han analizado y según hipótesis distintas basadas en el empleo simultáneo de reactores de agua ligera o convertidores avanzados con reproductores rápidos. La Tabla VI muestra las necesidades para un programa basado en reactores de agua ligera y reproductores rápidos, más la central de Vandellós.

La importancia de estas cifras y el volumen económico de los servicios asociados, justifica un esfuerzo progresivo para lograr que el suministro de los mismos se realice en la mayor escala posible dentro del país.

TABLA VI. NECESIDADES DE URANIO (t U_3O_8)

Años	Potencia	Demanda de uranio acumulada
1975	1,1	1 000
1980	8,0	10 500
1985	17,0	22 000
1990	29,5	35 000
1995	46,5	57 000
2000	71,0	75 000

8.1. Suministro de materias primas

La prospección e investigación de nuevos yacimientos prosigue a fuerte ritmo y hay indicios muy prometedores que permiten pronosticar un aumento sustancial de las reservas.

En cuanto a instalaciones fabriles, está prevista la construcción en Ciudad Rodrigo de una fábrica de uranio para una producción de unas 400 toneladas de U_3O_8 al año, a partir de 1974-1975. La construcción de otras fábricas dependerá de la importancia de los yacimientos que entren en explotación.

8.2. Servicios del ciclo

España estudia la participación en las posibles plantas de enriquecimiento europeas. En la actualidad acude a la contratación de este servicio en el extranjero. Con esta excepción, se proyecta efectuar el resto de los servicios del ciclo en el país con calendarios dependientes del mercado interior y del "umbral" económico de cada uno.

El primer servicio que se iniciará será la fabricación de los elementos combustibles, mediante una empresa mixta privada y estatal ya creada, con la ayuda técnica de la J.E.N. y el apoyo exterior que sea preciso. Los servicios de conservación a UF_6 y de reelaboración de los combustibles irradiados, para lo cual se cuenta con tecnología propia, se iniciarán cuando el mercado lo justifique.

8.3.- Política de los combustibles fisionables

La gestión del uranio, importaciones de combustible, etc., corren a cargo de la Comisión Nacional de Combustibles, a través de la Subcomisión de Combustibles Nucleares en la cual está representada la Administración y las empresas eléctricas. La política actual consiste en la contratación de combustibles y servicios por las empresas interesadas, pero con gestión unificada por una agencia conjunta de las partes interesadas.

El destino del plutonio procedente de los reactores térmicos depende del futuro programa de reactores rápidos. Si la comercialización de los reactores rápidos llega antes de 1980 será rentable almacenar todo el plutonio producido a partir de 1973. No obstante no se ha llegado a una conclusión firme a este respecto.

9. POLITICA EN LA CONSTRUCCION DE CENTRALES NUCLEARES

La ingeniería y la industria de fabricación bienes de equipo están en España en período de despegue. En algunos sectores, como el naval y, en gran parte, el eléctrico, puede decirse que la industria ha llegado a su mayoría de edad, representada por la autosuficiencia doméstica y la competitividad internacional. En el sector del equipo de generación de energía en centrales térmicas existen ya grandes empresas dedicadas a la fabricación de calderas, turbinas y alternadores con licencias extranjeras, y, paralelamente, sociedades de ingeniería capaces de concebir y realizar proyectos concretos de grandes centrales.

En la primera generación de Centrales Nucleares (Zorita, Santa María de Garoña y Vandellós) se adoptó la modalidad de contratación del proyecto "llave en mano", pese a lo cual ha intervenido ya un buen número de empresas españolas y sociedades de ingeniería. Las empresas manufactureras relacionadas con el equipo de la caldera nuclear han actuado, en la mayor parte de los casos, bajo plano del suministrador. La acción de la Administración de exigir determinados porcentajes de participación española al conceder la autorización y vigilar después, por medio de los Comités de Coordinación, el cumplimiento de este requisito, se ha revelado como un medio eficaz para estimular este resultado.

La participación nacional, en el caso de la central de Zorita, ha sido del 37,4%. Las cifras correspondientes a las centrales de Santa María de Garoña y Vandellós, aunque no se conocen todavía con carácter definitivo, puede afirmarse rebasarán los valores de 41% y 36%, respectivamente. La experiencia que se está adquiriendo en esta primera generación de centrales nucleares permite esperar que en las correspondientes a la segunda generación se pueda alcanzar un 50%.

Sin embargo, el estímulo más eficaz es el propio análisis del amplio mercado de componentes nucleares que se abre a la iniciativa empresarial. En efecto, se prevé que a partir de 1976 ó 1977 se contraten ya 1 500 MWe anuales en reactores térmicos, por un valor superior a 300 millones de dólares anuales, de los cuales corresponden a equipo unos 160 millones de dólares. Las cifras son bien elocuentes y justifican el interés de las empresas en el mercado de componentes nucleares.

La industria española ha tomado ya la iniciativa y se está preparando para ello, con la ayuda de la Junta de Energía Nuclear y el Servicio Técnico Comercial de Constructores de Bienes de Equipo (SERCOBE), organismo sindical que agrupa las empresas del sector. Los empresarios españoles están organizando sus equipos de producción para abordar el proyecto y construcción de componentes nucleares bajo especificaciones funcionales de los suministradores.

La capacidad actual es suficiente para la fabricación de los componentes de importancia intermedia, tan pronto como se pongan a punto las técnicas de control de calidad y ensayos no destructivos. Ya se han iniciado una serie de programas para el desarrollo de estas técnicas, en colaboración con organismos de la Administración.

Para las componentes de mayor dificultad, cuya fabricación sólo es rentable cuando se alcanzan producciones considerables, están en marcha estudios por parte de las empresas interesadas, a fin de decidir la instalación de nuevas fábricas y el adiestramiento de equipos de proyecto, para llegar a la producción de estos componentes con las adecuadas garantías de calidad y economia. Para ello se estudia la adscripción de estas actividades al régimen de fabricaciones mixtas, de gran éxito en fabricaciones análogas, y es posible la ayuda estatal mediante la llamada acción concertada. Los empresarios españoles no se limitan a la consideración del mercado interior, sino que tienen prevista la exportación de componentes y la colaboración con los países latinoamericanos a los que nos unen vínculos de fraternidad técnica muy considerables.

Cuando estos programas lleguen a su madurez no resulta aventurado predecir una participación nacional del orden del 70% en equipo solamente, o del 80-85% de la inversión total.

LONG-TERM PLANNING FOR NUCLEAR POWER IN THE NORDIC COUNTRIES

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Abstract–Résumé–Аннотация–Resumen

LONG-TERM PLANNING FOR NUCLEAR POWER IN THE NORDIC COUNTRIES.

Between the Nordic countries a very close electricity supply cooperation takes place within Nordel, which is the cooperation organizing the Nordic power companies. Several long-term studies have been carried out concerning the future development of electricity consumption. Studies have also been made of how to cover the increasing demand for energy optimally and have been primarily concerned with the period up to 1980 with speculations on 1985 and 1990. The electricity demand within the interconnected Nordel system is estimated to increase to some 330 TWh/yr and about 60 000 MW around 1980. At present hydro power covers - during years with normal precipitation - about 75% of the energy demand in the Nordel system and conventional thermal power the remaining 25%. Because of local natural conditions great differences exist between the Nordic countries concerning the production structure. Future expansion of the generating plants will take place differently in the different countries. In Sweden and Finland it is anticipated that the increase of the base-load production will mainly be covered through nuclear and oil-fired power stations in the 1970s, but in this period cheap hydro power will still be available in Norway, while in Denmark the most economic alternative will probably be thermal power based on fossil fuels. Iceland, which is not included in the interconnected Nordel system, has important energy resources in hydro power, of which around 8% has already been harnessed, and in geothermal heat. Nuclear power in the Nordel system is expected to rise to a share of 15 - 20% of the electricity production by 1980. Hydro power's share will decrease to about 55% whereas conventional thermal power will increase slightly to 25 - 30%.

In Sweden plans exist for an expansion of nuclear power to reach an installed capacity of about 7000 MW in 1980, with units in sizes of up to about 800 MW. For the 1980s 1500-2000 MW nuclear power will be installed annually, giving a total nuclear capacity in 1990 of 25 000 MW as a round figure.

In Finland the first nuclear power station will be commissioned in 1976. Up to 1990 a nuclear power program has been outlined including 10 units in five plants. In 1980 the installed nuclear capacity is estimated to be about 1500 MW and in 1990 between 6000 and 7500 MW.

In Norway possibilities for domestic use of nuclear energy have been closely considered since the early 1950s. A broad survey of the country's energy situation has been made for 1970-1990. Around 1985 nuclear power will represent a feasible source of electric power as a supplement to the Norwegian production system, which at present is mainly hydro-based.

PREVISIONS A LONG TERME POUR LE DEVELOPPEMENT DE L'ENERGIE NUCLEAIRE DANS LES PAYS NORDIQUES.

Pour l'approvisionnement en énergie électrique, une collaboration très étroite existe entre les pays nordiques au sein du Nordel, organisation de coopération des compagnies nordiques de production d'énergie. Plusieurs études à long terme ont été effectuées sur le développement futur de la consommation d'électricité. Des études ont été également faites sur les moyens qui pourraient permettre de faire face à l'accroissement de la demande d'électricité d'une façon optimale. Ces études portent principalement sur la période allant jusqu'à 1980, mais quelques estimations ont été faites pour les périodes allant jusqu'à 1985 et 1990. Il est prévu que la demande d'électricité au sein des réseaux interconnectés du Nordel passera à environ 330 TWh/an et environ 60 000 MW vers 1980. Actuellement, l'énergie hydro-électrique couvre environ 75% des besoins au sein du Nordel dans les années à conditions hydrologiques normales, le reste, soit environ 25%, étant couvert

par les centrales thermiques. Les conditions naturelles n'étant pas les mêmes dans les différents pays nordiques, il en résulte que la structure de la production d'énergie est différente suivant les pays et que l'expansion future des centrales ne s'effectuera pas de la même façon. En Suède et en Finlande, on prévoit que l'accroissement de la production de base au cours des années soixante-dix pourra être assuré principalement par des centrales nucléaires ou thermiques à combustible fossile. Au cours de cette même période, de l'énergie hydro-électrique bon marché sera toujours disponible en Norvège; au Danemark, la solution la plus économique sera vraisemblablement apportée par des centrales thermiques utilisant du combustible fossile. L'Islande, qui ne fait pas partie du réseau Nordel, dispose d'importantes ressources en houille blanche - dont seulement 8% environ sont actuellement exploités - et de chaleur géothermique. On estime d'une façon générale que la part de l'énergie nucléaire dans le réseau Nordel augmentera pour atteindre 15 à 20% de la production d'électricité en 1980. La part de l'énergie hydro-électrique tombera alors à environ 55% tandis que celle de l'énergie thermique conventionnelle augmentera légèrement pour passer à 25 ou 30%.

Des projets existent actuellement en Suède pour le développement de l'énergie nucléaire, qui prévoient une capacité installée d'environ 7000 MW en 1980 avec des unités d'une capacité s'élevant jusqu'à 800 MW. Pendant les années quatre-vingts, une capacité nucléaire de 1500 à 2000 MW sera installée chaque année; en 1990 la capacité nucléaire totale sera ainsi de 25 000 MW en chiffre rond.

En Finlande, la première centrale nucléaire sera mise en service en 1976. Un programme nucléaire prévoyant la construction de 10 unités groupées dans 5 centrales a été esquissé pour la période allant jusqu'en 1990. On estime que la capacité nucléaire installée atteindra environ 1500 MW en 1980, et 6000 à 7500 MW en 1990.

En Norvège, l'utilisation de l'énergie nucléaire pour la consommation intérieure a été sérieusement envisagée depuis le début des années cinquante. Une étude générale de la situation concernant la production d'énergie dans ce pays pendant la période 1970 - 1990 montre que l'énergie nucléaire pourra constituer à partir de 1985 un complément au système de production norvégien, qui est jusqu'à présent basé principalement sur l'énergie hydro-électrique.

ДОЛГОСРОЧНОЕ ПЛАНИРОВАНИЕ АТОМНОЙ ЭНЕРГЕТИКИ В СКАНДИНАВСКИХ СТРАНАХ.

Между странами севера Европы существует очень тесное сотрудничество по обеспечению электроэнергией в пределах энергосистемы "Нордель", которая представляет собой объединенную систему энергетических компаний скандинавских стран. В этих странах проведены долгосрочные исследования перспектив будущего роста потребления электроэнергии. Проведены также исследования по поискам наиболее оптимального способа удовлетворения возрастающих потребностей в электроэнергии; эти исследования охватывали в основном период до 1980 года и в перспективе – 1985 и 1990 годы. Предполагается, что потребности в электроэнергии в пределах энергосистемы "Нордель" к 1980 году возрастут примерно до 330 ТВт-ч/год, а общая мощность – до 60 000 МВт. В настоящее время гидроэлектростанции покрывают (в периоды нормальных водных режимов) около 75% потребностей в электроэнергии энергосистемы "Нордель", а на долю теплоэлектростанций приходятся оставшиеся 25%. Вследствие местных природных условий, между скандинавскими странами существует большая разница в способах производства электроэнергии. Поэтому в этих странах будущее развитие энергетики пойдет по-разному. В Швеции и Финляндии промышленные потребности в электроэнергии предполагается покрыть в основном за счет строительства в 70-х годах атомных электростанций и тепловых электростанций, работающих на нефти. Однако в этот же период в Норвегии будут еще использоваться гидроресурсы, обеспечивающие дешевую электроэнергию, а в Дании наиболее экономичными производителями электроэнергии будут теплоэлектростанции, работающие на угле. Исландия, которая не входит в энергосистему "Нордель", имеет богатые гидроресурсы, из которых в настоящее время используется уже 8%, и геотермальные источники. Таким образом, к 1980 году при помощи ядерной энергии в энергосистеме "Нордель" будет вырабатываться около 15-20% электроэнергии. Доля гидроэнергии снизится до 55%, а доля теплоэнергетики возрастет до 25-30%.

В настоящее время в Швеции разработана программа развития атомной энергетики; по этой программе к 1980 году установленная мощность всех АЭС составит 7000 МВт с энергоблоками мощностью до 800 МВт. В 80-е годы мощность АЭС будет ежегодно возрастать на 1500-2000 МВт и составит в 1990 году примерно 25 000 МВт.

В Финляндии первая АЭС будет введена в эксплуатацию в 1976 году. По программе развития атомной энергетики к 1990 году предполагается ввести в строй пять АЭС с 10 энергоблоками. Ожидается, что к 1980 году установленная мощность АЭС составит 1500 МВт, а в 1990 году – от 6000 до 7500 МВт.

Возможности мирного использования атомной энергии в Норвегии обсуждались в начале пятидесятых годов. Оценки потребностей в электроэнергии в период 1970-1990 годов показывают, что после 1985 года атомная энергетика будет представлять важный источник электроэнергии дополнительно к норвежской системе производства, которая в настоящее время обеспечивается в основном за счет гидроресурсов.

PLANES A LARGO PLAZO DE ENERGIA NUCLEAR EN LOS PAISES NORDICOS.

Entre los países nórdicos hay una cooperación muy estrecha en el suministro eléctrico que se lleva a cabo por medio de Nordel, organismo cooperativo de las compañías eléctricas nórdicas. Se han realizado diversos estudios a largo plazo en relación con el desarrollo futuro del consumo de energía eléctrica. Se han realizado también estudios sobre el modo de hacer frente de forma óptima a la demanda creciente de energía eléctrica. Estos estudios se extienden principalmente hasta 1980, aunque se hacen también previsiones hasta 1985 y 1990. Se estima que la demanda de energía eléctrica dentro del sistema interconectado del Nordel aumente hasta unos 330 TWh anuales y alrededor de 60 000 MW, hacia 1980. En la actualidad la energía hidroeléctrica cubre – en los años con precipitaciones normales – aproximadamente el 75% de la demanda de energía en el sistema Nordel y la energía térmica tradicional el 25% restante. A causa de condiciones naturales de la región, hay grandes diferencias en la estructura de la producción de los países nórdicos. La expansión futura de las centrales productoras de energía tomará diversas formas según el país. En Suecia y Finlandia se prevé que el aumento en la producción de carga-base se hará principalmente con centrales nucleares o de fuel en los años 70. Durante esta época seguirá disponiéndose en Noruega de energía hidroeléctrica barata y en Dinamarca la alternativa más económica será probablemente la energía térmica a base de combustible fósil. Islandia, que no está incluida en el sistema interconectado de Nordel, tiene importantes recursos de energía hidroeléctrica – de los que en la actualidad se explotan un 8% – y de calor geotérmico. En total se espera que la energía nuclear en el sistema Nordel aumente hasta representar alrededor del 15 al 20% de la producción de energía eléctrica hasta 1980. La contribución de la energía de origen hidráulico disminuirá entonces hasta un 55%, mientras que la de origen térmico tradicional continuará representando un 25 a 30%.

En Suecia existen en la actualidad planes para aumentar la energía nuclear que darían por resultado una potencia instalada del orden de 7000 MW en 1980, con unidades de un tamaño hasta 800 MW. De 1980 a 1990 se instalarán cada año de 1500 a 2000 MW nucleoeléctricos, lo que dará para 1990 una capacidad nucleoeléctrica total de 25 000 MW en números redondos.

En Finlandia la primera central nuclear entrará en servicio en 1976. Para el período que se extiende hasta 1990 se ha bosquejado un programa de energía nucleoeléctrica que incluye 10 unidades en cinco centrales. En 1980 la potencia nucleoeléctrica instalada se estima en unos 1500 MW y en 1990 entre 6000 y 7500 MW.

En Noruega las posibilidades de utilización doméstica de la energía nucleoeléctrica se ha considerado cuidadosamente desde los años cincuenta. Un amplio estudio de la situación energética del país durante el período de 1970-1990 indica que la energía nucleoeléctrica a partir de, aproximadamente, 1985, representará una posible fuente de energía eléctrica como suplemento del sistema de producción noruego, que en la actualidad está basado principalmente en la energía hidroeléctrica.

INTRODUCTION

Between the Nordic countries a very close electricity supply co-operation is taking place within Nordel, which is the co-operation organization of the Nordic power companies. Nordel is an advisory and recommendatory body, which is formed of the leading persons of the power companies. The interconnected Nordel system includes the electricity supply systems of Denmark, Finland, Norway and Sweden, see Fig. 1.

The most important domestic resources of natural energy in the Nordic countries are hydro power and wood fuel, primarily in the form of waste fuel from the forest industry. There are, however, great differences between the countries, and in Denmark for example these resources have no real importance. The possibilities of getting oil and gas from the North Sea are being explored, and the deposits which can be exploited have been found. There are some uranium deposits, yet at present too expensive to be exploited. Iceland, which is not included in the interconnected Nordel system, is rich in natural energy resources, both hydro power and geothermal energy.

To investigate how to cover the increasing demand for electric energy in an optimum way, several long-term studies have been carried out, primarily concerning the period up to 1980 but also viewing 1985 and 1990.

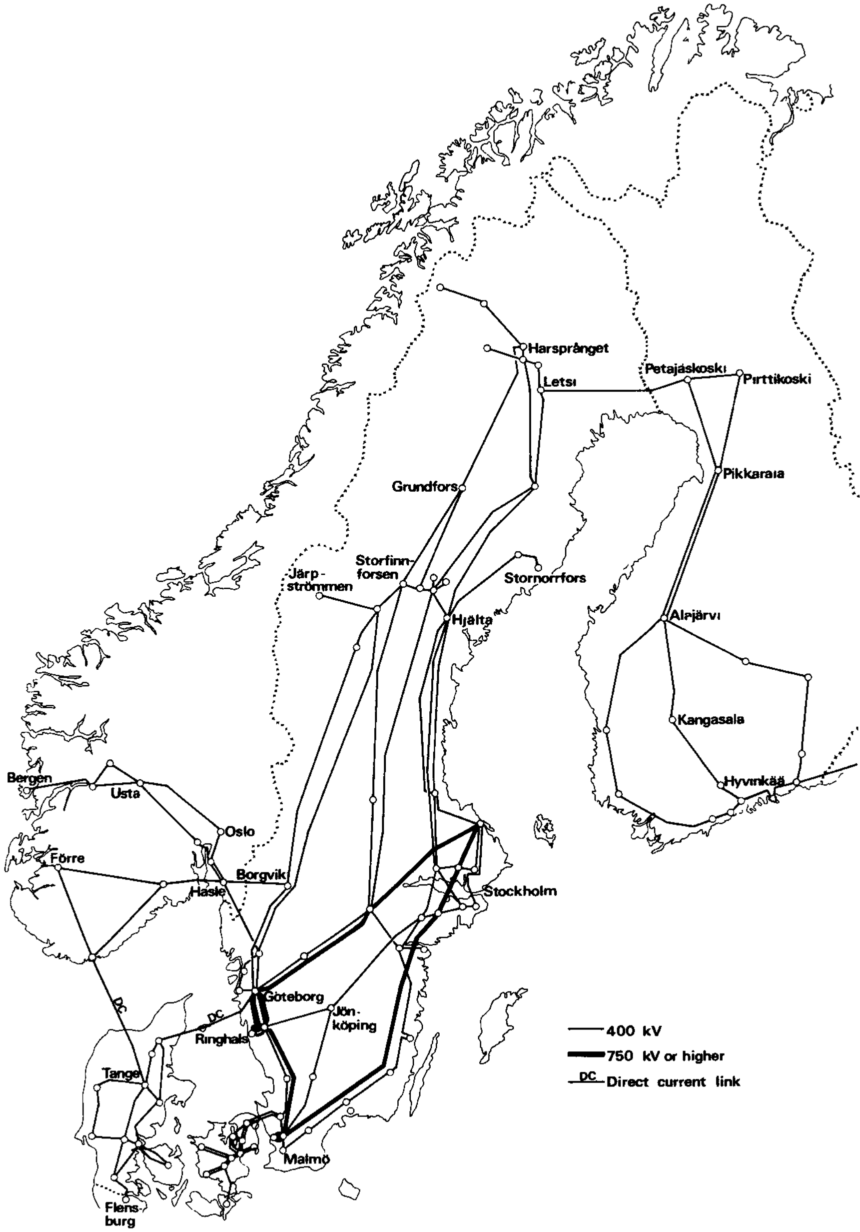

FIG.1. The high-voltage grids of the Nordel system in 1985.

The electricity consumption within the interconnected Nordel system was in 1970 just below 160 TWh, and it is estimated to increase to some 330 TWh/yr and about 60 000 MW around 1980. The consumption per inhabitant is at present between 6000 and 7000 kWh/yr for the four countries together. Norway has approximately 15 000 kWh per inhabitant and year, which is the highest rate in the world.

At present hydro power covers – during years with normal water conditions – about 75% of the energy demand in the Nordel system and fossil-fuelled thermal power the remaining 25%. At present Norway relies completely on hydro power, whereas the supply in Denmark is completely based on thermal power. Finland and Sweden both represent an intermediate position. In 1970 – a year of poor precipitation – the hydro power stations delivered in Finland about 45% and in Sweden about 65% of the total electricity consumption. In the 1970s the increase of the base-load production in Sweden and Finland is anticipated to be mainly covered through nuclear and oil-fired power stations. During this period cheap hydro power will still be available in Norway, and in Denmark the most economic alternative will probably be thermal power based on fossil fuels.

The expected future development in Sweden, Finland and Norway is described in three appendices. In Sweden (Appendix I) there are now plans for an expansion of nuclear power which will result in an installed capacity of about 7000 MW in 1980. In 1990 the nuclear capacity has been estimated to amount to about 25 000 MW. In Finland (Appendix II) a nuclear power program has been outlined for the period up to 1990. In 1980 the installed nuclear capacity will be about 1500 MW and in 1990 between 6000 and 7500 MW. In Norway (Appendix III) there are indications that from about 1980 nuclear power will represent a feasible source of electric power as a supplement to the Norwegian production system. The installed nuclear capacity is estimated to amount to between 3000 and 9000 MW in 1990.

Denmark will have about 8000 MW installed generating capacity at the end of 1970s, divided equally between the two separate areas east and west of the Great Belt. In both areas the load is growing at an annual rate of about 10%. No incentives have been found to embark upon nuclear program in the 1970s, when nuclear units should be of a size covering about twice the annual load increase in order to be competitive with conventional power. Uncertainties with respect to construction costs have contributed to the present reserved attitude to nuclear power, as well as the high interest rate and the low prices of fossil fuel in force until recently. The considerations have been further complicated by the possibilities of buying large quantities of natural gas from the North Sea. It is possible that natural gas may postpone the introduction of nuclear power somewhat further into the future than the years around 1980. Before placing firm contracts in connection with the first nuclear unit, three to four years for preliminary investigations of siting and technical-economical problems are foreseen. Furthermore the necessary project organizations shall be established or set up, and experience shall be collected. Essential parts of this preparatory work have been in progress for some time.

In Iceland the total production of electricity amounted in 1970 to about 1.5 TWh, of which 97% were generated by hydro power. Yet only about 8% of the country's total harnessable hydro power has been developed so far. Geothermal energy is of no less magnitude than hydro power and controls vast energy potentials capable of being converted into electricity, so far only carried out to a small initial extent. However, natural heat is used increasingly for space heating including almost the whole of the capital, Reykjavik. As the natural energy resources in Iceland are so extensive and utilized to such a small extent, it seems quite unlikely that nuclear power plants will be constructed there for a long time to come.

In total, nuclear power in the Nordel system is expected to rise to a share of 15 - 20% of the production of electric energy up to 1980. Hydro power will decrease to about 55% whereas conventional thermal power will increase slightly to 25 - 30%. The installed nuclear capacity within Nordel is estimated to be about 9000 MW, or 10 - 15% of the electricity generating capacity in 1980, and it will increase to some figure between 30 000 and 50 000 MW in 1990.

Owing to the large size of the nuclear power stations in almost all cases they will be connected to the 400-kV systems or even higher voltages in the Nordic countries. By the end of the 1970s 400-kV grids will probably be in operation in all the interconnected systems of the Nordic countries. Investigations have shown that the introduction of a system voltage of 750 kV or higher should be taken into consideration in Sweden, yet not be commissioned before the end of the 1970s. Figure 1 shows a map of the high voltage grids of the Nordel system in the middle of the 1980s according to preliminary plans of expansion. The existence of interconnections between the Nordic countries can facilitate the establishment of large nuclear power units and thereby the exploitation of the economic potential of nuclear power.

Finally it ought to be mentioned that an experience centre for nuclear power has been set up at the Swedish Ringhals nuclear power station which is under construction. This enables engineers from the Nordel companies to acquire technical know-how by participation in the work of this project. At two other Swedish nuclear projects there are similar opportunities of taking part in the work.

PART I

LONG-TERM PLANNING FOR NUCLEAR POWER IN SWEDEN

1. CONSUMPTION OF ELECTRIC ENERGY

For the 1970s a thorough forecast of the electric energy consumption has recently been made by the Central Operating Management (CDL), which is a co-operative body of the power utilities in Sweden. According to this forecast the annual increase of consumption will be 8.4 and 7.7% for the periods 1970 - 75 and 1975 - 78, respectively, meaning a rise of the annual load from 65 TWh in 1970 to 145 TWh in 1980.

For the 1980s no such certain forecast is yet available. For the planning studies that are now carried out, the same increase of consumption is assumed each year of the decade as the forecasted annual increase during the last year of the 1970s, implying a rise from 145 TWh in 1980 to 200 TWh in 1985 and 255 TWh in 1990.

2. DECREASING HYDRO POWER EXPANSION

During the 1970s the hydro power expansion will, according to present plans, be only 8 TWh, covering not more than 10% of the increase of consumption. The hydro power share of the total production, which during normal precipitation, amounted to 80% in 1970, will decrease to 40% in 1980.

At present it is difficult to estimate the expansion of hydro power after 1980. It is true that also after 1980 there will remain some economically harnessable projects, but due to environment considerations among others it is uncertain if they will be exploited. In the general planning studies for the 1980s only a few new hydro power stations are foreseen.

Thus, from 1970 onwards the increase of the energy consumption will, to more than 90%, be covered by fossil or nuclear thermal power, the choice between them to be made by technical and economical power balance calculations.

3. OPTIMUM SHARE OF POWER PRODUCTION EXPANSION

The general outlines concerning the optimum share of the different kinds of production are regularly investigated by the CDL. Resulting from such general studies a detailed plan for the next 15 to 20 years is then carried out, which also takes into account factors that cannot be considered in a general study. Between the Swedish power utilities a co-ordination of this planning is made by the CDL Planning Committee. The geographical and physical conditions – including possibilities for transmission lines – for conceivable thermal power stations are investigated by the CDL Siting Committee. This is made in co-operation with the authorities and includes all possible sites for large plants along the sea coast and at the large lakes. A special committee set up by the government is also studying the possibilities for locating nuclear power plants in or near large cities in order to use the plants for combined production of electricity and heat.

The last general study was made in 1970 and concerned the conditions during the 1970s. It was based on the mentioned forecast for this decade. It also took into account the hydro power expansion. Besides, the study also investigated the possible expansion of industrial and district heating back-pressure plants, which, owing to the combined production of heat and electricity, are found to be more economical than other kinds of thermal power. The calculations were carried out for different values concerning interest rates and fuel oil prices.

According to this theoretical study only nuclear power and peak production units should be installed, together with hydro and back-pressure installations. The fossil-fuelled condensing plants were not found economical, unless the oil price should be below 1.1 US $/Gcal. In spite of a considerable increase in installation costs and fuel costs since the time of the study, the conclusions concerning the optimum share still seem to be valid for the 1970s as well as for the 1980s.

Detailed planning considers more accurately the energy and peak load requirements and is therefore able to give more specific conclusions about the installations of nuclear, fossil-fuelled and hydro power. Regarding back-pressure power, the district heating capacity is, in the present study, scheduled to rise from 4 TWh in 1970 to 13 TWh in 1980 and to about 30 TWh in 1990; two-thirds of the increase in the 1980s is assumed to be nuclear.

Some increase of the fossil-fuelled condensing power is also assumed, despite the result of the general study. In reality, such units will be found justifiable, among other reasons because they can be used for peak load as well as for base load. It is also often economically favourable to install additional units in existing stations. Because of their relatively short erection time, fossil condensing units will also be chosen in case of an unexpected rapid increase of the consumption.

The detailed planning carried out hitherto has given the following figures for 1980 and 1990 regarding the share of energy production – in the case of normal precipitation – between nuclear, fossil-fuelled and hydro power. For comparison the energy balance for 1970 is also given:

	1970	1980	1990	
Hydro power	53	≈ 62	≈ 65	TWh/yr
Nuclear power	0	≈ 46	≈ 140	"
Fossil-fuelled power	12	≈ 37	≈ 50	"
	65	145	255	

Apart from the uncertainty of the load forecast, the figure for nuclear power for 1980 and 1990 must be considered as approximate. Two reasons for this have been mentioned, namely the difficulties to foresee the competitiveness of the fossil-fuelled power and to estimate the hydro power expansion. A third reason is an uncertainty regarding the possibilities of obtaining oil or gas from the North Sea and the Baltic; in the figures above no such possibilities have been considered.

The nuclear power expansion in the 1970s will result in an installed capacity of about 7000 MW in 1980, with unit sizes up to about 800 MW. For the 1980s, 1500-2000 MW nuclear power is to be installed each year, giving a total nuclear capacity in 1990 of 25 000 MW as a round figure. It is anticipated that the unit size will rise to about 1500 MW in 1985. Thus, one or two new units are required each year during the 1980s. According to the preliminary siting studies it is expected that about 10 sites will be used for these 25 000 MW.

4. CONCLUDING REMARKS

In the studies referred above no new production processes – except fast breeders – are assumed before the end of the 1980s. Thus, it is considered that the fusion reactor will not be in commercial use during the period considered, because it has not even been shown in laboratory scale that it is possible to create a stable fusion reaction, and that the experience from the conventional nuclear power has shown that it takes about 25 years from the laboratory stage to full commercial operation.

PART II

LONG-TERM PLANNING FOR NUCLEAR POWER IN FINLAND

1. CONSUMPTION AND PRODUCTION OF ELECTRIC ENERGY

The consumption of electric energy in Finland in 1970 amounted to 22 TWh totally or 4600 kWh per capita. The average annual growth-rate during 1950-1970 was 9.3%. The share of industry in the consumption of energy accounted for nearly 70%, while the forest industry alone used about 50%.

The average annual growth in the real volume of the gross national product during 1950-70 in Finland was 5%. This growth is supposed to slow down to some extent in the future. The long-term forecast of the electric energy is based on an annual average growth of 4% [1].

Accordingly the consumption of electricity is calculated to be in

1970	22 TWh
1980	44 "
1990	75 "
2000	120 "

Under average precipitation conditions water power covers about 50% of the present demand for electricity. The share of the thermal power produced in pulp and other industrial thermal processes and also in municipal district heating systems is about 30%. The water-power resources are almost totally exploited. Owing to limited expansion of district heating systems as well as forest resources, the share of the process thermal power will also decrease. Thus in the future most electricity demand must be covered by separate large condensing power stations. A general picture of the energy production is given in Fig. 2.

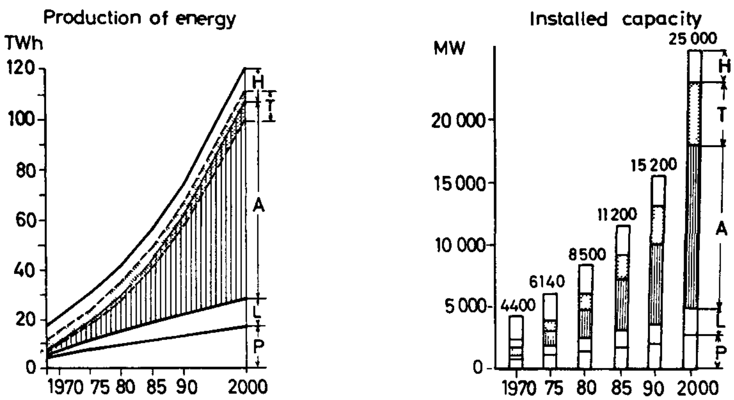

FIG. 2. Planned production of electric energy and installed capacity in Finland 1970-2000. P = industrial process power; L = district heating power; A = base load condensing power; T = peak load and reserve power; H = hydro power.

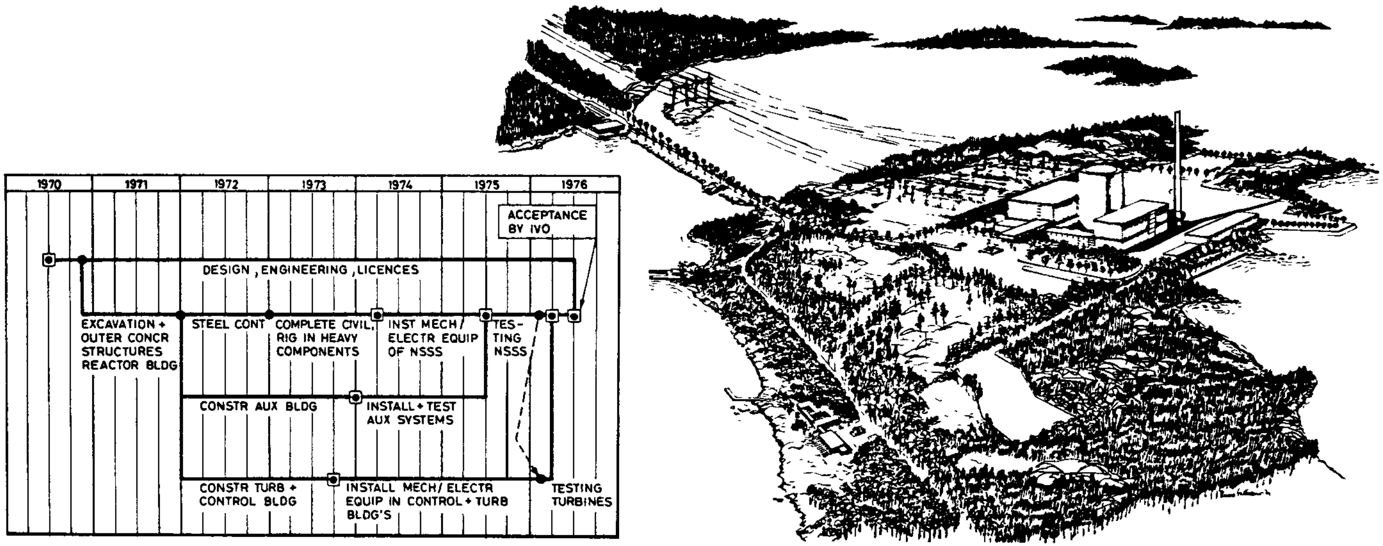

FIG. 3. The Loviisa nuclear power station under construction.

2. PLANNING FOR NUCLEAR POWER

Since the end of the 1950s the introduction of nuclear power has been studied in Finland and in 1960 an investigation made together with IAEA was completed [2]. According to this investigation the first nuclear power station of about 300 MW should have gone into operation at the beginning of 1970s. The final decision of the construction of the first station, Loviisa nuclear power station, was delayed until 1970. In the same year a contract was signed with the Soviet Technopromexport about the delivery of a Novo-Voronesh type pressurized-water reactor, two 220-MW turbines, and the first fuel loading and installation of this equipment, for a 420-MW station on an island near the town of Loviisa (see Fig. 3). The Finnish industry is participating to a great extent in the delivery of mechanical and electrical equipment. Also several West European and United States companies are taking part in the planning and in deliveries of the instrumentation and the safety system. Both the civil engineering and the general design are performed by the orderer, the state-owned Imatran Voima Osakeyhtiö.

This company is the prime contractor and will also adapt the station to the safety norms applied in the western countries. The Soviet Union equipment, which determines the schedule of the station, is so delivered that the station can go into commercial operation in spring 1976.

After commissioning the first unit in Loviisa the main part of the base load condensing power indicated in Fig. 1 will be covered with nuclear power [3]. This results in the nuclear power program shown in Fig. 4. In this program three units with a total capacity of 1500 MW will be commissioned by 1980. One of them is a 600-MW unit planned by Teollisuuden Voima Oy, a private-owned power company; the other two are the above-mentioned Loviisa I and Loviisa II. In the 1980s the nuclear power capacity will increase to comprise 10 units with a total capacity of 6000 - 7500 MW in five separate sites. Of these sites at least four will be located at the southern and western coasts. Presumably all the reactor units will be equipped with two turbines to keep the necessary enforcements of the network and because of the need to keep the reserve capacity moderate. One of the dimensioning criteria of the Finnish power system is the requirement that the disconnection of the largest turbogenerator shall not lead to an interruption of the electricity supply.

An extensive introduction of nuclear power in Finland is well founded because of the following reasons:

- Fossil fuels have not been found in Finland;
- The transport of fossil fuels to Finland is long and costly;
- Finland's fast-growing electricity demand, the well-developed transmission system and strong connections to neighbouring countries offer favourable conditions for the construction of large power stations;
- The southern and western coasts of Finland offer excellent sites for large nuclear stations, regarding ground conditions, cooling water supply and distance to the settlements;
- With regard to environmental protection, nuclear power is advisable since energy production is concentrated in relatively few locations where the problems concerning various environmental aspects can be effectively solved.

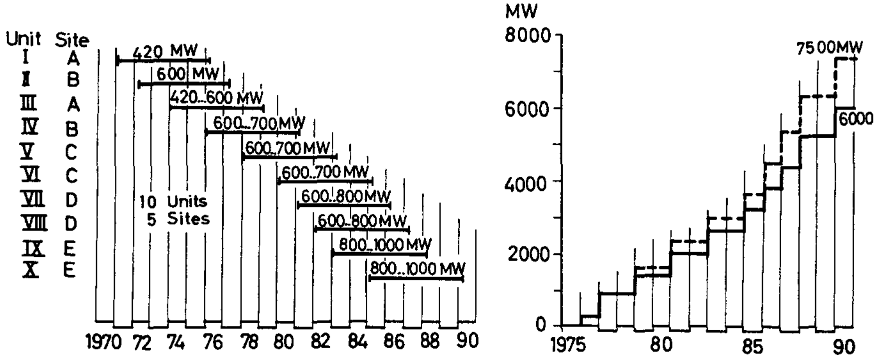

FIG. 4. Construction program for nuclear power until 1990 and installed nuclear capacity in Finland.

PART III

LONG-TERM PLANNING FOR NUCLEAR POWER IN NORWAY

Up to now Norway's only access to fossil energies has been a modest extraction of coal at Svalbard. Recent finds in the North Sea seem to promise future extraction of oil and gas from the Shelf. No occurrences of uranium are reported.

Abundant sources of hydro power scattered almost all over the country allowed early and extensive exploiting. The electricity consumption (60 TWh annually) now represents some 60% of Norway's total (inland) energy consumption, the remaining energy demand being mainly met by liquid fuels. The total energy consumption (per capita) averages that of Western Europe countries. Its high content of electricity shows an exceptionally high figure for the specific electricity consumption (approx. 15 000 kWh/inhabitant), only partly due to the demand from energy consuming industries.

Under normal precipitation conditions practically all electricity production originates from hydro power. The even and heavy industrial load allows the system to reach a high load factor.

A broad survey [4] of the future energy situation indicates: A growth in the general electricity consumption of approx. 5.5% p.a. up to 1980, giving a total consumption of at least 100 TWh for 1980 (a certain growth for the smelting industry included). With more than 50 TWh favourable hydro power unexploited, the greater part of the new demand can be met by hydro power. In spite of good storage possibilities, the variations in the precipitation from one year to another limit the possible amount of guaranteed power to be delivered from the hydro system. Thus certain amounts of oil-based energy (possibly delivered from neighbouring countries) represent the most feasible way of raising the guaranteed power ability.

The North Sea finds of oil and gas are not likely to have any marked influence on the time of introduction or quantities installed of this fossil-based supplement. With the value of the North Sea energy closely tied to the world market price level, there can be little difference for the economy of Norway should this energy come into use in these plants instead of purchased energy.

Nuclear power seems feasible as a supplement to the Norwegian system around 1985, due regard made to water resources and anticipated cost development even for other production means. Leaving the task of load regulating to the more flexible hydro power, the nuclear equipment can be allowed to run mainly on base load. Under these conditions the installation of atomic power may range from 3000 to 9000 MW in 1990.

The planning of the adaption of nuclear energy plants to the system is carried out with consideration of the distribution of hydro power sources and the location of consumption centres, aiming at solutions giving minimum production costs for the system as a whole [5,6]. The need for cooling water gives preference for locations close to the coast, but the topography is less convenient for plants of conventional design. Suitable areas, if they can be found, are attractive for alternative use. Thus suggestions to erect nuclear power plants underground in the bedrock have met with interest. This design will multiply the possibilities to finding locations without conflicting interests and will also take advantage of Norwegian engineers' very good experience in constructing underground water power plants. The cost incorporated will be somewhat higher than for a conventional design but, on the other hand, the safety improves which in turn may reduce the need for security zones surrounding the plant.

Investigations based upon the assumption that nuclear power plants can be placed rather freely along the Norwegian coast, indicates that the first plants will be placed within the Oslo-fjord region, with generator ratings of 500-800 MW and, towards the year 2000, from 3000 to 4000 MW. Sitings rather close to the heavier load centres seem realistic, so the introduction of nuclear power plants is not expected to require a higher transmission voltage than 380 kV, the highest voltage level at present in use in Norway.

The more general investigations in the nuclear field have been carried out by the Norwegian Institute of Nuclear Energy, founded in 1953. It has planned, built and operated three heavy-water scientific reactors, and built a water-vapour-producing reactor, placed completely underground in the city of Halden. The present main area of study of the Institute is reactor and fuel technology, process control, instrumentation, isotope technology, and problems concerning security.

Together with NVE and Norsk Hydro the Institute made a project study for an atomic power station of approx. 500 MW [7]. Both BWR and AGR were taken into consideration, with conventional as well as underground designs.

Central authorities are legally entitled to control the development of the electricity production system. Regarding nuclear power the need for central control is obvious. At the time of introduction the production from one single nuclear set corresponds well to the total annual consumption growth for the whole country. The responsibility for the planning, erection and running of these plants will most likely be laid to the State Power System.

The nuclear future concerns also the engineering industry in Norway. Through its deliveries this industry has played an active role in the development of the water power in Norway and is supposed to extend its activity into the new field. To develop national competence in future nuclear power technology is something which can be vital when it must be decided whether or not the first installation should be advanced to take place before the assumed optimal time.

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WORLD ENERGY REQUIREMENTS AND RESOURCES IN THE YEAR 2000

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Abstract–Résumé–Аннотация–Resumen

WORLD ENERGY REQUIREMENTS AND RESOURCES IN THE YEAR 2000.

The first part of this paper reviews existing long-term projections of energy demand at global and regional levels (for example, developed private enterprise economies, centrally planned economies and developing countries). An attempt is also being made to assess long-term factors influencing the demand for energy in countries in various stages of socio-economic development; and to identify the likely shifts in the demand for energy over the long-term period in the light of various assumptions relating, among others (a) to prospective economic growth-rates and (b) to technological changes and innovations that may produce major shifts in the long-term pattern of energy consumption. Special attention is paid to the changes in the sectoral composition of output and the prospective evolution of energy demand by major consuming sectors (industry, agriculture, transportation) is identified. Among the factors taken into account are the prospective growth-rates of population, technical progress, industrialization, urbanization, mechanization of agriculture, electrification, environmental considerations.

The second part of the paper brings together available information on estimates of reserves of conventional sources of energy (fossil fuels, etc.) and examines literature relating to prospective exploration activities which may result in the addition to such reserves. The paper contains a review of the forecasts of technological changes in the energy field affecting the availability of energy supplies with particular accent on new sources of energy. The paper ends with a brief discussion confronting energy demand with energy resource projections. An attempt is made to bring together the various qualitative considerations bearing on the substitution among the sources of energy with a view to estimating the relative shares of individual sources in meeting the total future requirements of energy.

ETAT DES BESOINS ET INVENTAIRE DES RESSOURCES EN ENERGIE DU MONDE JUSQU'A L'AN 2000.

La première partie du mémoire est consacrée aux projections à long terme de la demande d'énergie dans le monde et par groupes de pays (par exemple, pays développés à économie de marché, pays à économie planifiée et pays en voie de développement). Les auteurs cherchent aussi à déterminer les facteurs qui à long terme influent sur la demande d'énergie dans des pays qui en sont à des stades divers du développement économique et social. Ils s'attachent à prévoir les modifications probables à long terme dans la répartition de la demande d'énergie en adoptant diverses hypothèses concernant, entre autres, a) la prospective des taux de croissance économique, b) les changements et innovations technologiques qui peuvent entraîner d'importantes modifications dans la répartition à long terme de la consommation d'énergie. Ils accordent une attention particulière aux variations de la composition de la production par secteur et à l'étude de l'évolution future de la demande d'énergie des grands secteurs de consommation (industrie, agriculture, transports). Parmi les facteurs retenus figurent les taux d'accroissement de la population, le progrès technique, l'industrialisation, l'urbanisation, la mécanisation de l'agriculture, l'électrification et certaines considérations relatives à l'environnement.

La deuxième partie du mémoire est une compilation des renseignements disponibles sur les estimations des réserves des sources classiques d'énergie (combustibles fossiles, etc.) et une analyse de la documentation relative aux activités de prospection susceptibles d'aboutir à l'accroissement de ces réserves. Les auteurs passent aussi en revue les prévisions des changements technologiques dans le domaine énergétique qui influeront sur les approvisionnements en énergie et insistent sur les nouvelles sources d'énergie. Pour conclure, ils comparent brièvement les projections relatives à la demande et à l'offre d'énergie. Ils examinent les diverses considérations qualitatives qui interviennent dans la substitution des diverses sources d'énergie l'une à l'autre, en vue d'évaluer les parts respectives de ces sources dans les approvisionnements futurs en énergie.

МИРОВЫЕ ПОТРЕБНОСТИ В ЭНЕРГИИ И ЭНЕРГЕТИЧЕСКИЕ РЕСУРСЫ В 2000 году.

Первая часть данного доклада посвящена рассмотрению существующих долгосрочных прогнозов в области потребностей в энергии в мировом и региональном масштабах (например, страны с развитой экономикой, основанной на частнособственническом предпринимательстве, страны с центральным планированием экономики и развивающиеся страны). Делается попытка дать оценку долгосрочным факторам, влияющим на потребности стран в энергии на различных стадиях социально-экономического развития. Делается также попытка определить вероятные сдвиги в потребностях в энергии за длительный период в свете возможных перспектив, связанных, наряду с другими, с а) будущими темпами экономического роста и b) технологическими изменениями и новшествами, внедрение которых может значительным образом повлиять на долгосрочную программу потребления энергии. Особое внимание уделяется изменениям энергетических мощностей в секторах и перспективной оценке энергетических потребностей в основных потребляющих секторах (промышленности, сельском хозяйстве, транспорте). К принимаемым во внимание факторам относятся следующие: предполагаемые темпы роста населения, технический прогресс, индустриализация, урбанизация, механизация сельского хозяйства, электрификация, проблемы окружающей среды.

Во второй части доклада дается обобщение имеющейся информации относительно оценок запасов обычных источников энергии (виды ископаемого топлива и т.д.) и рассматривается литература по вопросам предполагаемых геологоразведочных работ, проведение которых будет способствовать открытию дополнительных месторождений. В докладе содержится обзор прогнозов технологических изменений в области энергетики, которые будут способствовать обеспечению энергией, при этом особое внимание уделяется новым источникам энергии. Доклад заканчивается кратким сопоставлением прогнозов относительно потребностей в энергии и энергетических ресурсов. Делается попытка обобщить различные соображения, касающиеся качественных сдвигов в источниках энергии с учетом оценки относительной доли отдельных источников в удовлетворении всего объема будущих потребностей в энергии.

RECURSOS Y NECESIDADES ENERGETICAS MUNDIALES HASTA EL AÑO 2000.

La primera parte de esta memoria pasa revista a las previsiones a largo plazo referentes a demanda de energía, a niveles mundial y regional (por ejemplo, regiones en que predomina una economía de empresas privadas en países desarrollados, economías de planificación centralizada y economías de países en desarrollo). Se propone describir y evaluar los factores a largo plazo que influyen en las necesidades de energía en países situados en diversas etapas de su desarrollo socioeconómico. Se procura predecir las probables tendencias en las necesidades de energía a largo plazo, sobre la base de diversas hipótesis entre las que se encuentran: a) el ritmo previsible de crecimiento económico; b) las transformaciones e innovaciones tecnológicas que pueden originar variaciones importantes en el esquema a largo plazo del consumo energético. Se concede especial atención a los cambios en la composición sectorial de la potencia generada, y se estudia la evolución probable de la demanda de energía por los principales sectores consumidores (industria, agricultura, transporte). Entre los factores a tener en cuenta figuran la tasa probable de crecimiento de la población, el progreso técnico, la industrialización, la urbanización, la mecanización de la agricultura, la electrificación y otras consideraciones del medio socioeconómico.

En la segunda parte del trabajo se recoge la información hoy disponible sobre los cálculos de las reservas de fuentes convencionales de energía (combustibles fósiles, etc.), y se examina la literatura referente a las actividades de exploración que puedan aumentar dichas reservas. La memoria contiene un estudio sobre los cambios technológicos que pueden producirse en el campo de la energía y afectar a la disponibilidad de suministros energéticos, dándose especial importancia a las nuevas fuentes de energía. El trabajo termina con un breve estudio en que se compara la demanda de energía con la expansión de los recursos energéticos. Se procura presentar todas las diversas consideraciones de orden cualitativo que pueden determinar la sustitución de una fuente energética por otra, con objeto de examinar la relativa proporción de cada fuente individual en la satisfacción de las necesidades futuras totales de energía.

I. INTRODUCTION

Over the years, mankind's social and economic development has been associated with an increasing utilization of energy. The vast bulk of energy is supplied at present by coal, oil and natural gas and, to a small extent, by hydroelectric and nuclear energy. Nuclear sources are however gaining ground, although the technological problems of radioactive waste disposal remain to be solved satisfactorily before nuclear energy can become a major energy source. Large reserves of hydroelectric energy still exist, especially in the developing nations, and other energy resources which exist in various parts of the world have not yet been utilized.

Information on estimated energy reserves and on projected demand for energy indicate that total reserves are adequate to meet the increase in demand to the year 2000 and for some time beyond that date. Future technological advances are expected to increase recovery factors of oil-in-place, result in production from deeper waters offshore and to permit the development of oil shale and tar sands, thus increasing substantially the quantities of available and economically utilizable resources. Such possible developments make uncertain the total available reserves of fossil fuels and complicate the development of policy on fuel and energy use.

In this paper, projections of demand for energy have been obtained by regression analysis based on time series and cross-section data on comsumption of energy and its components (solid and liquid fuels [1], gas, electricity) over the period 1955 to 1968. Projections for the developed market economies, centrally planned economies and developing countries have also been derived.

Environmental considerations will have an increasing influence on the type of energy resources developed. Less-polluting energy sources such as geothermal, hydroelectric, tidal and solar energy will receive increasing attention. However, conventional fuels such as coal and lignite, petroleum and gas are expected still to dominate the energy picture in the year 2000 A.D.

II. REVIEW OF PAST TRENDS IN WORLD ENERGY CONSUMPTION[2]

In the recent past, there has been a marked shift in consumption from solid fuels towards the use of liquid fuels and natural gas[3] which has been common to all regions of the world. In 1950, for example, 61% of the world's energy requirements were met by solid fuels and 25% by liquid fuels. During the period 1950 to 1968, however, world consumption of solid fuels rose at the rate of 2% p.a., while that of liquid fuels increased at the rate of 8% p.a., so that by 1968, the share of solid fuels had fallen to 38% and that of liquid fuels had risen to 40%.

Patterns of change in consumption are even more pronounced at the regional level, and in the developed market economies, the movement away from the use of solid fuels has been striking. Consumption rates of solid fuels in these countries remained stationary over the period 1950 to 1968, while liquid fuel consumption rose by 7% p.a. The demand for natural gas rose at the rate of 7% and for energy from hydroelectric and nuclear sources combined, at 6% p.a.

In centrally planned economies, the share of solid fuels declined from over 80% in 1950 to about 60% in 1968, the rise in the share of liquid fuels

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[1] Solid fuel refers to coal and lignite. Liquid fuel refers to petroleum.

[2] Non-commercial sources of energy such as wood and waste products are disregarded in this paper.

[3] "Changing Patterns in the World Energy Situation", United Nations E/C.7/2/Add.1, 12 January 1971.

accounting for nearly all the increase in total energy consumption between 1960 and 1968. The most significant change, however, was in natural-gas consumption which increased at the rate of 19% p.a.

Within the developing world, there are great differences in the level of energy consumption and in growth-rates both in terms of total demand and in terms of the various sources. In the developing countries as a whole in 1950, solid fuels contributed approximately 40% to the total consumption and liquid fuels and gas approximately 58%, but by 1968 the share of solid fuels had fallen to 23% and that of liquid fuels and gas had risen to 74%[4]. During the period 1950 to 1968, total energy consumption in the developing countries increased at the rate of 7.5% p.a., while solid fuels, liquid fuels, gas and electricity increased at the rates of 4, 8, 14 and 11% respectively.

III. FORECASTING FUTURE TRENDS IN WORLD ENERGY CONSUMPTION

Forecasts of future energy requirements can be made in different ways. In this paper, only two methods are used. The first, which requires long historical data, may be described as direct extrapolation, in which a consistent tendency noted in a time series of past data is projected into the future as an exponential rate of change, or as a logistic trend. In this approach, it is assumed that some regularity implicit in the conditions of past evolution will persist in the future.

The other is an extension of this method and consists of studying the ways in which tendencies in two series (historical series if available) have been related to one another. One of the two variables is the category to be forecast and the second, an indicative series for which a projection has already been made. The method consists in deriving an empirical relationship or correlation between these two series and using it to extrapolate one from the knowledge of the other. For the present study, per capita energy consumption is related to per capita gross domestic product; and using forecasts of population for the year 2000, future consumption of energy is predicted. This approach is mechanistic and is based on the assumption that the present relationship between energy consumption, gross domestic product and population continue into the future.

III.1. Past trend extrapolation

Since the time interval for which data are available is short, this method is applied only to per capita consumption of total world energy and not to individual energy categories[5].

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4 Of commercial energy.

5 In the case of an exponential trend, $Y_t = Y_0 \cdot B^t + A \cdot (1-B^t)/(1-B)$.

Here Y_t and Y_0 are per capita consumption of world energy in the period t and the initial starting period 0 is 1955. A and B are parameters estimated from the first-order auto regressive equation $Y_t = A + BY_{t-1}$.

In the case of a logistic trend we can write $Y_t = K/(1 + b \exp[-at])$.

Here, a and b are parameters estimated, after transformation, from parameters for the function $Z_t = A + B Z_{t-1}$ where Z_t is $1/Y_t$. The parameter of interest is K which shows an upper asymptote for the function and can be estimated from the two relations $A = (1 - \exp[-a])/K$ and $B = e^{-a}$. Using data for the period 1955 to 1968 and the two trend functions described above, per capita consumption of total energy has been forecast for the year 2000.

For an exponential trend, total energy consumption for the year 2000 will be 30 216 $\times 10^6$ t coal equivalent, while for the logistic trend, the consumption will be 28 086 $\times 10^6$ t coal equivalent.

III. 2. Energy consumption and gross domestic product

The relation between per capita consumption of primary energy and different types of energy (solid fuels, liquid fuels, gas and electricity) and real per capita gross domestic product for the world and for the regions has been examined. Regression functions have been fitted for total energy, using both time series data for the period 1955 to 1968 and cross-section data, for the regions and the world separately for the year 1968.[6]

The results indicate that per capita consumption of total energy, and of other types of energy, with the exception of solid fuels, are highly correlated with gross domestic product for the world and for individual groups of countries.

The coefficients of income elasticity estimated for gas consumption in the centrally planned economies and the developing countries which are listed in Table I are strongly influenced by the rapid growth in the use of gas in these regions in the time interval considered. Because such growth cannot realistically be assumed to persist unchanged until the year 2000, the coefficient of income elasticity for gas for the developed market economies given in Table I has been used in preparing the estimates of gas consumption in both the centrally planned economies and developing countries in the year 2000. Also listed in Table I are values for the annual growth in per capita gross domestic product in the period 1950 - 68 prepared by the United Nations Statistical Office. In the case of the centrally planned economies, the figure of 6.6% refers to gross material product rather than gross domestic product, data for which were not available. In preparing estimates of energy consumption in the year 2000, an estimated value of the annual increase in per capita gross domestic product of 5.0% has been adopted for the centrally planned economies. In the case of the developing countries, the annual growth in the per capita gross domestic product in the period 1950 - 68 was 2.4% and projections for the year 2000 have been made on this basis. A target of 3.5% p.a. for the per capita growth in GDP for the developing countries has been set for the United Nations Second Development Decade and for this reason projections based on this rate of growth have also been prepared.

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[6] The relationships are in long-linear form and the basic model used in this analysis is as follows:

$$\log C_p = a + b \log GDP_p + e$$

where C_p is per capita consumption of energy in kilograms, GDP_p is per capita gross domestic product in constant US dollars for the time series, and in US dollars for the cross-section analysis, e is a stochastic disturbance term in the model.

TABLE I. INCOME ELASTICITY OF ENERGY CONSUMPTION AND ANNUAL GROWTH IN PER CAPITA GDP IN THE PERIOD 1950 - 1968

	Total energy	Solid fuels	Liquid fuels	Natural gas	Primary electricity	Annual growth in per capita GDP per cent
World	0.8757	- 0.1207	1.6587	2.0551 (1.5868)	1.4330	3.4
Developed market economies	0.8654	- 0.3790	1.6410	1.5868	1.2306	3.2
Centrally planned economies	0.7579	0.3388	1.4156	3.2092 (1.5868)	1.6897	6.6 (5.0)
Developing countries (A)	1.6597	0.4564	1.7517	4.3238 (1.5868)	2.9339	2.4 (A)
Developing countries (B)	1.6597	0.4564	1.7517	4.3238 (1.5868)	2.9339	3.5 (B)

When two figures are shown the one enclosed by brackets has been used in estimating the growth-rate to the year 2000 set out in Table III.

TABLE II. PROJECTED GROWTH-RATES OF ENERGY CONSUMPTION PER CAPITA (% p.a.) AND WORLD POPULATION IN THE YEAR 2000

	Total energy (% p.a.)	Solid fuels (% p.a.)	Liquid fuels (% p.a.)	Natural gas (% p.a.)	Primary electricity (% p.a.)	Population ($\times 10^6$)
World	3.8	0.0	4.8	5.1	4.9	6494
Developed market economies	4.2	1.2	5.3	5.1	3.9	954
Centrally planned economies	5.1	1.7	7.1	7.9	8.4	1721
Developing countries (A)	3.8	1.1	4.2	3.8	7.0	3819
Developing countries (B)	5.7	1.6	6.1	5.6	10.3	3819

TABLE III. ENERGY CONSUMPTION PER CAPITA
(Actual values for 1955 and 1968 and projected values for 2000)
(kg coal equivalent)

		Total energy	Solid fuels	Liquid fuels	Natural gas	Primary electricity
World	(1955)	1 201	677	354	148	22
	(1968)	1 727	656	691	340	40
	(2000)	5 615	651	3 108	1670	186
Developed market economies	(1955)	3 736	1838	1 203	609	86
	(1968)	5 436	1571	2 484	1234	147
	(2000)	20 597	1068	12 967	6062	500
Centrally planned economies	(1955)	835	696	112	22	5
	(1968)	1 550	961	336	234	19
	(2000)	7 582	1648	3 017	2666	251
Developing countries	(1955)	183	58	110	11	4
	(1968)	299	68	184	38	9
	(2000)	986	97	686	125	78
Developing countries (3.5%)	(2000)	1 761	113	1 224	217	207

TABLE IV. PROJECTED ENERGY CONSUMPTION IN THE YEAR 2000
(× 10^6t coal equivalent)

	Total energy	Solid fuels	Liquid fuels	Natural gas	Primary electricity
World	36 463	4225	20 183	10 848	1207
Developed market economies	19 650	1019	12 371	5 783	477
Centrally planned economies	13 048	2836	5 192	4 588	432
Developing countries (A)	3 765	370	2 620	477	298
Developing countries (B)	6 726	432	4 674	829	791

The assumption that the above annual rates of increase in per capita gross domestic product will remain constant up to the year 2000 is open to question in view of the uncertainties which are involved in consideration of such a long time scale. Clearly, inaccuracies in these rates of increase will, by the year 2000, produce substantial errors in the magnitude of the energy consumption forecast.

The data presented in Table I have been used to estimate the growth-rate of energy consumption per capita in the future. These estimates, together with estimates of world population in the year 2000 from the United Nations Monthly Bulletin of Statistics for April 1971 are set out in Table II. In Table III, regional data for energy consumption per capita for the years 1955 and 1968, computed from United Nations World Energy Supplies, Statistical Papers, Series J, Nos 3 and 13 have been set out. These data together with the growth-rates of energy consumption from Table II have been used to make the forecasts of energy consumption in the year 2000, which also are set out in Table III.

The column headed "primary electricity" gives data for the production of electricity from hydraulic and nuclear plants in terms of per capita coal equivalent. This forecast, which is based on past trends, does not take into account the expansion of nuclear power generation which may take place during the next thirty years. It is impossible at present to determine with certainty future nuclear possibilities, but we may note that any substantial increase in electricity produced from nuclear power could reduce substantially the quantities of solid and liquid fuels and natural gas which would otherwise be burned in power stations.

In accordance with the United Nations practice, the coal equivalent of primary electric energy has been calculated assuming perfect efficiency of conversion. In examining the effects of substitution between primary electricity and that produced from fossil fuels, allowance must be made for the comparatively low practical efficiency of electricity generation in thermal power stations, which is such that substitution by electricity produced from nuclear plant would result in coal equivalent savings of fossil fuels which would be approximately three times as large as the coal equivalent of primary energy calculated in accordance with the above mentioned United Nations practice.

In Table IV, the world population data for the year 2000 from Table II and the per capita energy consumption data for the year 2000 from Table III have been used to estimate world energy consumption for the year 2000.

The two estimates of world energy consumption of 28 086 and $30\,216 \times 10^6$ t coal equivalent for the year 2000 derived by the analysis of past trends are in good agreement. In Table IV, the total world energy consumption has been derived from projected per capita energy consumption and population trends. The difference between this figure of $36\,462 \times 10^6$ t coal equivalent and the other two estimates is satisfactory when account is taken of the uncertainties in estimates of the relevant parameters. It should be noted, however, that the energy projections of Table IV will forecast energy consumption in the year 2000 with accuracy only to the extent that the economic and technical factors controlling energy consumption in the period 1955 - 68 remain unchanged.

Having arrived at projections of future consumption of energy, the available energy supply and factors affecting substitution between energy sources are discussed below.

IV. ENERGY RESERVES

IV.1. Coal and lignite reserves[7]

The estimate of world coal and lignite reserves[8] is 7.6×10^{12} t. The cumulative consumption figures for coal and lignite to the year 2000 will be approximately 140×10^9 t. So that about 2% of the total estimated reserves will have been consumed by then, leaving reserves for 1750 years at the consumption rate of 4225×10^6 t which is projected for the year 2000.

Centrally planned economies have the largest share or 56% of world reserves. The developed market economies have 33% of total world reserves and the developing countries have 10%.

The rate of increase in consumption of coal and lignite has been falling in the recent past. In 1955, total world production of coal and lignite represented 55% of the total energy produced in that year. By 1968 their share of total energy production had fallen to only 38%. The declining shares of coal and lignite have been replaced by an increase in the share of both petroleum and natural gas. However, the decline may not be permanent if technological advances provide better and less costly methods of exploitation, including techniques for processing coal to obtain synthetic liquid fuels or gas.

IV.2. Petroleum reserves

The problem of estimating available reserves of hydrocarbon fuels over the long term is a complicated one. Not only is it necessary to make allowance for deposits and even whole producing provinces not yet discovered, but it is also necessary to make allowance for the proportion of the reserves inplace, which can be economically recovered. The consideration of recoverable reserves of hydrocarbons (as of any other mineral, including coal) is in part, an economic problem, since the amount of recoverable reserves is a function of both physical availability and the value of these reserves in comparison with the cost of recovering them.

There are at present no universally accepted definitions of petroleum reserves. A number of countries (e.g. the USSR), divide their reserves into five categories, namely drilled proved reserves, undrilled proved reserves, discovered possible reserves, undiscovered possible reserves and hypothetical reserves.

Other countries find it sufficient to divide reserves into two or three categories. In the United States of America, for example, the American Petroleum Institute distinguishes between "proved reserves" and "indicated additional reserves". For most countries, the figures for reserves given in the technical press are not accompanied by precise definitions, and usually a single global figure is given.

It should be remembered, however, that in all cases the concepts of "reserves" apply to recoverable reserves, this definition being both economic and technical. From the technical point of view, primary reserves and those dependent on secondary recovery processes are grouped together.

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[7] Coal comprises all grades of anthracite and bituminous coal. Lignite refers to both lignite and brown coal.

[8] World Power Conference Survey of Energy Resources, 1968.

Estimates of recoverable reserves of liquid hydrocarbon fuels (crude petroleum including condensates) up to the year 2000 have been prepared by the Bureau D'étude Industrielle et de Coopération de l'Institut Français du Pétrole[9]. Reserves were divided into the three categories of proved, probable and possible reserves with the following definitions:

Proved reserves

"Quantities of liquid hydrocarbons which on the basis of geological and technical data can almost certainly be considered recoverable from known drilled reservoirs under present economic and technical conditions".

This definition is almost identical to that adopted by the American Petroleum Institute (API) for "proved reserves"; it excludes reserves contained in oil shale and sands, but on the other hand it includes condensates.

Probable reserves

"Quantities of liquid hydrocarbons which it is hoped can be recovered from known reservoirs, but without the certainty that would enable them to be included in the preceding category".

This definition needs to be clarified, by distinguishing between:

Probable reserves under present conditions

These correspond to the "Indicated additional reserves" of the API (but also include condensates).
They will be called "type A probable" reserves.

Additional probable reserves

These correspond to the additional reserves which might become recoverable from reservoirs already discovered, account being taken of technical and economic developments over the next twenty or thirty years.
This type of reserve can be estimated by studying the evolution of the reassessment of reserves during the period after the discovery of the deposits.
These will be called "type B probable" reserves.

Possible reserves

"Quantitites of liquid hydrocarbons which it is hoped can be discovered in reservoirs at present unknown and extracted under technical and economic conditions predictable over the next thirty years (1970 - 2000)".

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[9] Working paper ESA/RT/Meeting II/2, 8 February 1971, submitted to the United Nations ad hoc Panel of Experts on Projections of Demand and Supply of Crude Petroleum and Products (Headquarters, 9 - 18 March 1971).

This original definition does not correspond exactly to traditional concepts like "potential reserves" or "ultimate reserves", which are based simply on the geological criteria of quantities of oil actually in situ (for example, the calculation of "ultimate reserves"[10] of experts like L.G. Weeks or W.P. Ryman).

To a certain extent, this definition corresponds to the sum of possible and probable reserves contained in deposits not yet discovered and which might be discovered within the next thirty years.

The estimates, which are necessarily very approximate, are based on the following elements:

(i) Use of the geological concept of "ultimate oil reserves in situ", also based on statistical observations;
(ii) Expected change in the rates of discovery, as a function of statistics on past exploration in the various regions;
(iii) Possible reassessment of these future deposits (expected change in the average rate of recovery as a function of the expected change in petroleum prices and techniques).

The advantage of this new definition is to give a meaning to the term "possible reserves" that can be used by economists even if, as a result, recourse must be had to estimates which are inevitably debatable.

The various estimates as per the above categories are presented in Table V which indicates that all recoverable reserves by the year 2000 will amount to 350 000 $\times$ 10^6 t coal equivalent.

While it is generally agreed that the estimates under the categories of both proved and probable reserves, or similar classifications under other-estimates, are usually conservative, the estimate under the category of possible reserves is full of uncertainties such as future discoveries of oil and the exploitation of such deposits under technical and economic conditions which are expected to occur by the estimator thirty years hence; under these conditions much depends on the judgement of the estimator. Such estimates, therefore, should be used with caution in energy planning and should be revised regularly into shorter-term forecasts which would influence rational investment decisions in the development of energy resources.

The estimate of 350 000 $\times$ 10^6 t coal equivalent in petroleum reserves as shown in Table V includes reserves offshore under less than 200 m of water, and therefore excludes possible reserves in the deep ocean. In addition, as stated under the definition of proved reserves above, it does not include either oil shale or tar sands.

The projected consumption of petroleum products for the year 2000 is shown in Table IV by which time cumulative consumption is estimated at 305 000 $\times$ 10^6 t coal equivalent, thus leaving a balance of recoverable reserves at 45 000 $\times$ 10^6 t coal equivalent. Given the generally accepted belief that proved reserves are often underestimates and the great uncertainty of forecasting possible reserves over a long period, it is therefore considered that recoverable reserves of hydrocarbons on a global basis

[10] The concept of "ultimate recovery" is also used, but in a very different sense, for any given reservoir; it then indicates the total cumulative production at the date of the estimate, plus proved reserves at the same date.

TABLE V. PETROLEUM RESERVES AS AT 1 JANUARY 1969
(in 10^6 barrels)[a]

	Proved reserves	Probable reserves		Possible reserves	Total	Total in tonnes coal equivalent
		Type A	Type B			
World	490 000	101 500	323 600	1 062 000	1 977 100	350 000
Developed market economies	57 800	14 300	31 600	235 000	338 700	60 000
Centrally planned economies	42 000	10 300	31 000	155 000	238 300	42 000
Developing countries	390 200	76 900	261 000	672 000	1 400 100	248 000

Source: Working paper (ESA/RT/Meeting II/2) submitted to the United Nations Ad Hoc Panel of Experts on Projections of Supply and Demand of Crude Petroleum and Products, Bureau d' étude industrielles et de Coopération de l' Institut Français du pétrole, March 1971.

[a] 1 t (metric) of oil = 7.3 barrels of oil

1 t (metric) of oil = 1.3 t(metric) coal equivalent

will still be adequate to meet demand to the end of the 20th century, but may not continue to do so for an extended period beyond that time unless significant additions to reserves are made in the interim. If significant additions to reserves are not forthcoming, then substitution between petroleum and other energy sources must occur.

These effects may be expected to be more pronounced particularly in the developed market economies which are generally deficient in adequate indigenous reserves of petroleum to meet expected growth in consumption.

IV.3. Natural gas reserves

World consumption of natural gas has been estimated at 400×10^6 t coal equivalent in 1955 and at 1189×10^6 t in 1968, thus increasing its contribution from 12% to 19%. As indicated in the projections for natural gas consumption, the rates of increase in both the centrally planned economies and the developing countries were adjusted downwards.

There is inadequate knowledge of world natural gas reserves; however, total reserves have been estimated at 175 trillion cubic metres[11] ($233\,000 \times 10^6$ t coal equivalent) of which 14 trillion cubic metres had already been used by 1970.

By the year 2000, it is projected that $169\,000 \times 10^6$ t of coal equivalent will have been produced which would leave a balance of reserves equivalent to $74\,000 \times 10^6$ t. It must be emphasized, however, that no projection of natural gas reserves is presented here and even published figures on reserves such as those prepared by the World Power Conference Survey of Energy Resources, 1968, indicate that their coverage is far from complete.

IV.4. Tar sand reserves

Tar sands and similar oil-impregnated rocks are widely distributed throughout the world, but extraction of oil from them has been in small quantities only. A commercial plant of 45 000 barrels per day (8000 t/d coal equivalent) was put in operation in 1968 at the Athabasca tar sands of Alberta, Canada. Recent reports have indicated that additional plants will be constructed in the same area in the near future. The slow development of tar sands for oil extraction in the past may be attributed to technological factors as well as to the generally declining prices of crude oil of the past two decades. With the recent increases in these prices in some regions and the fact that some of the technological problems of oil extraction seem to have been solved, it may be expected that utilization will increase in the future.

The coverage of reported reserves of tar sands is rather limited since only scant attention has been given even to the evaluation of known reserves. The following reserve figures have, however, been estimated[12]. Canada ($126\,000 \times 10^6$ t coal equivalent); Venezuela ($36\,000 \times 10^6$ t coal equivalent); Madagascar (310×10^6 t coal equivalent); USA (60×10^6 t coal equivalent); and Albania (89×10^6 t coal equivalent).

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[11] N. A. Bykhover, "Economics of Mineral Resources" Nedra Moscow, 1967.

[12] Phizackerley, P. H., Scot, L. O., in Proc. Seventh World Petroleum Congr. 3, Mexico (1967).

IV. 5. Oil shale reserves

Oil shale is found in such abundance in many parts of the world that available estimates of oil shale reserves show that they are equivalent to 18 000 times the total world production of energy in 1968.[13] In the past oil shales have been used primarily as raw material for the production of liquid fuels but as a result of recent technical developments, oil shales may now also be used directly as fuel in thermal power plants and other boilers, and as raw material for the large-scale production of synthetic gas. The economics of the use of oil shales have been improved by the combined production of oil and fuel gas, steam, electricity, ammonium sulphate, sulphur, uranium and cement.

A well-documented[14] large-scale utilization of oil shale is taking place in the Estonian Soviet Socialist Republic where, in addition to synthetic gas and other chemicals, about 3000 MW of electric power is being generated from two plants[15]. Considerable research effort is being made in the United States of America for the utilization of the reserves of oil shale in Colorado and elsewhere for the production of shale oil but no commercial plant has as yet been constructed. Similarly, research is being carried out in Brazil for shale oil production.

Although no estimates are available on probable oil shale utilization by the year 2000, in the United States it has been estimated that by 1980 as much as 1×10^6 barrels of shale oil per day may be produced (178 000 t/d coal equivalent). It should be noted, however, that progress will depend not only on technological advance in mining and processing but also in the abatement of the adverse environmental effects which may accompany exploitation.

IV. 6. Hydroelectric energy reserves

Estimated world potential for hydroelectric energy production is $22\,856 \times 10^6$ MWh/yr.[16] Of this, 2.1 and 4.6% had been developed by 1955 and 1968, respectively. Projections indicate that by 2000 up to 34.0% of all the available energy potential may have been developed. The figures quoted are optimistic, especially when it is realized that potentials referred to are technical rather than economic.

Economic factors may work against a shift to hydroelectric development, particularly in the developed market economies where the best sites have already been exploited.

The developing countries have, by far, the largest hydroelectric energy potential (estimated at $15\,000 \times 10^6$ MWh). Of this potential, only 0.2 and 0.8% had been developed by 1955 and 1968, respectively, and projections suggest that not more than 11% may be developed by the year 2000.

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[13] United Nations, Utilization of Oil Shale - Progress and Prospects, Sales No. 67 II B20, New York (1967).

[14] Large-scale utilization of oil shales has also been reported in mainland China.

[15] Proc. United Nations Interregional Symp. on the Development and Utilization of Oil Shale Resources, Tallinn, Estonian SSR, 1968.

[16] World Power Conference Survey of Energy Resources, 1968.

In the developing nations, the capacities of many sites are much higher than local demand. If interconnection to neighbouring countries takes place, however, the trend will be for a faster development of the potential sites.

Current developments in low-temperature technology that would open prospects for long-distance electricity transmission at low cost may make large-scale electric energy transfer viable and could pave the way for the possibilities of electrical energy transfers from the major hydroelectric sources in the developing countries to highly developed power markets in other regions.

Of the total potential hydroelectric energy reserves in the developed market economies, about 18% had been developed by 1968. If the same rate of development continues, over 90% of total potential will have been utilized by the year 2000.

The estimated total of hydroelectric energy potential in the centrally planned economies is 3728×10^6 MWh, of which 4% had been developed by 1968. With the current rate of development, 60% of these reserves will have been developed by the year 2000.

IV.7. Tidal power reserves

Tidal energy reserves have yet hardly been utilized, the first major installation of tidal power being that of La Rance Estuary in France (1966) which has an initial capacity of 240 MW.

Other potential tidal power sites include[17]: San Jose in Argentina ($51\,500 \times 10^6$), Severn in England ($14\,700 \times 10^6$), France ($97\,811 \times 10^6$) and USSR ($140\,452 \times 10^6$), Passamaquoddy in the USA, Rana of Kutch and Cambay in India, and Secure Bay in Australia. A feasibility study of the possible utilization of the Bay of Fundy in Canada is currently underway.

IV.8. Nuclear energy reserves

Since the installation of the first industrial-sized nuclear power stations in 1956 and 1957, technical progress has advanced steadily and various reactor systems have become accepted as proven designs. It is anticipated that this trend will persist, particularly in the industrialized countries where, in many cases, large nuclear power construction programs are in hand. By 1980 the total installed nuclear capacity will probably exceed 320 000 MW(e).[18] However, the recent increase in fuel oil prices arising from the Teheran agreement can be expected to improve the relative competitive position of nuclear power and this may result in an even faster rate of development.

The present proved reactor systems depend upon the use of either natural or slightly enriched uranium as fuel and the substantial construction program expected over the next few years will result in a demand for considerable quantities of uranium.

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[17] Figures in brackets are potential annual energy production in kilowatt hours. Sources: TRENHOLM, N.W., Canada's Wasting Asset - Tidal Power Electrical Engng News 70 No. 2 (1961); and BERNSHTEIN, L.B., Tidal Energy for Electrical Plans, Isreal Program for Science Translations 1965.

[18] UNITED NATIONS Rep. of Group of Experts on the Contributions of Nuclear Technology to the Economic and Scientific Advancement of the Developing Countries, doc. A/7568, 24 July 1969.

It has been estimated[19] that reserves of 700 000 t uranium are recoverable at less than $10/lb U_3O_8 whilst an additional 700 000 t could be made available at less than $15/lb U_3O_8.

The next generation of nuclear reactors will be based on the breeders that are at present at the stage of technological development and which are expected to begin making a contribution to power generation in the 1980s. The advent of this new reactor type will relieve pressure on uranium sources and allow fertile materials to be converted into nuclear fuel.

Considerable work is being carried out on the development of a system which would utilize the energy of the fusion process. If these efforts are successful, then the long-term utilization of nuclear power will be assured without any possibility of fuel shortages.

IV.9. Geothermal energy reserves

At the present time, geothermal energy is being developed both for electric power generation and for direct use as heat. Power generation, mainly in Italy, New Zealand, Japan and the USA, has increased from 386 MW in 1960 to 681 MW in 1969, a growth-rate of 6% p.a., while total production, which includes a large contribution in the form of heat in the USSR, Hungary and Iceland, has increased from about 1000 MW heat equivalent to 7000 MW over the same period - that is, at a rate of over 24% p.a. In the USSR, it has been estimated that from 50 to 60% of the territory is underlain by thermal waters, with a total heat content commensurable with the coal, oil and peat resources of the USSR taken together.

Thermal energy stored in that part of the earth's crust which is accessible by drilling may exceed all the fossil fuel and fissionable nuclear reserves by orders of magnitude. Experience in known high-temperature geothermal fields suggests that the recoverable heat energy from areas of acid volcanism is equivalent to the heat from some 10^{12} t of coal. But these fields cover only a very small part of the land area, and if we take account of the much larger areas of higher than normal subsurface temperature, which may cover some twelve million square kilometres of land surface, the stored heat down to a depth of 3.5 km is equivalent to a further 2×10^{13} t coal. Even if only a rather small fraction of this heat is recoverable economically, the total will still be large.

IV.10. Solar energy

Solar energy constitutes by far the largest possible source of energy, but because of technical difficulties, solar energy has not been harnessed to any great extent. Successful application of this energy for heating has occurred in countries such as Australia, Isreal, Japan, the USA, and in a few of the developing countries (for hot water and cooking).

Solar energy also offers potential for the production of electrical energy though large-scale utilization of solar energy is, however, something for the future. Advances in technology of terrestrial and space conversion to electricity, may reduce the time-span considerably. There

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[19] KRYMM, R., "Economic aspects of nuclear power", paper presented at Symposium organized by the Society for Education in the Application of Science (S.E.A.S.), London, April 1969, sponsored by the Pugwash Conference on Science and World Affairs.

are, for example, possibilities for the development of solar cells that are of large capacity and capable of producing electrical energy at competitive rates per kilowatt-hour.

Possibilities for conversion of solar energy to electricity in space would involve the use of satellite collectors that would convert solar energy in space and then beam it to earth, appear attractive. Such satellites could be placed in synchronous orbit around the earth. High conversion efficiencies (of the order of 90%) are possible, but so far no detailed design concepts are available.

V. CONCLUSION

The data given in Table III indicate that in the developed market economies in the year 2000 per capita consumption of energy will be more than 20 t coal equivalent per annum; that in the centrally planned economies, consumption will be more than 7 t or about 1.4 times the per capita energy consumption in the developed market economies in 1968. In the developing countries in the year 2000 per capita consumption of energy will be 1.7 t of coal equivalent, that is slightly more than the per capita consumption of energy in the centrally planned economies in 1968, if the per capita GDP growth target of the United Nations Development Decade is achieved.

It is legitimate to inquire whether it is realistic to project energy consumption on the basis of a steadily accelerating use of energy. Since the available supply of energy in usable form is limited, it is apparent that at some stage, sooner or later, energy production from known sources will cease to grow. To the extent that the above considerations become more general in developed market economies and elsewhere the projections of Tables III and IV may represent upper limits for world energy consumption in the year 2000.

The data presented earlier in this paper indicate that a concerted effort is needed to rationalize and co-ordinate the compilation and publication of data on reserves of petroleum and natural gas. In any case the estimates show that present known reserves of petroleum and natural gas are barely adequate to meet projected demand to the year 2000 while on the other hand the reserves of coal and oil shale that are known to exist are very large even in relation to projected cumulative consumption in the year 2000. There will, therefore, be increasing incentives not only for the discovery of new resources of petroleum and natural gas but also for the development of techniques for the production of substitutes for natural petroleum and gas and their products, from coal and oil shale.

Non-polluting sources of energy, among them hydraulic and geothermal resources, are already receiving increasing attention which is likely to become greater in the future. The circumstances that the developing countries have large undeveloped resources of non-polluting power but relatively small markets for energy suggests an important use for techniques of long-distance power transmission using cryogenic technology, once these become fully developed. Geothermal energy, on the other hand, in addition to finding use in those countries lacking resources of fossil fuel will increasingly be used to supply relatively low-temperature thermal energy for space heating and cooling and for industrial processing, particularly in the developed countries.

Nuclear energy will consequently be expected to supply an increasing share of world energy supply but there remain problems associated with disposal or radioactive waste which require solutions that are environmentally acceptable and economic.

However, experience has shown that the reliability of forecasting decreases with the increase in the time span to be covered. In the case of energy, and in the case of global forecasts, we have two additional problems which make it necessary to realize the very tentative character of long-term forecasts and the care with which they have to be interpreted.

The figures given for energy represent computations of equivalent calorific values of fuels and primary electricity. Changes involving efficiency of conversion factors, shifts in the relative significance of various energy commodities, new sources of energy commodities, new technologies in the discovery, production, transmission and distribution of energy commodities and related questions would affect the validity of the projections presented in this paper. There are, however, also possible changes in the structure of the various energy commodity industries which indirectly may have a powerful impact, especially in the electricity generating industry. The economy of scale has long been regarded as a vital and important factor especially in the electricity industry. There are from time to time technical revolutions which allow smaller but in some way superior units to reduce the significance of large-scale units. Thus, for instance, cars and planes have reduced the significance of railways and passenger ships and similar structural changes cannot be excluded in the energy industry. Consequently, it is possible that the fuel cell, for instance, in its application to direct generation of electricity at the place of consumption, may have a powerful impact on electricity grid systems and the structure of the future electricity industries, and similar other structural changes cannot be excluded in long-term forecasts, such as electric car and trucks replacing or reducing fuel-driven vehicles.

Global estimates of demand and supply are statistical expressions and computations which have little relationship to practical energy programs and energy policies as applied by individual governments. It is difficult, therefore, to assume that long-term global forecasts will tally with the practical policy decisions which will have to be taken in individual countries. It would be safer, therefore, though much more complicated, to reach global figures based on the summary of energy long-term planning on the basis of policy decision by individual governments. Even if it were possible to provide global estimates as a summary of local planning decisions, the forecasts would be valid only over relatively short periods, in view of the observed facts that energy policy undergoes changes over time as a result of a variety of factors including technical, economic, social, financial and others.

The figures of energy resources as customarily made available, and contained in this paper, should also be taken with great caution. Energy resources forecasts have traditionally been underestimates. Since before the first world war, very long-term hydrocarbon reserve forecasts have proved to be conservative. We have today indications that hydrocarbons are available probably in very large quantities in waters deeper than 200 m, but we are far from having an estimate of the potential resources, their distribution over the globe, and their future cost of production. Similar uncertainties apply to practically every energy resource, including potentially new energy resources. We have learned that even for traditional energy resources, two factors have a powerful influence on the amount of money spent for exploration of such resources and for their utilization, namely technology and price. As prices for individual energy commodities rise or new technologies reduce costs, stimuli are created to spend more money on the proving of energy reserves, and, after a certain time delay, sometimes very drastic changes in energy resources estimates occur.

The foregoing remarks reflect the difficulty in interpreting long-term forecasting of global energy requirements and resources. They should not be interpreted as negating the value of forecasting, because policy decisions have to be taken, and many such policy decisions must be based on evaluation of future trends.

Energy in its many commercial forms has become such an important commodity and the factors affecting both its supply and consumption are so varied and far-reaching that energy policies now require to be examined not only nationally, but also with a broader prospective such as may be expected in the United Nations' Committee on Natural Resources.

DISCUSSION ON AGENDA ITEM 1.1

Survey of world energy demand and resources up to the year 2000

DISCUSSION ON THE FOLLOWING PAPER:

P/033 USA Presented by A.M. Weinberg

C. SALVETTI: Whilst I agree broadly with the conclusions reached by Messrs Weinberg and Hammond, I think I would be less optimistic about the problem of the overall heating of the earth due to the production of power by chemical and nuclear reactions. Using a very rough model and a doubling time of the order of ten years for the increase in power demand, I have come to the conclusion that the average temperature of the earth may increase by something of the order of 1°C in the next century. The effects of this on the ecological equilibrium will not be completely negligible.

We have only to consider, for example, the effect on the polar ice caps. Further studies are certainly required in order to reach a better understanding of this problem; but I should like to hear Mr. Weinberg's opinion.

A.M. WEINBERG: Mr. Salvetti assumes that the energy demand will continue to double every ten years for 100 years. This implies a 1000-fold increase in energy production, which gives a figure some 20 times higher than what we assumed to be the levelling-off point.

I do believe, however, that local heating effects will be very important and that they may well make ocean-siting of nuclear power plants essential.

K.S. PARIKH: Mr. Weinberg, in your analysis of the effects of thermal pollution on the world's weather, you assume that what you call energy parks will have the same distribution pattern as the population. But have you allowed for any geographical redistribution of population? It seems to me that if a more even distribution of population were assumed, a larger number of energy parks would be located in the warmer parts of the world. Would this increased thermal dissipation in the warmer parts of the world make a difference to your conclusion that the world's weather would not be significantly affected by a high level of energy consumption?

A.M. WEINBERG: Some time ago Mr. Washington performed model calculations in which he increased the total man-made energy input to a level seven times higher than we have assumed, and even at this level the global effects appeared to be small. Thus I would expect global effects to be tolerable, at the power levels we assume, over wide ranges of geographic distribution of the power input. However, as I said in replying to Mr. Salvetti, the question of local heating in the immediate vicinity of reactors remains an important, and to some extent unresolved, issue.

DISCUSSION ON THE FOLLOWING PAPER:

P/757 IANEC Presented by C. Vélez

M. SARRAM: It is true that Venezuela is rich in oil resources, but I was still struck by the fact that Table II in paper P/757 shows no nuclear power at all. Does this mean that Venezuela is not considering producing nuclear power before the year 2000?

C. VÉLEZ: Venezuelan experts agree that economic hydroelectric resources alone, which according to estimates would yield more than 20 000 MW of power, are sufficient to meet Venezuela's needs up to the year 2000.

L. TWUM-DANSO: Mr. Vélez says that there are ten research reactors in Latin America. I should be interested to know what types they are, and whether they are being used mainly for the production of radioisotopes.

C. VÉLEZ: As can be seen from Table I in my paper, research reactors in Latin America are of several different types. They serve for a combination of isotope production, training and irradiation, the extent to which they are used for these purposes varying from case to case.

DISCUSSION ON THE FOLLOWING GROUP OF PAPERS:

P/127 Australia Presented by R.D. Deas

P/135 Australia

P/780 Turkey Presented by S. Kakaç

M. SANDOVAL VALLARTA: As an admirer of Tasmania, may I ask if there are any plans to construct a nuclear power station there and, if so, where it is to be located and what its capacity is to be?

R.D. DEAS: I regret not being able to give a definitive answer. Tasmania has sufficient hydroelectric capacity to meet its needs for the next 10 to 15 years. However, the cost of developing hydroelectric sites is rising, as the better sites tend to be developed first. The point at which nuclear power becomes competitive will depend on the relative rates of cost increase in the two technologies. The island should have no shortage of suitable sites. I do not believe that units with capacities of less than 500 MW will be constructed.

A.M. WEINBERG: May I ask Mr. Deas what the position is with respect to the nuclear-powered aluminium extraction complex that was under consideration for Northern Australia? I had the impression that such an aluminium refinery might tolerate a non-continuous power supply and therefore might be powered by an isolated nuclear plant.

R.D. DEAS: Somewhat superficial studies have been made of the feasibility of nuclear industrial complexes. The various requirements never appear all to be met simultaneously. For example, there is a maximum size of aluminium smelter appropriate to the world market situation. We found that the cost of energy from a suitably sized nuclear station, remote from a major grid and hence having redundancy, would be too high to make smelting viable. To increase the station size so as to reduce the unit cost of energy results in surplus capacity.

A. AFSHAR-BAKESHLOO: Might I ask Mr. Kakaç and Mr. Aybers why the CANDU pressurized heavy-water reactor was selected as their reference design?

S. KAKAÇ: A country considering the construction of its first nuclear power station will undoubtedly give much thought to the choice of reactor type. There are several ways in which a developing country can procure its fuel. It is usually considered advantageous for a country to develop its own uranium extraction and fuel manufacturing industry if suitable uranium resources are available. A natural uranium open cycle is of particular interest to such countries. Natural-uranium-fuelled, heavy-water reactors also have other advantages, which prompted the authors to take the CANDU-PHW reactor as a reference plant.

DISCUSSION ON THE FOLLOWING GROUP OF PAPERS:

P/137 Egypt Presented by M.A. El Guebeily

P/009 Bulgaria

P/338 Poland

P/729 Spain Presented by F. Pascual

A. AFSHAR-BAKESHLOO: I should like to ask Mr. El Guebeily what type of reactor is to be incorporated in the first nuclear power station in Egypt.

M.A. EL GUEBEILY: No final choice has been made, but the first nuclear power station will certainly use one of the proven reactor types – light-water, heavy-water or gas-cooled.

R. JANIN: Figure 1 of the paper presented by Mr. El Guebeily shows a bulge in energy requirements between 1970 and 1980. Could he tell us why this is so?

M.A. EL GUEBEILY: The development rate for the period 1950-1970 reflects actual data, what has actually taken place. For the period 1970-1980 the development rate was derived from available data on economic development plans, the higher line representing the plans as scheduled for implementation and the lower line the average regular growth. The decrease in the rate of development evident in the period from 1970 to 1980 is understandable in the light of the relatively higher degree of industrialization and economic development achieved by the first and second five-year plans. It is also to be noted that, for the same reason, from 1980 to 2000 the rate of development (7.5%) is lower again than the rate anticipated from 1970 to 1980 (10.6%).

DISCUSSION ON THE FOLLOWING PAPER:

P/300 Sweden Presented by B. Nordström

There was no discussion on this paper.

DISCUSSION ON THE FOLLOWING PAPER:

P/420 UN Presented by G. V. Subba Rao

A.M. WEINBERG: I wonder whether we do not have to consider the limits to the use of fossil fuel imposed by the resulting pollution of the environment.

G.V. SUBBA RAO: This factor could undoubtedly affect the relative share of fossil fuels and impair their competitive position, just as the environmental problems raised by nuclear energy could similarly modify nuclear energy forecasts.

M.F. EL FOULY: Mr. Subba Rao, you stated that conventional fuel would continue to play a dominant role until the year 2000. Have you taken into consideration the fact that an increasingly large part of conventional fuel supplies may have to be diverted for use as raw material for many purposes, including the production of food for the exploding population of the world, and that there is also a tendency for the developing countries greatly to enlarge their consumption of energy?

Do you think that conventional fuel is likely to remain economically dominant in most countries of the world? Finally, have your studies taken into consideration the cost of energy transmission from such sources as hydroelectric plants in developing countries in Africa to countries of consumption?

G.V. SUBBA RAO: The view that conventional fuels are likely to remain dominant even in the year 2000 is based essentially on past experience. It is true, of course, that the demand for conventional fuel commodities for non-energy purposes (e.g. for the production of petrochemicals and fertilizers) will substantially increase during the next few decades. This factor, as you say, has to be taken into account in assessing the prospective demand for conventional fuels. We do predict, moreover, that the vast and as yet unexploited hydroelectric potential of the developing countries, and the equally vast but currently uneconomic low-grade fuel deposits in remote locations, will eventually be utilized. There are certain developments, notably in low-temperature technology, that might open up prospects of long-distance electricity transmission at low cost; this could pave the way for the development of intercontinental and intra-continental power grids, linking power-generating sites to power-consuming centres on a global scale. The technologies that would be required are currently under study.

K. OSHIMA: It seems to me that the predictions of Mr. Subba Rao's paper with respect to energy supply may be unduly optimistic because he restricts himself largely to an assessment of the material resources. It is my belief that the limits to energy supply will be imposed not so much by a failure of resources as by environmental or ecological conditions. Is there any United Nations program which takes such factors into account in assessing the world energy supply?

G.V. SUBBA RAO: Environmental and ecological factors impose penalties on the more polluting forms of energy production, and will result in preference being given to the less polluting forms (e.g. the harnessing of hydroelectric, geothermal, solar, tidal and wind sources). The documentation for the forthcoming UN Conference on the Human Environment is expected to take into account the limitations which environmental considerations must inevitably impose on the use of certain energy sources (fossil fuels for example).

AGENDA ITEM 1.2

Projected role of nuclear energy
in meeting future energy needs

Mesure dans laquelle l'énergie atomique
pourra répondre aux besoins en énergie

Предполагаемая роль
ядерной энергии в удовлетворении
будущих энергетических потребностей

Papel que puede desempeñar la energía nuclear
para satisfacer las futuras necesidades energéticas

Chairman

D.I. BLOKHINTSEV, USSR

Scientific Secretaries

R. SKJÖLDEBRAND, IAEA
R. ALAMI, IAEA

NUCLEAR POWER IN THE UNITED KINGDOM

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U.K. Atomic Energy Authority, London
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British Nuclear Fuels Ltd, Risley,
United Kingdom

Abstract–Résumé–Аннотация–Resumen

NUCLEAR POWER IN THE UNITED KINGDOM.

This paper discusses the changes that have taken place and the progress that has been made since the last Geneva Conference in 1964. It considers the changing attitudes of industry to the problems of an advanced technology not only in the United Kingdom, but in many countries. The changing industrial and commercial attitudes and problems are, however, seen in the context of unchanged objectives in nuclear power development. It is not the objectives but the route by which they will be achieved that is changing. The paper discusses in more detail the operating experience of the eleven nuclear power stations now in operation in the United Kingdom. It compares the six large nuclear stations now under construction with the stations that preceded them, and with particular reference to the change in industrial structure that has taken place in the United Kingdom since the last Conference. It illustrates also the continuity of United Kingdom development of gas-cooled reactors, which now includes work on reactors using helium coolant and graphite coated particle fuel. The reactor development program is approaching the stage when a choice will be made by the United Kingdom Electricity Authorities between the steam-generating heavy-water reactor (SGHWR) and the helium gas-cooled reactor. The latter, the Mk III GCR, will have many of the characteristics of the high-temperature reactor (HTR) design but will be based on the uranium/plutonium cycle instead of the uranium/thorium cycle used in earlier HTR designs. The choice of either the Mk III GCR or the SGHWR will make for easy integration of thermal and fast reactors since the plutonium produced in the thermal systems can be utilized subsequently in the fast reactors. Good progress has been made in the UK fast-reactor development program. The Prototype Fast Reactor at Dounreay is in the last stages of construction and consideration is being given to the construction of a large fast reactor of 1300 MW(e) for commercial use. The rationalization of the UK nulcear industry is described, as is the formation of a new Nuclear Fuel Company to provide the fuel services for the nuclear program. This Nuclear Fuel Company is in turn attempting to form international links to integrate the fuel-cycle activities on as broad a base as possible.

L'ENERGIE D'ORIGINE NUCLEAIRE AU ROYAUME-UNI.

Le mémoire examine les changements qui se sont produits ainsi que les progrès réalisés depuis la dernière Conférence de Genève, tenue en 1964. Il fait état des attitudes variables de l'industrie vis-à-vis des problèmes d'une technologie avancée non seulement dans le Royaume-Uni, mais dans de nombreux autres pays. Les attitudes et problèmes industriels et commerciaux sont, toutefois, examinés dans le contexte des objectifs inchangés du développement de l'énergie nucléaire. Ce ne sont pas les objectifs qui varient, mais seulement la manière dont ces objectifs seront réalisés. Le mémoire examine plus en détail l'expérience d'exploitation des onze centrales nucléaires actuellement en service au Royaume-Uni. Il compare les six grosses centrales nucléaires en cours de construction aux centrales qui les ont précédées, et il souligne le changement de la structure industrielle qui s'est produit au Royaume-Uni depuis la dernière Conférence. Il illustre, par ailleurs, la continuité du développement des réacteurs à réfrigérant gazeux au Royaume-Uni, couvrant à présent les travaux effectués sur les réacteurs qui emploient l'hélium comme réfrigérant ainsi que du combustible en particules revêtues de graphite. Le programme de développement des réacteurs approche le stade où les Services de production d'électricité du Royaume-Uni choisiront entre le réacteur à eau lourde générateur de vapeur (SGHWR) et le réacteur refroidi à l'hélium. Ce dernier, désigné par le sigle GCR Mk III, possédera bon nombre des caractéristiques du réacteur à haute température (HTR), mais il emploiera le cycle uranium/plutonium plutôt que le cycle uranium/thorium utilisé précédemment par les réacteurs HTR. Le choix des réacteurs GCR Mk III ou SGHWR permettra d'intégrer facilement les réacteurs thermiques ou rapides, puisque le plutonium produit dans les systèmes thermiques peut être utilisé par la suite dans les réacteurs rapides. D'importants progrès ont été réalisés dans le programme de développement des réacteurs rapides

au Royaume-Uni. Le réacteur prototype rapide (PFR) à Dounreay se trouve aux derniers stades de construction, et l'on envisage la construction d'un gros réacteur rapide de 1300 MW (e) pour l'utilisation commerciale. Le mémoire décrit la rationalisation de l'industrie nucléaire britannique, ainsi que la création d'une nouvelle Compagnie de combustible nucléaire qui assurera les services de combustible pour le programme nucléaire. Cette compagnie tente, à son tour, de forger des liens internationaux afin d'intégrer les activités en matière de cycle du combustible sur une base aussi étendue que possible.

ЯДЕРНАЯ ЭНЕРГЕТИКА В ВЕЛИКОБРИТАНИИ.

В настоящем докладе обсуждаются изменения, происшедшие со времени последней Женевской конференции в 1964 году, а также прогресс, достигнутый в этой области. В докладе рассматриваются изменения в подходе промышленных кругов к проблемам усовершенствованной технологии не только в Великобритании, но и во многих других странах. Однако, изменения в подходе к этому вопросу промышленных и коммерческих кругов, а также связанные с этим проблемы рассматриваются в рамках общих целей развития ядерной энергетики. Меняются не цели, а путь осуществления этих целей. В докладе более подробно обсуждается опыт эксплуатации одиннадцати атомных электростанций, работающих в настоящее время в Великобритании. Сравнивается шесть сооружаемых АЭС с действующими станциями, с учетом изменения промышленной структуры, происшедшей в Великобритании со времени последней конференции. Иллюстрируется также разработка реакторов с газовым охлаждением, которая на данном этапе включает работу по реакторам с гелиевым охлаждением и топливом в виде частиц, покрытых графитом. Программа развития реакторов приближается к такой стадии, когда Управления электроэнергией в Великобритании должны будут сделать выбор между парогенерирующим тяжеловодным реактором и реактором с гелиевым охлаждением. Последний реактор с газовым охлаждением Mk III будет обладать многими характеристиками высокотемпературного реактора, но будет основан на цикле уран/плутоний вместо цикла уран/торий, применяемого в более ранних конструкциях высокотемпературного реактора. Выбор между реакторами с газовым охлаждением типа Mk III и парогенерирующим тяжеловодным реактором предоставляет возможность легкого интегрирования реакторов на тепловых нейтронах и быстрых реакторов, так как плутоний, произведенный в тепловых системах, может впоследствии применяться в быстрых реакторах. В программе развития быстрых реакторов в Великобритании достигнут большой прогресс. Прототип быстрого реактора в Дунрее находится в последней стадии сооружения. Рассматривается также возможность строительства крупного быстрого реактора мощностью 1300 МВт (эл) для коммерческого использования. В докладе описывается рационализация ядерной промышленности Великобритании, а также создание новой компании по ядерному топливу для поставки топлива в соответствии с ядерной программой. Компания по ядерному топливу, в свою очередь, старается установить международные связи для интегрирования деятельности по топливному циклу по возможности на более широкой основе.

LA ENERGIA NUCLEAR EN EL REINO UNIDO.

La memoria trata de los cambios que han tenido lugar y el progreso realizado desde la última Conferencia de Ginebra en 1964. Considera los cambios en actitudes en la industria sobre los problemas de una tecnología avanzada, no sólo en el Reino Unido sino también en muchos otros países. Los cambios en problemas y actitudes industriales y comerciales se ven, no obstante, en el ámbito de objetivos incambiados en el desarrollo de la energía nuclear. No son los objetivos los que cambian sino los medios por los cuales serán conseguidos. La memoria trata con más detalles las experiencias operativas de las once centrales de energía nuclear que hay en funcionamiento en el Reino Unido. Compara las seis grandes centrales nucleares bajo construcción ahora con las centrales que las precedieron, haciendo referencia especial al cambio en la estructura industrial que ha tenido lugar en el Reino Unido desde la última Conferencia. Revela también la continuidad del desarrollo en el Reino Unido de los reactores refrigerados por gas, que incluye ahora trabajo sobre reactores empleando el helio como refrigerante y el combustible de partículas revestidas de grafito. El programa de desarrollo de reactores se aproxima ahora a la fase en que las Juntas de Electricidad en el Reino Unido tendrán que escoger entre un reactor de agua pesada generador de vapor (SGHWR) y un reactor refrigerado por helio. Este último, el Mk III GCR, tendrá muchas de las características del reactor a alta temperatura (HTR), pero se basará en el ciclo de uranio/plutonio en vez del ciclo uranio/torio empleado anteriormente en los diseños del HTR. La elección del Mk III GCR o del SGHWR facilitará la integración de reactores térmicos y rápidos, ya que el plutonio producido en los sistemas térmicos puede ser empleado más tarde en los reactores rápidos. Se han efectuado buenos progresos en el programa de desarrollo de los reactores rápidos en el Reino Unido. El reactor prototipo rápido en Dounreay se encuentra ahora en las últimas fases de su construcción y se está considerando ahora la construcción de un reactor rápido más grande, de 1300 MW(e) para uso comercial. La memoria describe también la normalización de la industria nuclear británica, como por ejemplo en el caso de la

formación de la nueva Nuclear Fuel Company (Compañía de combustible nuclear) para proporcionar servicios de combustible para el programa nuclear. Esta Nuclear Fuel Company procura a su vez la formación de lazos internacionales, para integrar las actividades del ciclo de combustible sobre la base más amplia posible.

INTRODUCTION

It is useful to look back over the papers of the last Geneva Conference in 1964 if for no other reason than to appreciate the changes that have taken place since that time. The most obvious change is, of course, the great advance that has been made in nuclear technology. Less obvious, but equally important, have been the changes in attitude towards the building of nuclear power stations and the approach to new development projects.

In the commercial and industrial field there is a much greater maturity and sense of realism than at our last meeting. At that time there were certainly substantial nuclear programmes in several countries, but by comparison with today the practical experience of constructing, commissioning and operating nuclear power stations was inevitably limited. At that time the initiative in the discussions of nuclear power costs was being taken largely by the vendors and national laboratories. Today the utilities, as the potential purchasers, are making the close economic studies that go with large contractual commitments. Today, nuclear power generation is established as a major industry and future planning must take place within this commercial environment.

These changes have been fundamental and have had their effect in modifying substantially the attitude towards nuclear power in many countries. It is, however, equally important to see how the general principles on which we were working and the technical goals we were trying to achieve are almost unchanged.

The thermal reactor has been the first to be developed. All the established systems use natural or, more usually, slightly enriched uranium. They all produce plutonium as a by-product. The conservation of uranium by using plutonium in fast reactors is still the principal development objective in many countries. The use of plutonium in place of ^{235}U and the adoption of the thorium/^{233}U fuel cycle in thermal reactors is still being actively pursued. Good progress is being made in the incredibly difficult technology of fusion [1].

All these objectives are unchanged and are the fundamental objectives of our nuclear development programmes. Some programmes, for example in the fast reactor field, are keeping pretty well to the time table that was discussed seven years ago [2,3]. Others, like fusion, are taking appreciably longer to develop than was originally anticipated. It is also clear that the whole development and engineering of atomic energy in the commercial and industrial field has taken more effort and time than we envisaged in those starry days of the early conferences here in Geneva.

This does not imply that we will not reap the benefits that we expected from atomic energy. Quite the reverse. We are, in fact, at the point where these benefits are starting to be delivered in a substantial way. The amount of electricity being generated from atomic energy is already significant on a world basis and with the commissioning during the next few years of a very large programme of nuclear power plants, the practical benefits of nuclear power will be enjoyed by an expanding proportion of the world population.

THE NUCLEAR POWER STATIONS IN THE UNITED KINGDOM

But now let me turn to the particular circumstances of the United Kingdom which illustrate well the general situation that I have just outlined.

All the stations of the first nuclear programme have been completed, eleven stations in all, totalling 5,000 MW(e). These stations are all natural uranium, graphite moderated and CO_2

cooled, sometimes called "Magnox" stations or Mark I Gas Cooled Reactor stations. They are all working reliably at the present time [4,5]. The earliest reactors at Calder Hall have now been in continuous operation for over fifteen years. They are operating at full power at a load factor of approximately 90%. The stations at Berkeley and Bradwell have been operating for nine years at an average load factor of nearly 80%. The Scottish station at Hunterston [6] has been operating for seven years at a similar load factor and the whole of the programme of these natural uranium reactors has averaged a load factor of over 70%. The Electricity Boards now have over 100 reactor years of experience of this type of reactor and if the Calder and Chapelcross stations of the Atomic Energy Authority are included, the United Kingdom experience amounts to well over 200 reactor years.

It would be idle to pretend that we have obtained this experience without any adverse factors. Of course, we have not; we have had turbine troubles on some stations. We had difficulties with the charge and discharge mechanisms, particularly in the early days, and we have been troubled by a somewhat higher rate of corrosion of steel in CO_2 than was anticipated. This has necessitated a reduction in outlet temperature for some stations and consequential reduction in maximum output capacity. However, I believe the most important fact is that, taken as a whole, these stations have performed remarkably reliably. They have enabled the industry and the electricity authorities to obtain a depth of practical experience of nuclear power which we judge will be invaluable in the introduction of the much larger nuclear programmes of the future.

From 1965 the design of gas cooled reactors ordered in the United Kingdom was changed to use slightly enriched uranium clad in stainless steel, a design which we short-sightedly called the AGR (Advanced Gas-Cooled Reactor), although it should have been regarded as a Mk II, improved, version of the earlier natural uranium reactors. The ordering of these nuclear power stations in the United Kingdom has proceeded at a rate somewhat above that predicted seven years ago.

The rate at which new nuclear stations are ordered will depend upon the relative economics of nuclear stations and fossil fuelled stations and also the total requirement for new electrical generating capacity. The relative economic position keeps changing. Since our last conference the coal price in the United Kingdom has risen substantially to the advantage of

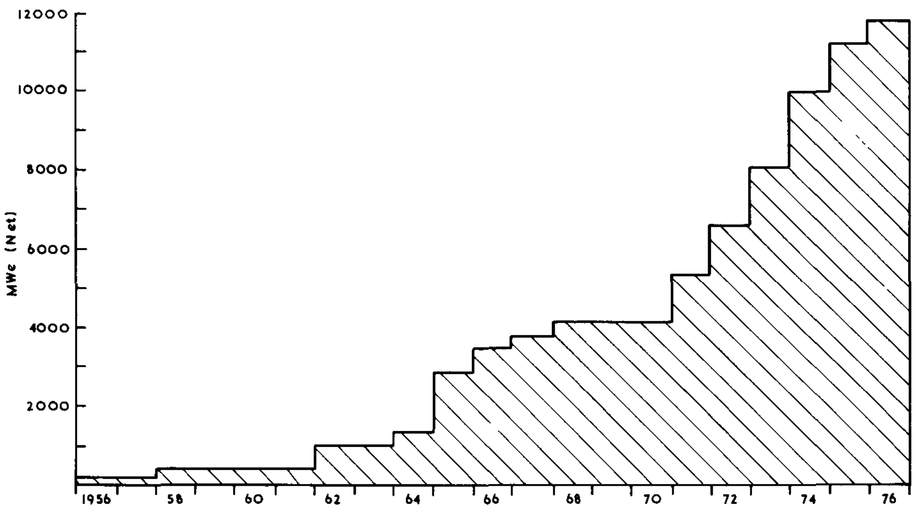


FIG. 1. UK nuclear generating capacity, 1956-1976.

new oil and nuclear fuelled plant. Interest charges and the cost of money then rose rapidly to the detriment of the more capital intensive nuclear power. More recently increases in oil costs have changed the balance again.

The ordering of new electrical generating capacity in the United Kingdom has for the last five years been substantially lower than in the previous five year period. This has resulted from several factors of which the most important were a slower total growth in demand and a change in demand characteristics.

The construction of new nuclear plants has nevertheless continued on an expanding scale, an expansion not so much in terms of number of stations to be ordered, but in size. The pattern of nuclear power installation in the United Kingdom between 1956 and 1976 is illustrated in Fig. 1. We now have five Mk II Gas Cooled Reactor stations under construction in the United Kingdom. All these stations have two reactors, each driving a standard 660 MW turbo-alternator giving a net output of approximately 1,250 MW.

The stations are:–

		Planned Onpower dates
Hinkley Point 'B'	1,250 MW	1972-3
Hunterston 'B'	1,250 MW	1972-3
Dungeness 'B'	1,200 MW	1974
Hartlepool	1,250 MW	1974-5
Heysham	1,250 MW	1975-6
	6,200 MW	

The five stations listed above amount to half the total capacity of stations expected to be commissioned in the United Kingdom during that period. This will provide a nuclear generating capacity, including the 5,000 MW already in operation, of over 11,000 MW. Further orders for thermal nuclear reactor stations are expected within the next year or so. The first of these will probably be located at Sizewell and consist of four units of 660 MW each. This programme demonstrates clearly the firm confidence in nuclear power of the electricity authorities of the United Kingdom.

This confidence in nuclear power has not been shaken by the fact that the timescale for the construction of the Dungeness 'B' station has had to be extended. This was not due to any basic faults in the system but to a number of particular factors enhanced by the effect of organisational changes in the structure of the nuclear industry, which particularly affected the companies responsible for Dungeness 'B' [7]. The strengthening through amalgamation of the design organisations referred to later will prevent a repetition of this situation. No comparable delay is expected on any of the other stations.

Perhaps the greatest difference between the programme of the Mk II Gas Cooled Reactor stations listed above and the programme of natural uranium Mk I GCR stations that preceded them has been in the degree of standardisation that has been achieved. Whereas in the first programme each new station had reactors of different design, in the case of the current programme the reactors at Hinkley Point 'B', and Hunterston 'B' are to the same basic design and are identical apart from detailed improvements shown by experience to be desirable. The same applies to the reactors at Hartlepool and Heysham. Again in the case of the first nuclear programme of Mk I GCR stations, each station had turbo-alternators that differed in size or manufacturer. In the later stations all the turbo-alternators are of a standard size which has also been adopted for fossil stations and made now by only two manufacturing groups.

This degree of standardisation stems from a more widespread understanding of the costs of innovation in a high technology industry. Replication and continuity of manufacture reduce production costs and the time required for construction and commissioning. This approach to standardisation does not imply that we have reached the limit in nuclear power, neither does it result from any lack of inventiveness on the part of our scientists or designers – rather that it is important to avoid unnecessary change or the introduction of additional unknowns without good reason for doing so.

A further important feature of these gas cooled reactors is the freedom they offer in relation to siting. The thermal efficiency of present designs is very much higher than the earlier gas cooled reactors or any water reactors. This limits the requirement for cooling water to no more than that of the latest fossil-fired stations, while the prestressed concrete pressure vessel enables the reactors to be sited much nearer to built-up areas than before [8].

THE REACTOR DEVELOPMENT PROGRAMME

We have for many years been investigating a wide range of nuclear reactors. In gas cooled reactors, new fuel concepts were being developed for operation in a CO_2 environment. We were studying gas turbines that could operate on a CO_2 cycle. Helium was an alternative coolant which would permit the use of graphite clad particle fuel with improved ratings, temperatures and neutron economy. Direct cycle helium gas turbines were an alternative to the steam cycle. There were the alternatives of uranium/plutonium or uranium/thorium fuel cycles which implied very different fuel technologies. We investigated several water reactor systems and built a 100 MW(e) prototype Steam Generating Heavy Water (SGHW) reactor [9]. We have a very substantial programme of fast reactor development.

We believe, however, that there will not be large differences in overall generating cost between any of the contemporary thermal reactor systems. We also believe that the great improvement in fuel utilisation that is possible in the fast reactor will rapidly make it the preferred nuclear system. These conclusions have led to some narrowing of the programme and the concentration of our resources.

In considering our future strategy we have considered the problems of introducing the fast reactor on an industrial scale and we have attempted to produce a realistic programme leading to its introduction into the generating network. Our programme of development of thermal reactors is being assessed in the light of the United Kingdom nuclear power programme as it is today, and how we expect it will evolve when fast reactors are introduced.

FAST REACTOR

If I may I will describe first the position we have reached on fast reactors. In 1964, my predecessor, Lord Penney, reported to the last Geneva Conference our plans for a large prototype fast reactor, and forecast that the first commercial fast reactor station could be on power towards the end of the 1970s. Construction of our 250 MW(e) Prototype Fast Reactor (PFR) is now nearing completion [10] and a recent thorough review has led to the formulation of a strategic plan for development of the fast reactor and its introduction into the electricity network. While all such planning is subject to review, it is gratifying that the plan is consistent with Lord Penney's 1964 forecast.

The principal factors underlying this plan are:—

(a) our continued confidence in the long term economics of the fast reactor system,

(b) our recognition that the introduction of the fast reactor must be phased to permit the build-up of confidence in the system by those responsible for design, construction, licensing and operation,

(c) the need to correlate the programme with the build-up of efficient and economic fuel cycle services, and

(d) that it is an essential step towards the most efficient means of using the world resources of nuclear fuel.

Progress in our understanding of the fuel cycle of the fast reactor continues to support our confidence that low fuel costs can be achieved with fast reactors. Capital costs should be little if at all higher than for thermal reactors of the same size and built at the same time. Though fuel fabrication and reprocessing costs will, of course, be dependent on the level of output required from fuel plants, we are confident that even at today's uranium prices fuel costs for a programme of fast reactors should show advantages of at least ½ mill per kWh over the best that thermal reactors available at the same time could offer. Such a differential, although it appears small, when applied over a substantial installation programme, represents a large saving in generating costs mostly in the cost of imported uranium.

A comparison of the difference in the consumption of uranium with and without fast reactors highlights the importance of the fast reactor in the conservation of world uranium resources (see Fig. 2). A full appreciation of its impact on the energy situation can, however, only come from an overall analysis of the part to be played by both thermal and fast reactors in a given generating system. Such studies permit us, in particular, to analyse the alternative ways in which plutonium can be used [11]. We could, for example, use it in place of enriched uranium in our thermal reactors until the demand for use in fast reactors grows big enough to use all we are producing. However, not only would this entail the construction of special plutonium fuel fabrication plants at considerable cost and with perhaps limited lives; it would also mean less plutonium available for fast reactors when, in the not too distant future, demand will exceed supply. We believe it is preferable on current assumptions to store plutonium for fast reactor use. This conclusion is in line with our confidence both in the long term economics of the system and in its prospects for early introduction into the United Kingdom.

The United Kingdom's present strategic plan, and by this I mean a plan endorsed by the electricity authorities, the nuclear power industry and the Atomic Energy Authority, assumes

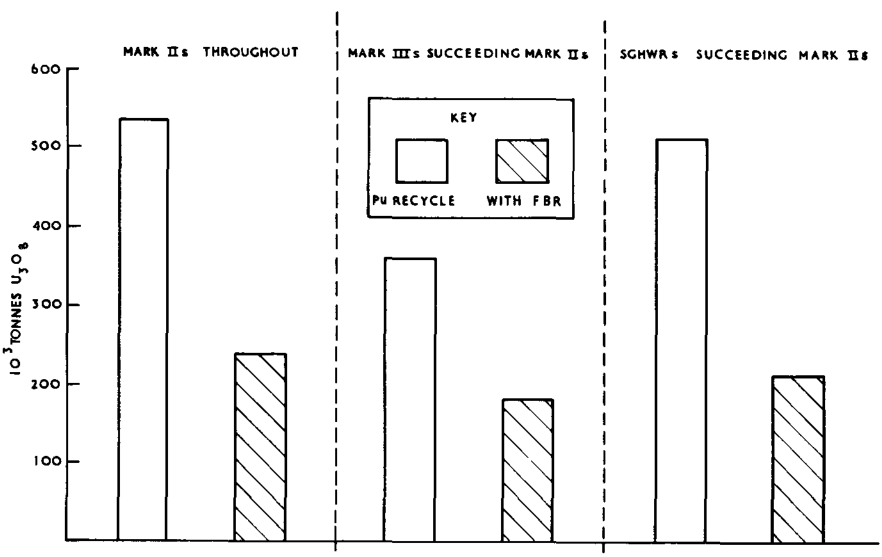
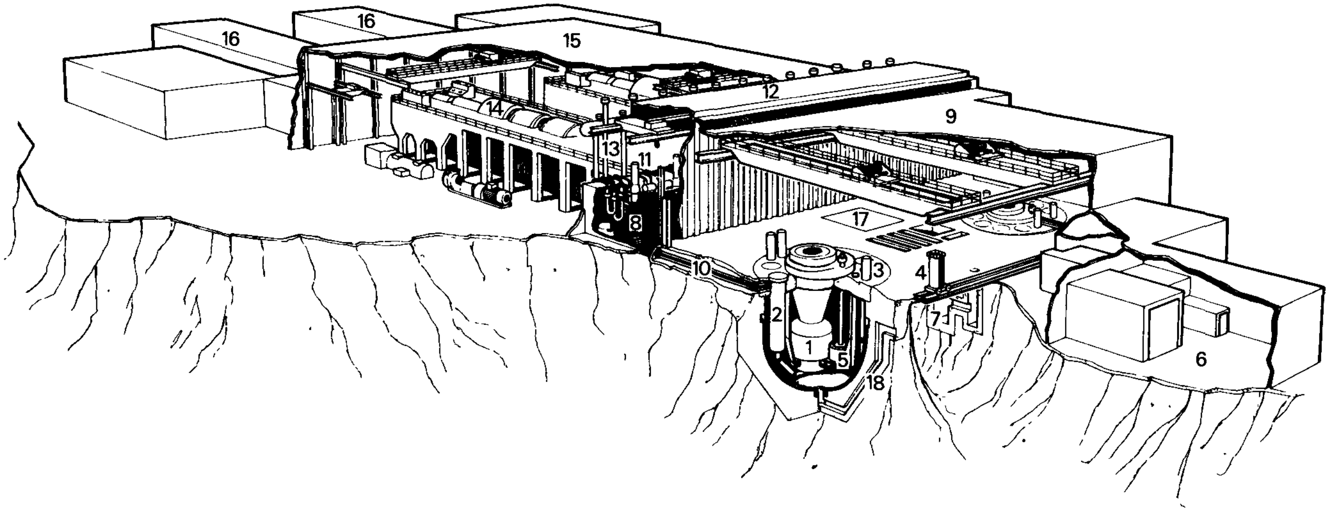


FIG. 2. UK uranium ore requirements, 1976-2010.



1. Reactor Core
2. Intermediate Heat Exchanger
3. Primary Sodium Pump
4. Fuel Transfer Flask
5. Fuel Store
6. Fuel Handling Building
7. Fuel Caves
8. Steam Generator Cells
9. Reactor Hall
10. Secondary Sodium Pipework
11. Secondary Sodium Pump
12. Steam Generator Building
13. Deaerator Plant
14. Turbo-generator
15. Turbine Building
16. Generator Transformer
17. Primary Cold Trap Loop Cell
18. Reactor Vault Cooling Duct.

FIG 3. 2 × 1320 MW(e) commercial fast-reactor station.

that the first 1,300 MW(e) Commercial Fast Reactor would go on power as part of the United Kingdom generating system in 1979. To achieve this, the station would be ordered in 1974 and, if so, be followed by perhaps two or three further stations over the next few years. This time table allows some three years from now for satisfactory completion of the approval procedures required for a first large fast reactor, including the build-up of staff and experience required by the licensing authorities, while by 1979/80 we should have seven years' operating experience with the PFR, constructional experience of perhaps three or four large commercial stations, and initial generating experience from the first of these larger units. On this basis we would expect that by about 1980 we would have sufficient confidence and experience to incorporate fast reactors into the United Kingdom generating system to the maximum extent consistent with the availability of fissile material and the growth of demand for new generating plant. Whether such a time table can, in fact, be achieved will depend on technical developments over the next few years. This, however, is the plan to which we are working and so far we see no reason why it should not be achieved. Fig. 3 gives an impression of the possible layout of a commercial fast reactor station.

THERMAL REACTOR DEVELOPMENT

The thermal reactor development programme has been determined in the light of the overall plan for the introduction of the fast reactor, and also the background of experience and expertise in gas cooled reactors that we have in the United Kingdom. We were anxious to build on that experience and it appeared that the greatest potential of gas cooled reactors lay in the adoption of graphite coated particle fuel with helium as a coolant. Until recently, however, all the experience of this fuel concept was based on the thorium/^{233}U fuel cycle which was quite incompatible with our plans for plutonium fuelled fast reactors; an incompatibility that would have involved a duplication of all our fuel fabrication and reprocessing plants.

However, progress in the development of coated particle fuels and in their fabrication technology has made it possible to develop a coated particle fuel having a higher heavy metal density, thus permitting the use of low enrichment uranium in the particle fuel [12]. This in turn allows the reactor to operate on a uranium/plutonium fuel cycle capable of being integrated into a thermal reactor/fast reactor combined programme. This development in gas cooled reactor technology has the promise of the 10 per cent or more improvement in cost compared with CO_2 gas cooled reactors, which will be needed to justify it. The performance of the fuel so far compares well with alternative nuclear fuels and it has been incorporated in a design of reactor which makes full use of previous extensive experience of gas cooled systems [13,14]. The best features of the earlier gas cooled reactors will be retained, pre-stressed concrete pressure vessels, high efficiency steam cycles and the use of conventional turbines.

Following an extensive design study, the two United Kingdom nuclear design and construction companies have recently submitted proposals to the Central Electricity Generating Board for a lead station having a single 750 MW(e) reactor and turbo-generator to be built at the Oldbury site.

As well as this development in gas cooled reactors we have, for some years now, devoted a significant effort to the development of a water-cooled and moderated reactor, the SGHWR, of which a 100 MW(e) prototype has been successfully operating since the beginning of 1968. This reactor was designed to achieve the advantages of water cooling, the neutron economy associated with heavy water moderation, and the ease of design and construction possible if the need to provide a massive steel pressure vessel can be avoided. In the SGHWR design, the fuel channels are pressurised, but the main tank of moderator material is not. A large proportion of the components of the core can be produced and assembled in line with normal industrial practice. The fuel performance which we expected has materialised, and the prototype has given us valuable experience with which to assess the prospects for water reactors in general, and the potential of the SGHWR in particular, both for use in the United Kingdom and in other parts of the world where the SGHWR's special features – in terms of size, flexibility and ease of construction – may be of particular importance [15]. A tender has been submitted for a two-reactor SGHWR station to be constructed at Stake Ness in Scotland.

The outcome of these quotations for a gas cooled reactor at Oldbury and for an SGHWR at Stake Ness will determine the priorities in our thermal reactor development programme for the future.

INDUSTRIAL ORGANISATION

I have just outlined how the development programme has been simplified and applied with greater force to a narrower front. The same is true in the United Kingdom of the nuclear industry and also the industry that supplies the conventional parts of nuclear stations. At the time of our last conference, there were in the United Kingdom no less than four separate groups designing and constructing nuclear power stations. Three of these groups were private firms engaged in building Mk I GCRs and the design and construction team in the Atomic Energy Authority was engaged on the construction of prototype reactors. This dispersion of design effort was compounded by the ordering of the conventional parts of the stations from a number of quite independent component manufacturers. The result was that each new station built was significantly different from its predecessor – they were all, in one way or another, effectively prototypes. That they have incorporated so much engineering novelty and still operated reliably is a high tribute to the designers, but it is not the most efficient way to run an industry.

Three years ago a rationalisation was carried out in which the four nuclear design teams were effectively reduced to two, The Nuclear Power Group Ltd. and British Nuclear Design and Construction Ltd., and at about the same time, but quite independently, a rationalisation of the heavy electrical industry in the United Kingdom resulted in large turbo-alternator manufacture being concentrated into two groups.

The electricity authorities have played their part in the overall rationalisation by standardising the size of the generating units they have been ordering to 660 MW, with, of course, the result that other subsidiary components have become standardised in turn. These factors have resulted in our achieving a degree of standardisation which is essential for projects of this type, but which was unattainable under the conditions of fragmented industrial groups that existed a few years ago.

The practical result of this standardisation and re-grouping is apparent from the earlier part of this paper where I described the five nuclear power stations that have been ordered in the United Kingdom since our last conference in 1964.

FUEL SERVICES

Although the cost of nuclear fuel is proportionately less than conventional fuel it is nevertheless a significant part of the overall cost of generating electricity from nuclear stations. Because of the enormous heat capacity of nuclear fuel it has got the characteristic of high technical content and relatively small throughput. Moreover, as fuel designs improve, the complexity increases but with increasingly high burn-up the throughput does not go up in proportion to the size of the nuclear programme.

This is the classic problem for modern advanced technological industries in all but the largest of countries. In many parts of the fuel cycle the advantages of scale are so great that self-contained fuel cycle capability for even the larger countries of western Europe is not economically viable. This too has been widely recognised since our last conference, and we in the United Kingdom have been seeking friendly partners in other countries to try to integrate and associate our activities in a wider context than that prescribed by the frontiers of our island home.

With this objective we have formed a tripartite association with Holland and the Federal Republic of Germany for the development of the ultra centrifuge and the construction of enrichment plants based on this technology. We are in discussion with other countries who might wish to join with us. Two companies have now been formed, based in Western Germany and the United Kingdom, to carry out this work. They are owned equally by the countries who are participating in the enterprise [16].

Technical progress continues to be most satisfactory, particularly in the field of applying mass production techniques to the manufacture of centrifuge units. Prototype semi-production scale plants are now under construction in both the United Kingdom and Holland, and the experience of building and operating these plants will make possible an accurate assessment of the role of the centrifuge in supplying enrichment as an alternative to other enrichment processes.

In the reprocessing of irradiated fuel, where again the advantages of scale are so important, we are trying to forge the international links that we regard as so vital for the future.

In the fuel services in the United Kingdom we have also taken one further step earlier this year which is both important and illustrative of the trend in nuclear power. We have reorganised all the commercial activities in this field, which were once part of the Atomic Energy Authority, into a company structure – British Nuclear Fuels Limited. This change was made for two reasons. The first was to recognise that nuclear fuel services are now a fully commercial and industrial enterprise, and secondly, to facilitate more ready association with similar nuclear industrial organisations in other countries in pursuance of our main objective of cheap nuclear power for the future.

THE FUTURE AND FUSION RESEARCH

Let me, in conclusion, say a few words about the longer term future. It would be unwise to assume that with the sodium-cooled fast reactor, the development of fission reactors will come to an end: further advances will certainly be made though the scope for additional improvements may become progressively less. For a further major step forward fusion may well be the answer. Scientific progress in this area has been very great. Controlled fusion has been demonstrated. With improving technology, substantial pulses of fusion neutrons should become available in the laboratories of the world in the quite near future. But we have not yet reached the equivalent point to the first atomic pile of 1942, and we all now recognise the vast technological undertaking in proceeding from a "zero energy" fusion reactor to a fusion power station.

On the face of it, the undertaking looks almost too difficult with present technology. But who would be so brave as to say that in the next twenty years there will not be discovered somewhere in the world one of the missing scientific or technological bricks that would make the problems of the fusion engineers so much easier?

Fusion development is being carried out on a world-wide basis with the fullest interchange of information between all laboratories and workers in this field. It is a most excellent example of international co-operation in the field of advanced technology.

With so much of our thinking in nuclear power directed to cost effectiveness, replication, rationalisation and industrial reorganisation, I hope we will not lose all sense of striving for the future or of interest in the undiscovered, nor refuse to make any journey unless every step can be counted and measured in advance. The road to a successful and economic fusion power station is uncharted. I hope we can maintain our resolve to continue the exploration.

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L'EVOLUTION DU PROGRAMME NUCLEAIRE D'ELECTRICITE DE FRANCE

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Abstract–Résumé–Аннотация–Resumen

THE DEVELOPMENT OF THE NUCLEAR PROGRAM OF ELECTRICITE DE FRANCE.

As soon as the researches of the Commissariat à l' Energie Atomique made it possible, Electricité de France started a large experimental nuclear program within the natural uranium, graphite, CO_2 layout. When the Saint-Laurent-des-Eaux plant was put into service and the selected layout was proved technically satisfactory, considerations essentially economic in nature convinced Electricité de France, in agreement with the Public Authorities, to "diversify" its nuclear program and, while waiting for the realization of industrial breeders, to engage mainly enriched uranium water-moderated reactors.

L' EVOLUTION DU PROGRAMME NUCLEAIRE D' ELECTRICITE DE FRANCE.

Dès que les recherches du Commissariat à l' énergie atomique lui en ont ouvert la possibilité, Electricité de France a engagé un important programme nucléaire expérimental dans la filière technique uranium naturel, graphite, gaz carbonique. Au moment où la mise en service de la centrale de Saint-Laurent-des-Eaux a démontré que la filière choisie était techniquement bien au point, des considérations essentiellement d' ordre économique ont conduit Electricité de France, en accord avec les Pouvoirs publics, à « diversifier » son programme nucléaire et, en attendant l' avènement industriel des surgénérateurs, à s' engager principalement dans la voie des réacteurs à uranium enrichi, ralentis à l' eau naturelle.

РАЗРАБОТКА ПРОГРАММЫ ПО ЯДЕРНОЙ ЭНЕРГЕТИКЕ "ЭЛЕКТРИСИТЕ ДЕ ФРАНС".

Исследования Комиссариата по атомной энергии дали возможность обществу "Электрисите де Франс" приступить к осуществлению широкой ядерной экспериментальной программы по созданию реакторной системы на природном уране, с графитом и углекислым газом. Когда ввод в эксплуатацию АЭС в Сен-Лорен-дез'О показал, что выбранная реакторная система является удовлетворительной с технической точки зрения, общество "Электрисите де Франс" решило по соображениям главным образом экономического порядка и с согласия государственных организаций "разнообразить" свою ядерную программу и, пока не появились промышленные реакторы-размножители, строить в основном водные реакторы на обогащенном уране.

LA EVOLUCION DEL PROGRAMA NUCLEAR DE ELECTRICITE DE FRANCE.

En cuanto las investigaciones del Commissariat à l' énergie atomique le abrieron esa posibilidad, Electricité de France emprendió un importante programa nuclear experimental sobre la familia técnica, uranio natural, grafito, gas carbónico. Desde el momento en que la puesta en servicio de la central de Saint-Laurent-des-Eaux ha demostrado que la familia escogida está lograda desde el punto de vista técnico, consideraciones esencialmente económicas han aconsejado a Electricité de France, de acuerdo con los poderes públicos, « diversificar» su programa nuclear y, mientras llega el advenimiento industrial de los reactores reproductores, dedicarse principalmente a los reactores de uranio enriquecido moderados con agua natural.

En 1964, lors de la troisième Conférence internationale de Genève sur les applications pacifiques de l'énergie atomique, M. Cabanius, d'Electricité de France (EDF), et M. Horowitz, du Commissariat à l'énergie atomique (CEA), ont présenté un rapport commun sur le programme français de centrales nucléaires. A cette époque, le programme français était presque exclusivement axé sur l'emploi de l'uranium naturel, modéré au graphite et refroidi au gaz carbonique. Vers la fin de 1969 un changement important est intervenu: il a été décidé que l'effort principal porterait dorénavant sur les filières techniques utilisant l'uranium enrichi, modéré et refroidi à l'eau naturelle.

L'objet du présent rapport est d'exposer les motifs de ce tournant de la politique nucléaire française dans le domaine des centrales électriques.

1. RAPPEL DU PROGRAMME NUCLEAIRE INITIAL D'ELECTRICITE DE FRANCE

1.1. Situation énergétique de la France

Si les circonstances ont entraîné une évolution profonde du programme nucléaire français les motivations de ce programme restent constantes: l'objectif est toujours de produire de l'électricité dans des conditions sûres et au moindre prix. Ce sont les moyens d'y parvenir qui ont changé et cela, comme nous le verrons, pour des raisons économiques et non pour des raisons techniques.

En raison du rôle important et croissant de l'électricité, EDF doit évidemment s'adapter à la situation énergétique générale de notre pays.

Une politique énergétique cohérente, en France comme ailleurs, comporte trois objectifs essentiels:
- assurer avec une marge raisonnable de sécurité l'approvisionnement du pays en énergie primaire,
- obtenir cet approvisionnement au plus bas prix possible, compte tenu des impératifs de sécurité reconnus nécessaires,
- éviter dans la mesure du possible de grever trop lourdement la balance des comptes par des importations excessives de produits énergétiques.

Ces trois objectifs, à des titres divers, sont sous-jacents dans la politique nucléaire de la France et en justifient l'évolution.

Longtemps la politique énergétique de notre pays a été dominée par l'ambition de trouver sur notre propre territoire l'essentiel de nos approvisionnements en énergie primaire, d'où le développement de l'énergie hydraulique, l'encouragement à la production du charbon, les prospections de pétrole et de gaz naturel.

Malheureusement nos ressources métropolitaines classiques demeurent modestes et sont appelées à décroître en valeur relative, tandis que nos besoins augmentent en raison de notre développement industriel.

Les gisements hydro-électriques que l'on peut équiper à un prix acceptable sont de plus en plus rares. Nos mines de charbon s'épuisent et leur coût de production s'élève au-delà de ce qui est supportable pour notre économie. Enfin les recherches de produits pétroliers ont été décevantes en métropole et, à part le gisement de gaz naturel de Lacq qui n'est qu'un appoint, on n'a pas trouvé dans notre sous-sol assez de ressources pour assurer une part suffisante de nos approvisionnements énergétiques.

Rappelons que le déficit de nos besoins en énergie primaire, qui était de 30% environ en 1950, est passé à 60% en 1968 et doit atteindre 75% en 1975, époque à laquelle la tendance à l'aggravation pourra enfin être corrigée grâce à l'énergie nucléaire.

La sécurité de nos approvisionnements en énergie ne pouvant être assurée par des ressources tirées de notre sol, c'est par une diversification aussi grande que possible de nos importations qu'il convenait donc de la rechercher.

A cet égard l'uranium est particulièrement intéressant. Il est très répandu dans le monde. Il peut être stocké dans des conditions peu onéreuses. Enfin, grâce à l'action du Commissariat à l'énergie atomique, la France possède ou contrôle environ 10% des gisements mondiaux d'uranium.

Du point de vue du prix de revient de l'électricité l'uranium, dans l'immédiat, ne modifie pas la situation car les centrales nucléaires ont un coût de production très voisin de celui des centrales classiques. Cependant une marge de progrès technique supérieure paraît leur être offerte. Mais ce qui est le plus important c'est que l'énergie nucléaire constitue une garantie contre une élévation du prix de revient du kWh pour le cas où la part croissante du pétrole dans l'approvisionnement des grands pays industriels viendrait accentuer les tendances actuelles à la hausse du coût de cette source d'énergie primaire.

Enfin, du point de vue de la balance des comptes, l'emploi de l'uranium constitue un facteur d'amélioration. Nous disposons en effet de ressources importantes en France et dans la zone monétaire du franc. En outre, la part du combustible dans le prix de revient du kWh des centrales nucléaires est moitié moindre environ que dans les centrales classiques. Enfin, à plus long terme, lorsque les surgénérateurs auront été mis au point, la part de l'uranium dans le prix de revient du kWh deviendra extrêmement faible.

Pour un pays comme la France, le recours à l'énergie nucléaire se présentait donc dans des conditions particulièrement attrayantes.

Le rôle de l'énergie nucléaire paraissait tellement important qu'Electricité de France s'est engagée dans un programme initial de caractère expérimental dès que les premières recherches et réalisations industrielles du Commissariat à l'énergie atomique lui en ont ouvert la possibilité.

1.2. Le programme nucléaire expérimental d'Electricité de France

Si EDF n'a pas attendu que l'énergie nucléaire soit compétitive c'est qu'il importait de former des hommes au plus vite et de préparer l'industrie à la construction des centrales nucléaires appelées manifestement à jouer dans l'avenir un rôle rapidement croissant dans nos programmes énergétiques.

La France, comme la Grande-Bretagne, s'est engagée dans la filière à l'uranium naturel, modéré au graphite et refroidi au gaz carbonique.

A l'origine cette voie n'était pas moins séduisante sur le plan technique que les autres, et elle avait en outre l'avantage, grâce à l'emploi de l'uranium naturel, de rendre notre pays indépendant des sources d'uranium enrichi. En fait cette filière était la seule possible pour nous à une époque où l'uranium enrichi était encore considéré comme une matière stratégique et l'eau lourde trop rare pour un programme industriel important. L'alternative était ou de s'engager dans la technique uranium naturel-gaz-graphite, ou d'attendre, comme d'autres pays l'ont fait, que l'accès aux autres filières soit ouvert.

Notre pays a choisi d'explorer la seule technique qui s'ouvrait à lui, soutenu par une longue tradition scientifique dans le domaine nucléaire et encouragé par la création et le développement du Commissariat à l'énergie atomique.

Le programme français des centrales nucléaires gaz-graphite est bien connu. J'en rappellerai seulement les principales étapes.

La voie a été ouverte à Marcoule avec les piles plutonigènes G1, G2 et G3 où EDF s'est associée au CEA pour récupérer l'énergie produite par ces piles. Les premiers kWh d'origine nucléaire ont ainsi été produits dès 1956 grâce au petit réacteur G1.

C'est près de Chinon, au bord de la Loire, qu'Electricité de France a entrepris de construire les premières centrales où son rôle de maître d'œuvre comprenait non seulement, comme à Marcoule, la partie classique, mais aussi la partie nucléaire, le CEA intervenant désormais comme conseil. Les étapes successives à Chinon ont été:

Chinon I avec 70 MW(e) mis en service en 1963
Chinon II avec 200 MW(e) mis en service en 1965
Chinon III avec 480 MW(e) mis en service en 1966.

Trois faits caractérisent ce programme initial:
- l'absence de duplication tant que le seuil de rentabilité n'est pas atteint ou en vue,
- une cadence rapide des mises en service,
- une croissance remarquable des tailles unitaires – 70, 200, 480 MW(e) – dans l'espoir d'atteindre rapidement la compétitivité, l'effet de taille dans le nucléaire ayant un impact considérable sur le prix de revient du kWh.

Rappelons que les caissons de Chinon I et Chinon II étaient en acier, les pièces étant assemblées et soudées sur le chantier. A partir de Chinon III on a adopté des caissons en béton précontraint qui, entre autres avantages, affranchissaient la filière gaz-graphite des limitations de taille unitaire inhérentes aux enceintes en acier et qui, d'ailleurs, avaient déjà été essayés antérieurement avec succès à Marcoule.

La filière a été développée ensuite à Saint-Laurent-des-Eaux, également sur la Loire.

Pour Saint-Laurent I, les conditions économiques de l'époque où la centrale a été entreprise permettaient d'escompter raisonnablement que l'on pourrait atteindre grâce à elle la compétitivité avec les centrales à mazout.

Le fuel lourd valait alors environ 1,1 centime la thermie (1000 calories) et les taux d'intérêt de l'argent n'avaient pas encore atteint les niveaux très élevés observés par la suite, taux élevés qui défavorisent les centrales nucléaires dont les investissements sont plus lourds que ceux des centrales classiques.

Le projet de Saint-Laurent I a été conçu de manière à atteindre enfin l'objectif de la compétitivité avec les centrales classiques.

Pour bénéficier de l'effet de duplication on a décidé que le cœur du réacteur serait identique à celui de Chinon III, avec la même puissance de 480 MW(e). Cependant, une modification importante faisait encore de Saint-Laurent I un prototype: c'était la disposition dite «intégrée» où les échangeurs de chaleur étaient placés dans la même enceinte en béton précontraint que le cœur du réacteur. Cette disposition permettait des économies de construction tout en renforçant la sécurité de l'ensemble.

Saint-Laurent II a été entrepris 3 ans après dans la même optique. Des améliorations de détail ont permis de porter la puissance de SL II de 480 MW(e) à 515 MW(e) sans perdre le bénéfice de l'effet de duplication.

Je rappelle que c'est dans le contexte de cette époque qu'a été entreprise à Vandellos près de Tarragone la construction d'une centrale franco-espagnole de 480 MW(e) identique à Saint-Laurent I.

Outre les perfectionnements sur la conception d'ensemble des progrès avaient également été accomplis parallèlement dans le domaine des éléments combustibles.

Le Commissariat à l'énergie atomique, en liaison avec Electricité de France, a pu, grâce à de multiples expérimentations, améliorer progressivement le rendement des éléments combustibles en augmentant leur puissance spécifique et leur taux d'irradiation. Des barreaux pleins de Marcoule on est passé aux tubes creux de Chinon et de Saint-Laurent-des-Eaux, les dimensions des tubes et la forme des ailettes des gainages en magnésium évoluant progressivement. Des éléments combustibles dits annulaires (toujours en uranium métallique) ont été également mis au point dans lesquels le gaz carbonique refroidit à la fois l'intérieur et l'extérieur des éléments combustibles, ce qui permet d'augmenter sensiblement leur puissance spécifique. Une centrale de 540 MW(e) utilisant des éléments annulaires est en construction sur le site dit du Bugey, sur le Rhône, en amont de Lyon. Elle doit entrer en service en 1972.

Parallèlement aux réalisations dans la filière uranium naturel-gaz-graphite, Electricité de France, pour diversifier ses connaissances, a participé à deux expériences de portée limitée, l'une dans la technique de l'eau lourde, l'autre dans celle de l'eau naturelle. Ce furent les réalisations du réacteur EL4 de 70 MW(e) dans la centrale des Monts d'Arrée en Bretagne — où, comme à Marcoule, le CEA a construit la partie nucléaire et Electricité de France la partie classique — et d'un réacteur PWR de 266 MW(e) à Chooz dans la centrale franco-belge des Ardennes, sur la Meuse.

L'effort principal restait cependant axé sur la filière nationale gaz-graphite dont des progrès constants avaient permis la mise au point. La production d'un milliard de kWh au cours des sept premiers mois de la mise en service de Saint-Laurent I, en 1969, avait prouvé le plein succès de la filière française sur le plan technique.

Et cependant, le 16 octobre 1969, au cours d'une conférence de presse, Le Directeur général d'Electricité de France était conduit à annoncer, non pas l'abandon, mais l'effacement de la filière gaz-graphite au profit des filières à l'uranium enrichi et à l'eau naturelle.

2. LE TOURNANT VERS LES FILIERES TECHNIQUES A L'EAU NATURELLE

2.1. Motifs du changement de politique nucléaire d'Electricité de France

Ce changement d'orientation était motivé essentiellement par des raisons économiques et non par des raisons techniques.

Certes la filière française avait connu de graves difficultés comme toutes les techniques qui en sont encore au stade des prototypes. Ces «maladies de jeunesse» cependant avaient été surmontées et l'arrêt ultérieur du réacteur Saint-Laurent I pendant un an fut la conséquence d'une fausse manœuvre qui ne mettait pas en cause une réussite technique par ailleurs indiscutable. Cet incident était dû à une erreur de programmation à la suite de laquelle un rondin de graphite, qui devait être placé par l'appareil de chargement à la périphérie du cœur, a été mis dans un canal destiné à recevoir des éléments combustibles. Le refroidissement insuffisant qui en est résulté a provoqué la fusion de cinq éléments combustibles, soit 50 kg d'uranium.

Bien que lourde de conséquences immédiates cette fausse manœuvre ne mettait pas en cause la valeur technique de la filière gaz-graphite. Ce sont des raisons exclusivement économiques qui ont motivé l'effacement de la filière française dont le prix de revient s'est révélé à l'expérience supérieur à celui atteint au moyen des techniques américaines. L'énergie devant être produite au plus bas prix possible, pour que notre économie reste compétitive, il fallait en tirer les conséquences et y adapter notre politique nucléaire.

Le tableau qui figure en annexe donne les résultats d'un calcul comparatif fait par EDF au début de 1971.

Pour le thermique classique on a fait état d'un prix de la thermie fuel de 0, 65 centime pour tenir compte de la tendance à la hausse déjà observée à l'époque. On obtient 3, 70 centimes par kWh contre 3, 64 centimes avec une installation nucléaire à l'eau ordinaire. En raison des incertitudes de calcul l'écart n'est pas significatif et si l'on considère la supériorité, au moins provisoire, du thermique classique au point de vue de la fiabilité on peut admettre simplement qu'il y a équivalence entre le classique et le nucléaire (centrale PWR de Fessenheim) quand la calorie fuel atteint 0, 65 centime par thermie. Des calculs antérieurs aux accords de Téhéran et de Tripoli avec 0, 6 et 0, 5 centime par thermie, prix effectivement obtenus dans des contrats à moyen terme, donnaient un léger avantage au thermique classique, d'où, comme nous le verrons, une certaine hésitation à engager trop de centrales nucléaires au début du Sixième Plan.

La comparaison entre la filière PWR et la filière gaz-graphite a été faite en prenant d'une part les prix de construction de deux tranches de 890 MW(e), connus grâce au contrat de Fessenheim, et d'autre part les résultats d'une étude faite sur deux tranches de 890 MW(e) dans la technique de Saint-Laurent-des-Eaux (désignée par le sigle SL 900).

Pour comparer les deux filières il fallait en effet tenir compte de l'effet de taille et extrapoler à 900 MW(e) les chiffres obtenus à Saint-Laurent-des-Eaux pour des réacteurs de l'ordre de 500 MW(e). On trouve ainsi 4, 19 centimes par kWh pour le gaz-graphite contre 3, 64 centimes pour l'eau naturelle, soit 15% de différence. Une hypothèse plus optimiste, tout en restant réaliste, sur les durées d'irradiation des éléments combustibles ramènerait le prix du projet SL 900 à 4, 10 centimes par kWh et la différence à 12%. L'écart, de toute manière, reste significatif malgré les incertitudes inhérentes à ce genre de calcul.

C'est dans le contexte antérieur aux accords de Téhéran et de Tripoli qu'était intervenue le 13 novembre 1969 la décision annoncée par un communiqué de l'Elysée de «diversifier» le programme nucléaire français. Diversifier signifiait que les études sur les techniques dites éprouvées, notamment la filière gaz-graphite, seraient poursuivies mais que l'effort principal porterait désormais sur les filières qui à l'évidence se révélaient dans l'immédiat comme les plus économiques, en l'espèce les filières à l'eau naturelle.

Depuis la décision de construire Saint-Laurent I le prix de la calorie fuel, comme nous l'avons vu, avait fortement baissé, passant de 1,1 centime environ par thermie à 0,6 et même 0,5, tandis que simultanément les taux d'intérêt augmentaient, rendant de moins en moins attrayantes les techniques qui, comme la filière française, exigeaient de gros investissements.

Saint-Laurent-des-Eaux n'était pas seulement un succès technique. Sur le plan économique Saint-Laurent-des-Eaux avait également tenu ses promesses et aurait atteint la compétitivité avec les centrales classiques si les conditions qui prévalaient au moment de sa conception avaient persisté. La conjoncture ayant changé, le moment où l'énergie nucléaire devait remplacer avantageusement les autres sources d'énergie primaire s'éloignait une fois de plus. Il en était de même d'ailleurs en Europe pour les filières à l'eau naturelle, mais dans une moindre mesure car elles sont moins sensibles, du fait des investissements plus faibles qu'elles exigent, à la hausse des taux d'intérêt.

Le premier effet de cet important changement de la conjoncture économique a été un arrêt provisoire des programmes nucléaires d'Electricité de France, qui a duré près de 5 ans.

Il importait cependant de maintenir en haleine les équipes de qualité que la pratique avait formées, tant au CEA qu'à Electricité de France et au sein de l'industrie. Il convenait de maintenir leur entraînement par une certaine «gymnastique nucléaire», pour reprendre une expression de M. Boiteux, Directeur général d'EDF, au cours de sa conférence de presse du 16 octobre 1969.

C'est dans cet esprit qu'Electricité de France a lancé en 1970 un appel d'offre pour la construction, à Fessenheim sur le Rhin, d'une centrale à l'eau naturelle. On pouvait escompter que son prix de revient ne s'écarterait pas trop de celui d'une centrale au fuel et serait donc acceptable. Electricité de France bénéficiait en effet de l'expérience récente de la mise en chantier de la centrale franco-belge de Tihange dans la technique américaine de l'eau sous pression (PWR).

Tandis que la construction de la centrale de Tihange était déjà décidée, Electricité de France participait avec des sociétés suisses, auxquelles des sociétés allemandes se sont jointes, à l'étude d'une centrale d'une puissance équivalente à Kaiseraugst sur le Rhin, en amont de Bâle. Il s'agissait cette fois d'une réalisation dans la technique à l'eau bouillante (BWR). Electricité de France pouvait accéder ainsi à l'expérience de chacune des deux sous-filières américaines à l'eau naturelle utilisant l'uranium enrichi comme combustible.

Ces entreprises à frais partagés ont confirmé l'intérêt de ces techniques pour l'Europe, intérêt déjà reconnu dans les conditions économiques des Etats-Unis. Mais c'est la décision de construire en France à Fessenheim, sans participation étrangère, une centrale à eau naturelle qui a véritablement concrétisé le tournant de la politique nucléaire d'Electricité de France.

Si le choix des filières à uranium enrichi était dû essentiellement à leurs meilleures perspectives de rentabilité, il convient de noter que d'autres considérations sont également intervenues.

L'importance croissante des programmes de centrales à eau naturelle aux Etats-Unis, puis dans le monde, avait démontré la confiance que ces filières inspiraient sur les plans technique et économique. Il était raisonnable d'admettre que la somme d'expérience accumulée grâce à de nombreuses réalisations faciliterait des mises au point rapides, en cas d'incidents toujours possibles, et, par conséquent, garantirait rapidement une bonne fiabilité pour ce type de centrales.

D'autre part, les marchés d'exportation sont manifestement appelés, pendant de nombreuses années, à se développer principalement dans les techniques à l'eau naturelle. Il était donc judicieux que les constructeurs français puissent se familiariser au plus tôt avec ces techniques qui, actuellement, ouvrent les meilleures perspectives commerciales.

Toutes ces considérations jouaient incontestablement en faveur des techniques à l'eau naturelle. Dans ces conditions, le changement d'orientation de la politique nucléaire d'Electricité de France s'imposait.

2.2. Aperçu des futurs programmes d'Electricité de France

2.2.1. Perspectives des filières à l'eau naturelle

La politique étant ainsi orientée, à moyen terme tout au moins, vers les techniques à l'eau naturelle, fallait-il choisir entre l'eau sous pression et l'eau bouillante?

Electricité de France a considéré que ces deux sous-filières étaient techniquement équivalentes. L'appel d'offre pour la centrale de Fessenheim a été lancé auprès de deux groupements industriels français, l'un appartenant au groupe Schneider représenté par FRAMATOME et qui mettait en œuvre la technique Westinghouse, l'autre au groupe CGE-ALSTHOM représenté par SOGERCA, licencié de la General Electric Company.

Le contrat a été passé en novembre 1970 avec FRAMATOME, qui était le moins disant pour la chaudière nucléaire, tandis que le groupement CGE-ALSTHOM se voyait attribuer la commande du groupe turbo-alternateur.

Les deux groupements présentant les mêmes garanties techniques, grâce aux liens qu'ils ont noués avec leurs licencieurs américains, la compétition reste désormais ouverte sur le plan commercial entre les représentants actuels des deux sous-filières à l'eau naturelle, lesquelles devraient logiquement trouver leur place l'une et l'autre sur le marché français.

Entre-temps, les fuels lourds ayant subi une hausse importante, la compétitivité de l'énergie nucléaire s'est trouvée favorisée.

Le 26 février 1971 un communiqué interministériel a annoncé une accélération du programme de centrales nucléaires d'Electricité de France au cours du Sixième Plan. Fixé d'abord à 4000 MW(e) pour les cinq années du Plan ce programme pourrait être porté à 8000 MW(e), suivant en cela les recommandations des experts de la Commission de l'énergie du Plan.

La première mesure concrète dans le sens de l'accélération a été la décision d'entreprendre la construction de trois centrales de l'ordre de 900 MW(e) chacune d'ici à la fin de 1972 au lieu de deux, toujours dans les filières à l'eau naturelle. Il est probable que les tranches unitaires, à partir de 1973, seront de l'ordre de 1200 MW(e) chacune et que le total construit au cours des cinq années du Sixième Plan (1971 à 1975) atteindra 8000 MW(e).

Il est évident que les péripéties de Téhéran et de Tripoli ont favorisé l'accélération du programme nucléaire d'Electricité de France. Il faut noter toutefois que cette accélération avait déjà été envisagée antérieurement puisqu'elle était explicitement prévue dans la loi du 9 juillet 1970 qui a approuvé les options du Sixième Plan. Une politique énergétique cohérente s'inscrit en effet dans une prospective à long terme et les variations accidentelles de la conjoncture économique ne sont pas de nature à modifier les perspectives plus lointaines de l'énergie nucléaire: elles interviennent seulement pour accélérer ou ralentir temporairement les programmes à long terme de centrales nucléaires. Actuellement il est évident que la tendance est à l'accélération.

2.2.2. Perspectives des filières intermédiaires et des surgénérateurs

Rappelons cependant, en reprenant les termes du communiqué présidentiel du 13 novembre 1969, que les réalisations dans les techniques à l'eau naturelle constituent pour Electricité de France une «diversification» de ses programmes nucléaires. Parallèlement, des études continuent sur les autres filières susceptibles de concurrencer, à plus ou moins long terme, les techniques à l'eau naturelle.

Tandis que les études sur le graphite-gaz sont poursuivies, d'autres voies sont d'ores et déjà explorées: l'eau lourde, avec un projet portant sur un prototype de 600 MW(e) dont l'expérience canadienne en cours à Pickering viendra confirmer ou non l'intérêt, et des idées de coopération avec l'étranger, non encore concrétisées, dans le domaine des réacteurs à haute température. Ces derniers présentent pour Electricité de France un intérêt particulier du fait qu'ils mettent en œuvre le graphite, le gaz comme fluide caloporteur et les caissons en béton précontraint, toutes techniques que notre expérience antérieure nous a rendues familières.

Dans le domaine des réacteurs avancés l'effort principal se portera sur les surgénérateurs à neutrons rapides, refroidis au sodium liquide.

Après le succès du réacteur expérimental RAPSODIE, la réalisation de la centrale nucléaire PHENIX de 250 MW(e) viendra confirmer, on peut l'espérer, la valeur de la technique des réacteurs à neutrons rapides refroidis au sodium liquide. Après la mise en service de PHENIX, prévue pour 1973, un prototype de taille industrielle est envisagé, de l'ordre de 1000 MW(e). Des études sont déjà en cours mais aucune décision de construction ne sera prise avant la mise en service de PHENIX. Il est prévu que cette réalisation devrait se faire en commun avec des partenaires européens.

CONCLUSION

Il n'est pas possible de faire des prévisions plus lointaines. Il n'est plus contesté que l'avenir appartient au nucléaire pour la production de l'énergie électrique, à moyen terme dans les filières à l'eau naturelle et dans un avenir plus lointain grâce aux surgénérateurs. Il est possible que des réalisations interviennent dans des filières intermédiaires, à l'eau lourde ou à haute température, si la mise au point des surgénérateurs se révélait plus longue qu'on ne l'espère actuellement.

Quelles que soient les voies techniques qui seront suivies Electricité de France consacrera à l'énergie nucléaire, comme elle l'a fait dans le passé, tous les moyens compatibles avec les impératifs financiers auxquels sont soumis ses programmes d'équipement.

Cette politique nucléaire va dans le sens de l'intérêt général: elle favorise l'indépendance énergétique de la France, elle conduit à plus ou moins long terme à un abaissement du prix de revient du kWh et enfin elle améliore la balance des comptes de notre pays.

Enfin, à une époque où les problèmes de pollution et d'environnement deviennent de plus en plus préoccupants, l'énergie nucléaire constitue actuellement un moyen de produire pratiquement sans nuisances le courant électrique, lequel est incontestablement pour l'utilisateur la forme d'énergie la plus propre.

ANNEXE

COMPARAISONS ECONOMIQUES

Coûts [a]	Centrale classique 2×600 MW(e)	Centrale nucléaire	
		Eau ordinaire PWR 2×890 MW(e)	Projet SL 900 gaz-graphite 2×890 MW(e)
Coût d'investissements (F/kW)			
Frais de construction	627	807	1010
Frais indirects [b]	141	244	306
Total	768	1051	1316
Coût moyen du kWh (centimes/kWh)			
Investissements [c]	1,42	1,94	2,43
Frais d'exploitation	0,77	0,72	0,89
Combustible	1,51 [d]	0,98 [e]	0,87 [f]
Total	3,70	3,64	4,19

[a] Coûts calculés aux conditions économiques du 1er avril 1970, hors taxes, avec une durée d'amortissement de 30 ans pour le thermique classique et de 20 ans pour le nucléaire.

[b] Comprennent un pourcentage du prix de construction:
- 5% pour charges du maître d'œuvre
- 23% d'intérêts intercalaires
- 1,1% pour frais de préexploitation: essais et formation du personnel.

[c] Moyenne par kWh calculée avec, pour le nucléaire, une durée d'utilisation de 3000 h la première année, de 5000 h la deuxième année et ensuite de 6600 h par an; pour le thermique classique on a admis les mêmes utilisations.

[d] Prix de la thermie 0,65 centime.

[e] Coût d'enrichissement égal à 32 $EU/kg UTS et une teneur de rejet de 0,26%.

[f] Combustible tubulaire à âme de graphite avec une irradiation moyenne de rejet de 5000 MWj/t environ.

PERSPECTIVES D'UTILISATION DE L'ENERGIE D'ORIGINE NUCLEAIRE EN YOUGOSLAVIE

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Abstract–Résumé–Аннотация–Resumen

PROSPECTS FOR THE UTILIZATION OF NUCLEAR ENERGY IN YUGOSLAVIA.

Studies carried out in Yugoslavia to determine the future development rate and characteristics of power production in that country are reviewed in the paper. By application of a number of projection and optimization methods, a long-term assessment of power production and consumption was obtained. The conclusions drawn from the studies refer to conditions in which nuclear power stations will be competitive and to possibilities for their integration into the national system. The reactor type to be selected from the standpoint of profit-earning capacity, the use of domestic nuclear raw materials, and the optimum contribution to implementation of the nuclear program to be expected from the national potential in science, technology and industry are among the problems dealt with. In the analysis work, special attention was paid to the competitiveness threshold and the optimum structure for nuclear power stations for meeting the needs of the north-western part of the country. Many alternative programs were investigated with a view to selecting optimum installations from the point of view of power requirements and provision of a reasonable margin to take account of variations in hydroelectric production.

PERSPECTIVES D'UTILISATION DE L'ENERGIE D'ORIGINE NUCLEAIRE EN YOUGOSLAVIE.

Le mémoire passe en revue les études qui ont été effectuées en Yougoslavie en vue d'établir le taux et les caractéristiques du développement futur de la production d'énergie dans ce pays. On est parvenu, en utilisant plusieurs méthodes de prévision et d'optimisation, à faire une évaluation à long terme de la production et de la consommation d'énergie électrique. Les conclusions tirées de ces études se rapportent aux conditions dans lesquelles les centrales nucléaires seront compétitives et à leur possibilité d'intégration dans le système national. Les problèmes traités comprennent le choix de la filière du point de vue de la rentabilité, l'utilisation des matières premieres nucléaires d'origine domestique et la contribution optimale du potentiel national scientifique, technique et industriel à la réalisation du programme nucléaire. Les analyses ont porté en particulier sur le seuil de compétitivité et la structure optimale des centrales nucléaires destinées à faire face à la demande dans la partie nord-ouest de la Yougoslavie. De nombreuses variantes du programme ont été examinées en vue de choisir les installations optimales en tenant compte des besoins en énergie et de la nécessité de s'assurer une marge raisonnable compte tenu des variations de la production des centrales hydrauliques.

ПЕРСПЕКТИВЫ ИСПОЛЬЗОВАНИЯ АТОМНОЙ ЭНЕРГИИ В ЮГОСЛАВИИ.

В докладе рассматриваются исследования, проведенные в Югославии с целью определения темпов и особенностей будущего развития национальной энергетики. Путем использования различных методов прогнозирования и оптимизации удалось осуществить долгосрочную оценку производства и потребления электроэнергии. Выводы, сделанные из этих исследований, согласуются с условиями конкурентоспособности атомных электростанций и с возможностью их включения в национальную энергосистему. Рассматривались проблемы выбора типа реактора с точки зрения рентабельности, использования местного ядерного сырья и оптимального вклада национального научно-технического и промышленного потенциала в реализацию ядерной программы. В частности, анализировались степень конкурентоспособности и оптимальная структура атомных электростанций, предназначенных удовлетворить спрос на энергию в северо-западной части Югославии. Были рассмотрены многие варианты программы с целью выбора оптимальных установок, имея в виду энергетические потребности и необходимость обеспечения соответствующей резервной мощности с учетом неустойчивой работы гидроэлектростанций.

PERSPECTIVAS DE UTILIZACION DE LA ENERGIA DE ORIGEN NUCLEAR EN YUGOSLAVIA.
Esta memoria examina los estudios realizados en Yugoslavia con objeto de establecer el ritmo y las características del futuro desarrollo de la producción de energía en el país. Mediante varios métodos de predicción y optimización se ha llegado a hacer una evaluación a largo plazo de la generación y el consumo de energía eléctrica. Las conclusiones extraídas de estos estudios se refieren a las condiciones que harán entrar en competencia a las centrales nucleares y a las posibilidades que éstas tienen de integrarse en el sistema de generación de energía del país. Los problemas analizados son· la elección del tipo de reactor desde el punto de vista económico, la utilización de materias primas nucleares nacionales y la aportación óptima del potencial científico, técnico e industrial del país a la realización de un programa nuclear. Los análisis se centran en los valores de competencia y en la estructura óptima de las centrales nucleares que hayan de satisfacer la demanda en la parte noroeste de Yugoslavia. Se consideran numerosas variantes del programa con el fin de seleccionar las instalaciones óptimas según la demanda de energía y según la necesidad de dejar un margen razonable, habida cuenta de las variaciones de la producción de las centrales hidráulicas.

1. INTRODUCTION

Nous nous proposons d'examiner dans ce mémoire les problèmes liés à l'intégration des centrales nucléaires dans le réseau de production d'énergie électrique en Yougoslavie. Nous passerons en revue les travaux effectués et les progrès accomplis et décrirons l'évolution qui s'est produite depuis le moment où a été envisagée pour la première fois la possibilité d'installer des centrales nucléaires en Yougoslavie jusqu'au jour où on s'est mis à en étudier les aspects économiques et à procéder à des travaux préparatoires en vue de la construction de la première centrale nucléaire.

Les études préliminaires (1963/1964) ont porté sur les conditions générales et la validité d'une telle intégration. Elles avaient pour objectif l'examen de tout un complexe de questions ayant trait à l'élaboration et au développement d'un programme à long terme de production d'énergie nucléaire. Ce n'est qu'après des études détaillées et des analyses d'investissement qu'on a conclu à la nécessité de construire une centrale nucléaire d'environ 600 MW(e) dans la région nord-ouest de la Yougoslavie. Il est prévu que cette centrale sera mise en marche en 1976/1977. On a appliqué lors de ces études les méthodes appropriées d'optimisation de la structure de la production dans le cadre d'un système unifié et de sous-systèmes régionaux.

2. POTENTIEL ENERGETIQUE

Les ressources énergétiques dont dispose la Yougoslavie sont consignées dans le tableau I. On y voit que le charbon (lignite) et le potentiel hydraulique représentent les ressources principales du pays; on les trouve surtout dans l'est du territoire national.

3. METHODES ADOPTEES ET DEROULEMENT DES ETUDES

Les problèmes que pose l'introduction des centrales nucléaires en Yougoslavie ont été étudiés en plusieurs phases successives. La première phase (1963-1965) correspond aux études et analyses de caractère global

TABLEAU I. RESSOURCES ENERGETIQUES EN YOUGOSLAVIE

Nature des ressources	Réserves connues		Réserves potentielles		Consommation d'énergie primaire en 1970	
	(10^{12} kcal)	(%)	(10^{12} kcal)	(%)	(10^{12} kcal)	(%)
Charbon (lignite)	40 144	85,0	8 276	49,0	96,0	51,5
Pétrole brut	485	1,0	1 915	11,4	66,7	36,0
Gaz naturel	396	0,8	184	1,1	10,0	5,4
Schistes bitumineux	-	-	1 280	7,5	-	-
Energie hydraulique	5 480	11,2	1 720	10,0	13,3	7,1
Combustible nucléaire	1 031	2,0	3 600	21,0	-	-
Total	47 536	100	16 975	100	186,0	100

et préliminaire effectuées dans le cadre d'un projet à long terme, et dont les conclusions n'avaient qu'une valeur indicative. Pourtant, ces projets présentaient un certain intérêt en raison des conclusions qu'on a pu dégager en ce qui concerne le rôle que la première centrale nucléaire pourrait être appelée à jouer. En prenant comme base de calcul une puissance de 500 MW(e) environ on a établi le facteur de charge annuel durant toute la vie de la centrale. Les constatations faites ont justifié la phase suivante (1965-1968), où les études ont été plus étendues et plus approfondies. A cette occasion on a appliqué avec succès les nouvelles méthodes d'optimisation du système. C'est par des analyses comparatives de caractère économique qu'on a déterminé les dimensions et la cadence de construction des centrales hydrauliques, thermiques et nucléaires. En faisant appel à plusieurs variantes du programme de développement nucléaire à long terme on a pu mettre en évidence les avantages de différentes filières de réacteurs de puissance, leurs conditions optimales d'utilisation du point de vue technico-économique et énergétique, et les répercussions de leur intégration dans l'ensemble du réseau yougoslave par tranches successives jusqu'en 1985. C'est par une série d'analyses paramétriques qu'on a examiné dans quelle mesure les résultats sont influencés par la variabilité des données d'entrée (investissements, coûts du combustible et du retraitement, taux d'actualisation, etc.).

Au cours de la troisième phase (1968-1970), l'attention s'est portée sur l'application de deux nouvelles méthodes d'optimisation. Il s'agissait cette fois de l'étude des conditions d'implantation des centrales nucléaires dans des régions déterminées, étude qui a été poursuivie dans l'optique de l'introduction des centrales dans les régions nord-ouest et sud, déficientes en énergie. Les entreprises de production d'électricité, elles aussi, ont commencé leurs études; elles ont abordé entre autres questions celle des investissements à prévoir pour les premières centrales nucléaires.

La quatrième phase est en cours. L'effort se concentre à l'heure actuelle sur la mise au point de l'appel d'offre et autres travaux préliminaires. On prévoit de construire la première centrale nucléaire dans la région nord-ouest (Républiques socialistes de Croatie et de Slovénie).

La cinquième phase sera consacrée à la construction proprement dite; la mise en service de la centrale est prévue pour 1976/1977.

4. ESTIMATIONS PRELIMINAIRES CONCERNANT LA PRODUCTION D'ENERGIE D'ORIGINE NUCLEAIRE – CHOIX DE LA FILIERE

Lorsqu'on aborde l'étude du développement de l'énergie d'origine nucléaire à long terme, le problème sur lequel il faut se pencher d'emblée est celui de l'utilisation efficace des matières premières nucléaires domestiques. On a analysé, pour la période s'étendant de 1975 à 2000, la consommation cumulative de matières premières et les coûts de revient

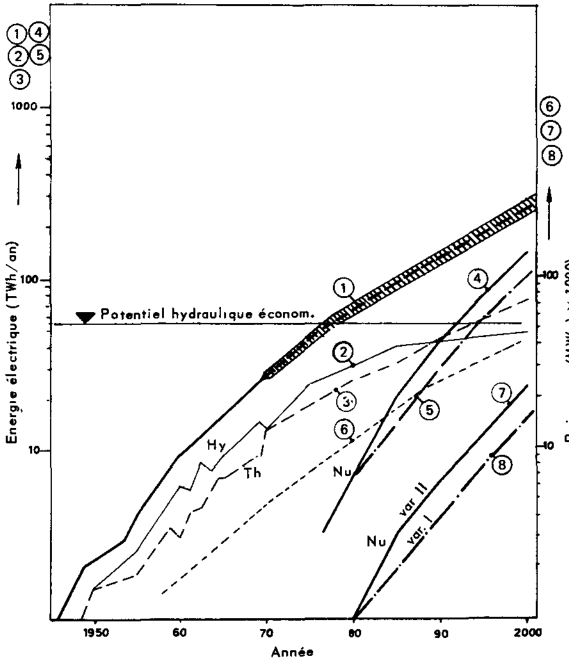

FIG. 1. Evolution probable de la consommation, de la production et des puissances disponibles en Yougoslavie.

1 – Consommation totale d'énergie électrique.
2 – Production des centrales hydrauliques.
3 – Production des centrales thermiques.
4 – Production des centrales nucléaires (var. II).
5 – Production des centrales nucléaires (var. I).
6 – Charge de pointe.
7 – Puissance disponible des centrales nucléaires (var. II).
8 – Puissance disponible des centrales nucléaires (var. I).

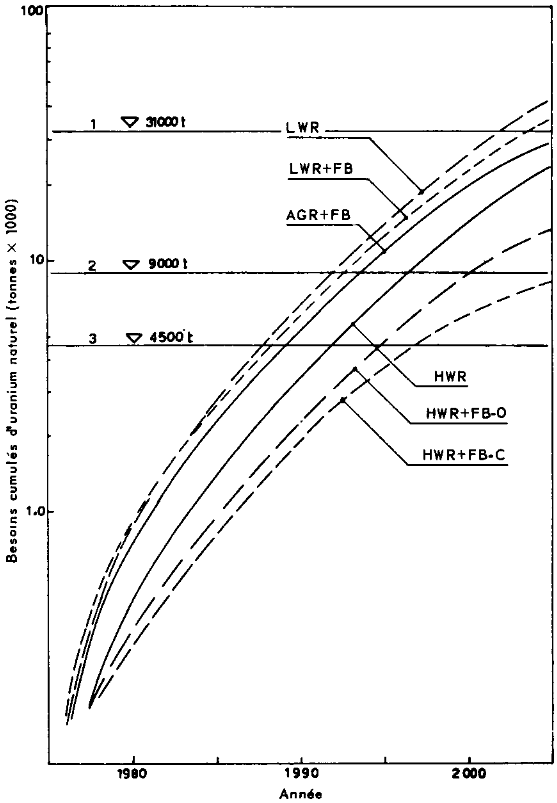

FIG.2. Demande cumulée d'uranium naturel pour diverses stratégies: LWR, HWR, LWR+FB, AGR+FB, HWR+FB-O, HWR+FB-C.
1 — Réserves potentielles d'uranium.
2 — Réserves connues d'uranium.
3 — Réserves d'uranium à un prix inférieur à 10 $EU/lb.

de l'énergie électrique pour différents types de réacteurs, en supposant, soit que l'on ferait appel à des réacteurs du même type pour toutes les centrales, soit que l'on combinerait différents types de réacteurs dans l'ensemble du système [1, 2].

Ce n'est qu'après avoir évalué l'évolution de la demande et analysé les possibilités de construire des centrales conventionnelles qu'on a pu définir la production qui pourra être attendue des centrales nucléaires. La figure 1 présente les courbes de production et de puissance des centrales conventionnelles et nucléaires. Etant donné qu'il s'agissait surtout de l'analyse comparative de certaines options techniques, ces études avaient pour objectif la détermination des effets matériels et macroéconomiques réciproques. L'hypothèse initiale reposait alors sur la variante I du programme nucléaire (voir fig. 1, courbes 5 et 8).

Six différentes «stratégies» ont été étudiées: programmes faisant appel à des réacteurs d'un seul type: a) réacteurs à eau légère (LWR),

b) à eau lourde (HWR) ou c) réacteurs poussés à gaz et graphite (AGR); et programmes combinant des réacteurs de chacun de ces types à des surgénérateurs au plutonium à neutrons rapides (FB): d) LWR + FB, e) HWR + FB, f) AGR + FB.

La combinaison HWR + FB est donnée en deux variantes: l'une avec pour combustible l'oxyde $PuO_2 + UO_2$ (désignation HWR + FB—O) et l'autre avec le carbure PuC + UC (désignation HWR + FB—C). Les besoins cumulés exprimés en uranium naturel équivalent pour les six stratégies étudiées sont présentés à la figure 2, où sont également indiqués les niveaux des réserves d'uranium domestique par catégories: uranium d'un prix inférieur à 10 \$EU/lb, réserves totales selon les estimations actuelles, et réserves potentielles totales; la figure montre ainsi clairement jusqu'à quand chaque catégorie pourra suffire selon le programme choisi. On voit que la combinaison HWR + FB—C est la plus avantageuse (consommation cumulée d'uranium minimale). Mentionnons à titre d'exemple que dans le cadre d'un tel programme le premier réacteur à neutrons rapides pourrait être mis en marche en Yougoslavie en 1988. Les réacteurs de ce type pourraient atteindre une capacité de 7000 MW(e) à la fin du siècle.

Grâce aux analyses globales faites en Yougoslavie on a pu formuler assez nettement les critères et les objectifs des études détaillées à effectuer et on a pu définir les programmes de recherche d'une manière adéquate. En ce qui concerne les réserves nationales d'uranium, on a pu en évaluer l'importance réelle pour l'exploitation future.

5. CRITERES ET METHODES D'OPTIMISATION

La détermination de la contribution optimale des centrales hydrauliques, thermiques et nucléaires à la production d'énergie électrique en Yougoslavie soulève des problèmes difficiles à résoudre. Un problème particulièrement complexe est celui que posent les irrégularités des variations des débits d'eau; celles-ci sont très accentuées, ce qui provoque des oscillations relativement grandes de la productibilité des centrales hydrauliques au cours d'un mois, au cours d'une ou de plusieurs années en fonction de l'hydraulicité. Par exemple, au cours d'une année humide la productibilité augmente de 25% par rapport à l'hydraulicité moyenne. Au contraire, lors d'une année sèche la productibilité diminue de 30%.

Les oscillations mensuelles sont encore plus accentuées; elles varient au cours de l'année de ±50%. Ces variations ne concordent pas avec celles de la demande d'énergie, aussi faut-il les compenser en aménageant des centrales avec bassin d'accumulation permettant une régulation saisonnière, annuelle et pluriannuelle, puis en engageant les centrales thermiques dans l'ordre de priorité établi, puis, en dernier lieu, en imposant des restrictions à la consommation. L'application de méthodes adéquates devenant de plus en plus importante et nécessaire à mesure que se développent l'interconnexion et l'expansion du système, nous avons orienté nos efforts vers la recherche et la mise au point de telles méthodes. La solution consiste à établir un programme de construction de centrales hydrauliques, à adopter un régime de remplissage et de vidange des réservoirs et à engager les centrales thermiques de façon à maintenir au minimum le total des dépenses d'exploitation du système. Ces dépenses englobent les frais de combustible des centrales thermiques et ceux découlant des restrictions à la consommation dues à l'insuffisance des puissances disponibles ou aux défaillances de l'équipement. Réduire les interruptions de la consommation au minimum, assurer l'alimentation en énergie avec un degré de sécurité aussi élevé que possible, et maintenir les frais au minimum sont, eu égard aux conditions hydrauliques aléatoires, des exigences qui rendent fort complexe le problème de l'utilisation optimale des bassins et des autres ressources du système.

La programmation optimale – par des méthodes de simulation mathématique et la programmation linéaire à l'aide d'ordinateurs – du développement d'un grand système de production d'énergie électrique a fait ces dernières années l'objet d'études approfondies en Yougoslavie. Ces études ont été rendues particulièrement nécessaires par l'intégration envisagée des centrales nucléaires.

Compte tenu des caractéristiques de l'énergie d'origine nucléaire et du cycle du combustible, il est indispensable de faire des prévisions quant au développement de ce type d'énergie dans le cadre d'un programme à long terme. On a adopté de nouvelles méthodes scientifiques, après les avoir modifiées et adaptées aux conditions qui prévalent en Yougoslavie. Une étude détaillée portant sur la répartition optimale de la production entre les centrales nucléaires et classiques a été entreprise dans le cadre du programme de recherche de la Commission fédérale de l'énergie nucléaire. On a mis en pratique la méthode de programmation linéaire et la méthode de simulation du modèle réel du système de production, et ceci en deux étapes: la première pour le système national intégral, la deuxième pour les régions déficientes en énergie: Républiques socialistes de Slovénie, de Croatie et de Macédoine.

Les résultats obtenus devraient contribuer à l'élaboration d'un programme à long terme de recherche scientifique et technico-industrielle en Yougoslavie.

Dans la première étape l'accent a été mis sur la mise au point de méthodes destinées à l'analyse des conditions électro-énergétiques et l'établissement d'un programme optimal de construction de centrales nucléaires au fur et à mesure du développement du système. L'analyse économique comparative de plusieurs solutions, pour différentes étapes de l'expansion future du système, a donné des résultats intéressants. Bien qu'approximatifs ces résultats mettent en lumière les problèmes fondamentaux actuels et font prévoir ceux qui se présenteront au cours de l'étape suivante.

La méthode suédoise [3] de simulation a été utilisée, avec un modèle englobant 108 centrales hydrauliques (42 TWh). Cette méthode permet l'optimisation du système de centrales hydrauliques et thermiques. C'est ainsi que, en utilisant les accumulations tout en tenant compte des fluctuations du niveau au bief, en appliquant le procédé itératif de la manière la plus rationnelle et en prenant en considération les dépenses dues au préjudice encouru du fait des restrictions à la consommation, on a calculé les dépenses actualisées minimales pour le système entier. Etant donné les caractéristiques spécifiques du potentiel hydro-énergétique et l'irrégularité des débits naturels, le procédé suédois a dû être modifié; cette méthode a été mise au point avec l'assistance d'experts suédois offerte par l'AIEA à la Yougoslavie.

Le modèle mathématique de ce système est une simulation des conditions de fonctionnement réelles; il permet de déterminer la totalité des frais variables pour différentes structures de production et pour différents stades de développement du système. Toute une série de calculs relatifs à la consommation prévue et aux conditions de production pour certains intervalles de temps a été effectuée sur ordinateur (IBM, Elliot); ces calculs étaient basés sur les statistiques hydrologiques établies pour chacun des douze mois des 30 dernières années. Pour tenir compte de tous les facteurs plausibles à l'avenir on a fait varier les données des modèles, frais de combustible, rapport des puissances des centrales hydrauliques, thermiques et nucléaires, puissance disponible des centrales thermiques, mode d'utilisation des réservoirs, facteur de sécurité d'approvisionnement, préjudice découlant des restrictions à la consommation, etc. On est parvenu à une solution optimale pour chaque hypothèse de départ.

Introduisant le terme «facteur de risque» en tant que facteur décisifs pour l'optimisation, il est possible de fixer d'avance les critères de gestion optimale des réservoirs des centrales hydrauliques et de déterminer l'ordre d'engagement des centrales thermiques. Une augmentation de la valeur du facteur de risque a pour conséquence une diminution des dépenses variables des centrales thermiques et une augmentation des frais liés aux réductions de la consommation. Les calculs ont démontré que ces méthodes, par rapport aux autres méthodes utilisées jusqu'à présent, permettent de réduire de 8 à 12% les frais annuels variables dans le système.

Les résultats obtenus se rapportent au système entier; les régions ne sont pas considérées individuellement et les sites où seraient construites les centrales nucléaires ne sont pas précisés. L'objectif de ces études était surtout de démontrer que les centrales nucléaires pourraient devenir compétitives dans un proche avenir et de jeter les bases des programmes d'étude ultérieurs.

L'étape suivante a été consacrée à l'analyse des ressources et des besoins énergétiques de régions déterminées. Toute une série d'analyses a été faite concernant les sites choisis, en s'appuyant sur les offres préliminaires d'équipement pour les centrales nucléaires.

6. PREVISIONS CONCERNANT L'ACCROISSEMENT DE LA PRODUCTION ET DE LA CONSOMMATION D'ENERGIE ELECTRIQUE

De nombreux organismes participent à l'analyse prospective de la consommation d'énergie électrique en Yougoslavie. Ce sont les instituts de recherche, les instituts de la Fédération et des Républiques socialistes pour la planification, les entreprises d'électricité et les bureaux d'étude.

Quinze études englobant 50 conceptions différentes ont été conduites par ces organismes. Les différentes méthodes utilisées, les divers modèles et leurs nombreuses variantes ont permis d'obtenir toute une gamme de pronostics dont la moyenne représentera probablement la consommation d'énergie électrique jusqu'à l'an 2000. Les valeurs estimées de la consommation totale (voir bande le long de la courbe 1, figure 1) sont prises comme base pour de nombreux calculs et analyses de la structure de la production, de la cadence d'expansion des puissances installées de différents types de centrales, des charges maximales dans le système, etc.

TABLEAU II. DEVELOPPEMENT PREVU DE LA PRODUCTION D'ENERGIE ELECTRIQUE EN YOUGOSLAVIE

Année	Production totale (TWh)	Production des centrales			Production des centrales nucléaires (% de la production totale)
		hydrauliques	thermiques	nucléaires	
1970	26,5	13,6	12,9	-	-
1975	44	24,5	19,5	-	-
1980	65	31,5	26,8	6,7	10,4
1985	92	40,0	32,0	20,0	21,7
1990	130	43,5	44,0	42,5	32,7
1995	180	45,0	58,0	77,0	42,5
2000	260	48,0	72,0	140,0	54,0

Il en ressort que la consommation spécifique serait:

en 1975 de 2000 kWh par habitant
en 1980 de 2850 kWh par habitant
en 1990 de 5200 kWh par habitant
en 2000 de 9600 kWh par habitant

ce qui peut être considéré comme raisonnable et réaliste compte tenu des prévisions concernant le développement économique du pays.[1]

La figure 1 donne les courbes de puissance, de production, de charge de pointe, etc., qui se dégagent de ces études. En ce qui concerne la taille et la cadence de construction des centrales nucléaires, différentes méthodes d'évaluation ont conduit à deux variantes: la première, comportant un programme de construction modeste, est représentée par les courbes 5 et 8 (var.I), l'autre, qui correspond à un programme plus large, est donnée par les courbes 4 et 7 (var.II). La puissance installée des centrales nucléaires selon la variante I présente un décalage d'environ deux ans par rapport à la variante II. Bien que ces deux variantes doivent être considérées comme des approximations, les pronostics établis constituent une base suffisamment solide pour une analyse complète de leurs effets sur les plans énergétique, économique et technique [4, 5].

On trouvera au tableau II les données numériques de la variante II qui sont à la base des analyses et calculs.

C'est surtout la structure de la production qui changera à l'avenir, ce qui se traduira par une diminution de la contribution de l'énergie hydraulique (52% en 1970, 18,5% à la fin du siècle), tandis que celle des centrales thermiques et nucléaires ira en augmentant. Une telle contribution des ressources thermiques et nucléaires à la production totale permettra d'augmenter la sécurité d'alimentation, de mieux compenser les effets

[1] On prévoit que le revenu national brut par habitant en 1985 atteindra $EU 2000 (selon le pouvoir d'achat réel en Yougoslavie). Les estimations pour la fin du siècle indiquent un montant de $EU 3400 à 3800 par habitant.

des irrégularités de la production hydraulique et d'améliorer le fonctionnement du système. D'autre part, entre 1970 et 2000, la mise en valeur du potentiel hydraulique devra reposer sur la promotion des centrales à grands bassins d'accumulation de façon que l'énergie que représentent les bassins par rapport à la production hydraulique totale passe des 15% actuels à la limite possible de 29%. Les centrales à accumulation par pompage (~2500 MW(e)) gagneront elles aussi en importance.

7. COMPETITIVITE DES CENTRALES NUCLEAIRES DANS LE CADRE DU PROGRAMME DE 12 000 MW(e)

Les analyses ont montré qu'on peut s'attendre à un coefficient élevé d'utilisation annuelle de la capacité installée (de 6700 à 5500 h/an) pour la première centrale nucléaire de 500 MW(e) ainsi que pour les suivantes. Une analyse a été faite de la possibilité d'installer des centrales nucléaires d'une capacité totale de 12 000 MW(e), dont la construction s'étendrait sur une période de 20 ans [6]. Les effets économiques ont été calculés en prenant pour base les valeurs actualisées pour une durée de vie des centrales de 25 ans et un taux d'actualisation de 6,5%, pour différentes options techniques: pour des centrales thermiques seules (Th), pour des réacteurs du type HWR, ou pour des réacteurs du type LWR, le programme de production étant le même. Ces calculs ont montré que les dépenses totales actualisées pour le programme de 12 000 MW(e) en % correspondraient pour les réacteurs du type HWR à 85%, et pour ceux du type LWR à 90% des dépenses actualisées afférentes aux centrales thermiques seules.

Si on prend en considération les frais de transport de l'énergie électrique des centrales thermiques jusqu'aux centres de consommation, qui s'élèveraient à environ 1 p/kWh [2], ces valeurs seraient ramenées à 75% pour les réacteurs HWR et 78% pour les réacteurs LWR.

Ainsi, dans les conditions actuelles les centrales nucléaires sont particulièrement avantageuses par rapport aux centrales thermiques lorsque les régions de consommation se trouvent éloignées des sources thermiques. En Yougoslavie, ces distances sont de l'ordre de 300 à 600 km.

Les analyses montrent donc que dans le cas d'un large programme la stratégie «à l'eau lourde» (HWR) présente un léger avantage du point de vue économique par rapport à celle «à l'eau légère» (LWR). Les dépenses afférentes au programme LWR sont de 5 à 6% supérieures à celles afférentes au programme HWR. Dans le cas d'un programme plus restreint cet avantage des HWR se manifeste par une économie de 2 à 3% sur les dépenses actualisées totales par rapport aux LWR. Cependant, lorsque intervient le transport d'énergie les centrales nucléaires (de n'importe quel type) offrent un avantage significatif par rapport aux centrales thermiques puisque les dépenses sont inférieures de 28 à 32%. Les résultats sont consignés dans le tableau III.

En ce qui concerne les dépenses en devises, elles sont pour les HWR de 24 à 45% et pour les LWR de 31 à 53% des dépenses totales selon le mode de valorisation du plutonium et d'approvisionnement en uranium et en eau lourde.

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[2] 1 p (para) = 0,01 dinar.

TABLEAU III. COUTS DE PRODUCTION MOYENS DU kWh (p/kWh)[a] (actualisation du programme de 12 000 MW(e))

	BWR	PWR	HWR
Données de référence	5,77	5,89	5,57
En cas d'augmentation des coûts spécifiques d'investissement de 10%	6,10	6,23	5,98

[a] 1 p (para) = 0,01 dinar.

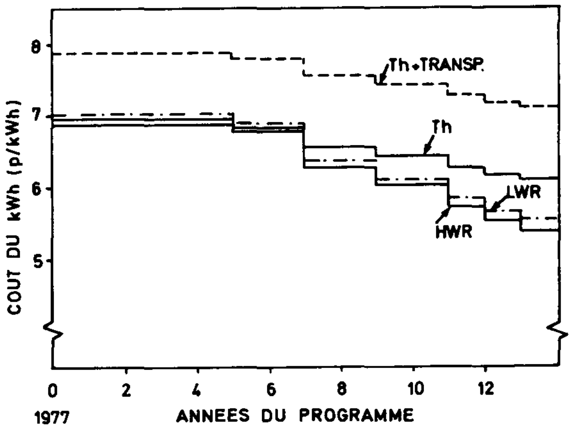

FIG.3. Coût moyen du kWh pour différentes options du programme.

A titre d'illustration la figure 3 présente les coûts moyens actualisés pour différentes options.

Ces résultats assez disparates et surtout leurs limites de précision montrent bien qu'il n'est pas facile de se décider pour une filière uniquement sur la base des paramètres économiques des premières centrales, et encore moins à partir d'évaluations à très longue portée. La possibilité d'assurer l'autonomie du cycle de combustible, par exemple, ou la fiabilité des types éprouvés et d'autres facteurs encore peuvent être décisifs dans des cas concrets et conditionner le choix de l'un ou l'autre type de réacteur. En Yougoslavie, où persiste une pénurie de capital d'investissement, surtout dans les entreprises d'électricité en raison de la dépression des prix, le coût spécifique d'investissement de la centrale pèse lourdement sur la balance. En conséquence, les constatations faites pourraient être modifiées, la dynamique du programme nucléaire pourrait même être ralentie, sous l'influence de facteurs reflétant des intérêts sociaux, politiques, financiers, etc., et notamment de ceux que peuvent affecter l'incertitude de l'avenir. Dans ces circonstances on s'inspire plutôt de raisonnements pragmatiques.

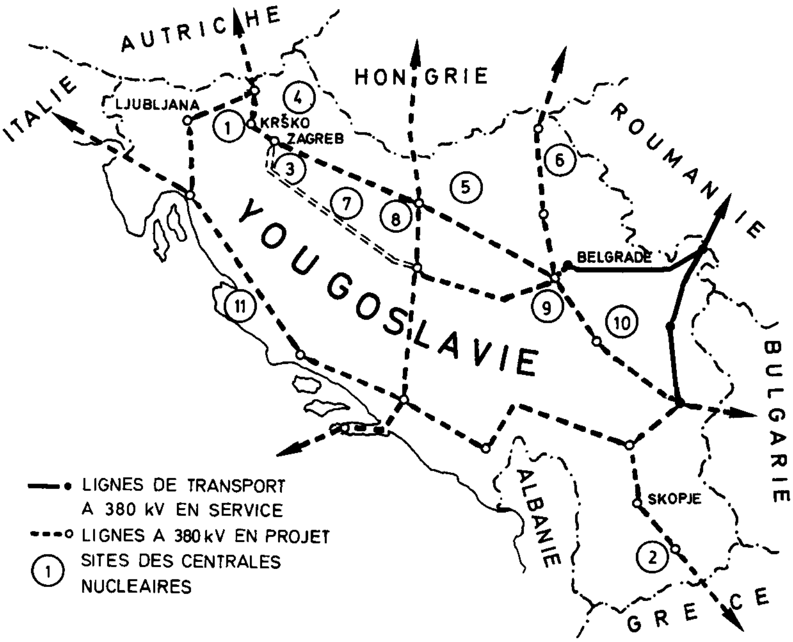

FIG.4. Réseau d'interconnexion à 380 kV en Yougoslavie (en 1985).

8. CONFIGURATION DU RESEAU D'INTERCONNEXION ET SITES DES CENTRALES NUCLEAIRES

Le système actuel de transport à 110 kV (8500 km) et 220 kV (3500 km) reliant le pays entier ne répond pas par sa configuration et ses capacités de transport aux besoins de la production et de la consommation. En raison du manque de lignes à plus haute tension ou de retards dans leur construction le fonctionnement optimal du système n'est atteint qu'avec difficulté. La première ligne de 380 kV (280 km) a été ouverte en 1970; elle relie la centrale hydraulique du Danube (Portes de fer) à Belgrade.

Les lignes électriques principales de 380 kV du réseau interconnecté dont la construction est prévue[3] sont indiquées sur la figure 4, de même que les onze sites envisagés pour les centrales nucléaires, lesquels se trouveront en général dans les régions déficientes en énergie du nord-ouest, du nord et du sud-est. Cette répartition des centrales nucléaires aura sans doute une influence sur les mouvements d'énergie et sur la configuration et les dimensions du réseau. Il a été montré par exemple [7] qu'une puissance nucléaire de 1000 MW(e) installée dans la région ouest du pays pourrait conduire à des économies sur les investissements dans les réseaux de 300 din/kW par rapport à la solution sans centrales nucléaires.

[3] On envisage de construire d'ici à 1985 au total 2700 km de lignes à 380 kV, ce qui exigera des investissements de 200 millions de dollars.

On a aussi envisagé de relier le réseau de 380 kV à ceux des pays voisins de sorte que le système yougoslave soit connecté avec les systèmes CAEM[4], UCPT et SUDEL, ce qui permettrait l'interconnexion de ces systèmes internationaux par l'intermédiaire du réseau yougoslave.

9. TAILLE DES CENTRALES NUCLEAIRES

Le territoire de la Yougoslavie a été étudié en vue de choisir l'emplacement des futures centrales nucléaires [8]. A partir de critères déterminés on a choisi et classé les sites comme suit (voir la figure 4, où les sites sont numérotés dans l'ordre de priorité):

Priorité 1: sites sur la Sava (n° 1), sur le Vardar (n° 2), sur la Sava, en aval de Zagreb (n° 3).
Priorité 2: sites sur la Drava (n° 4), sur le Danube (n° 5), sur la Tisa (n° 6), sur la Sava, en amont de Slavonski Brod (n° 7 et n° 8).
Priorité 3: sites sur la Sava (n° 9), sur la Morava (n° 10), sur la Côte adriatique (n° 11).

Les emplacements situés dans les régions nord-ouest, nord et sud-est du pays sont d'un intérêt préférentiel. Cependant, la plupart d'entre eux se trouve dans la zone à séismicité élevée (degrés VIII et IX de l'échelle Mercalli). Il faudrait donc appliquer des méthodes de construction aséismique. Les sites énumérés ne sont retenus qu'à titre indicatif; à l'exception des emplacements n°1 et n°2, ils ne sont pas examinés en détail ou sous l'angle de la demande actuelle.

Le site n° 1 a été étudié dans le détail et désigné pour la première centrale nucléaire de 600 MW(e).

Le site n° 2, Krivolak, en Macédoine, a aussi été étudié; il a été retenu pour une centrale nucléaire dans cette région.

10. IMPLANTATION DES CENTRALES CONVENTIONNELLES ET NUCLEAIRES DANS LA REGION NORD-OUEST — STRUCTURE OPTIMALE

La région nord-ouest de la Yougoslavie, qui comprend la République socialiste de Slovénie et la partie nord de la République socialiste de Croatie, est caractérisée par un degré élevé d'électrification et une forte consommation traduisant un développement intense de l'économie. D'autre part, les ressources énergétiques conventionnelles — surtout hydrauliques — de cette région seront bientôt épuisées dans la mesure où elles peuvent être exploitées économiquement. C'est pourquoi on compte sur l'importation d'énergie des autres régions et sur l'implantation de centrales à combustible nucléaire ou liquide (fuel). En appliquant les méthodes déjà employées pour l'optimisation du système électrique entier (méthode suédo-yougoslave et programmation linéaire) on a analysé les moyens qui pourraient permettre d'assurer l'alimentation en énergie des utilisateurs de cette région.

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[4] Conseil d'assistance économique mutuelle.

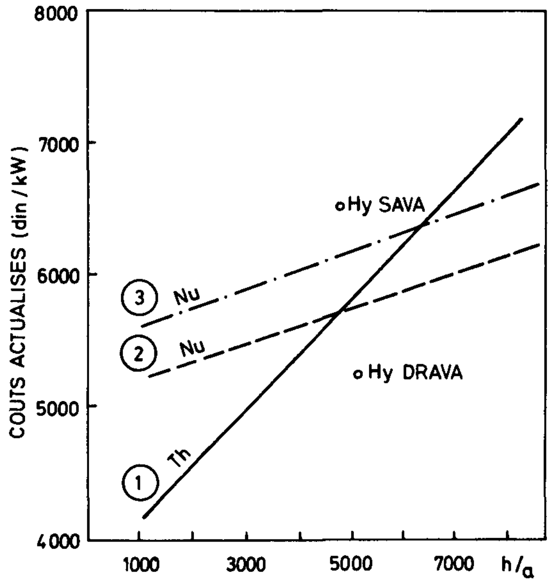

FIG. 5. Coût actualisé par unité de puissance.
1 — Centrale thermique de 300 MW(e).
2 — Centrale nucléaire de 2× 250 MW(e).
3 — Centrale nucléaire de 340 MW(e).
Hy Sava — Centrale hydraulique sur la Sava, de 187 MW(e).
Hy Drava — Centrale hydraulique sur la Drava, de 104 MW(e).

Les méthodes ont été appliquées et vérifiées indépendamment l'une de l'autre; les résultats obtenus ont ensuite été comparés [9, 10].

Les études avaient pour premier objectif de déterminer la taille optimale de la première centrale nucléaire, d'établir dans quelle mesure elle pourrait contribuer à couvrir la charge de base, et à vérifier qu'elle pourra être intégrée au réseau de la région sans en compromettre le fonctionnement. La consommation totale en 1985 dans cette région est évaluée à 33,14 TWh (8,9 TWh étant l'énergie de pointe). Il s'ensuit qu'il serait justifié de construire dans cette région des centrales nucléaires d'une puissance totale de 1200 MW(e) en 1978 et de 3800 MW(e) en 1985.

On a procédé également sous un autre angle à une étude régionale approfondie [11] de l'optimisation du système, limitée cette fois-ci à la République socialiste de Slovénie. Cette analyse a porté sur 13 combinaisons différentes de centrales classiques et nucléaires. La variante la plus adéquate prévoit la construction d'un ensemble de centrales comprenant deux centrales nucléaires (340 + 2 × 250 MW(e)), une centrale thermique de 300 MW(e) et trois centrales hydrauliques d'une puissance totale de 160 MW(e). La figure 5 présente à titre d'illustration les coûts spécifiques actualisés par kW installé.

Partant de ces études les entreprises d'électricité ont élaboré les avant-projets d'une centrale de 600 MW(e) qui serait installée sur la Sava (site n° 1, fig. 4) entre les villes de Zagreb et de Ljubljana.

Aux termes d'un accord entre les gouvernements des Républiques de Croatie et de Slovénie (signé le 27 octobre 1970) les entreprises d'électricité des deux régions sont invitées à se charger ensemble de la construction de ladite centrale. On prévoit que l'appel d'offre pour la fourniture de la centrale et de son équipement sera mis au point avant la fin de l'année 1971.

11. PROJET DE CENTRALE NUCLEAIRE DANS LA REGION SUD-EST

L'avant-projet de la centrale nucléaire de 300 MW(e) qui serait construite sur l'emplacement de Krivolak, au sud de la ville Skopje, dans la République socialiste de Macédoine, a également été élaboré. Les études se poursuivent à l'heure actuelle.

12. PARTICIPATION YOUGOSLAVE A L'ERECTION DES CENTRALES NUCLEAIRES

Il est évident que la première centrale nucléaire de Yougoslavie devrait être d'un type éprouvé. Bien que la majeure partie de l'équipement doive être assurée par des fournisseurs étrangers, l'industrie et les bureaux d'étude et de génie civil yougoslaves participeront eux aussi à la réalisation de l'œuvre. Les évaluations ont montré que la participation nationale dans la réalisation entière pourrait être de 45 à 55% du total. Les chercheurs des instituts nucléaires, les ingénieurs des compagnies industrielles seront appelés à remplir de nombreuses tâches telles que, par exemple, l'élaboration des programmes d'investissement et des avant-projets, les analyses de sûreté, le choix des sites, l'établissement de l'appel d'offre, l'évaluation des offres; ils participeront aussi à des activités telles que la réception des éléments combustibles, la mise en marche, l'exploitation optimale du cycle de combustible, etc. Il est d'une importance non négligeable que les universités et les centres nucléaires soient capables de former le personnel nécessaire à l'exploitation des centrales nucléaires.

Il existe en Yougoslavie des groupes de chercheurs et de technologues compétents qui seraient en mesure, le moment venu, de mettre au point avec leurs partenaires étrangers la production des éléments combustibles [12].

La construction de la première centrale et des centrales suivantes fournira à la Yougoslavie l'occasion de se familiariser avec la nouvelle technologie et d'en acquérir la maîtrise, et de mettre ainsi en valeur son potentiel intellectuel et technique.

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СОЮЗ СОВЕТСКИХ СОЦИАЛИСТИЧЕСКИХ
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ПЕРСПЕКТИВЫ РАЗВИТИЯ ЯДЕРНОЙ ЭНЕРГЕТИКИ СССР

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Abstract–Résumé–Аннотация–Resumen

PROSPECTS FOR NUCLEAR POWER IN THE USSR.

Having completed its experimental stage, the Soviet nuclear power industry has now proceeded to the construction of large atomic power stations whose technical and economic characteristics are not inferior to those of modern condensation coal-fired plants. The paper reports some achievements in the construction and operation of atomic power stations in the USSR. Among the numerous types of thermal reactors available for atomic power plants, those which have proved most suitable for use under Soviet conditions and which constitute the basis of the Soviet nuclear power program in the immediate future are vessel-type pressurized-water reactors and channel-type uranium-graphite boiling-water reactors. At the same time extensive technological development work on fast reactors is being pursued. As the technical problems are solved and experience is gained in operating these reactors it is planned to construct large fast reactors associated with thermal reactors in proportions governed by the conditions of breeding and by the circulation of the fuel in the nuclear power fuel cycle. Scientific and technical progress in the development of atomic power stations is taking the form of an increase in the capacity of units and of their initial parameters, enhanced reliability, an improvement in the fuel-utilization and regeneration factors and the unification and standardization of basic plant assemblies. Finally, the paper considers some promising reactor types, their unit capacities, prospective characteristics and fuel availability.

LES PROGRES DE L'INDUSTRIE NUCLEO-ELECTRIQUE EN UNION SOVIETIQUE.

En Union soviétique, l'industrie nucléaire a dépassé le stade des travaux expérimentaux et s'est lancée dans la construction de grandes centrales qui du point de vue technique et économique ne le cèdent en rien aux centrales modernes au charbon. Les auteurs exposent quelques résultats obtenus dans la construction et l'exploitation des centrales nucléaires en Union soviétique. Parmi les nombreux types de réacteurs a neutrons thermiques (lents), on considère comme particulièrement utile au progrès de l'industrie nucléo-électrique en Union soviétique la mise en service de filières à eau légère sous pression et les réacteurs du type canal à uranium-graphite, refroidis à l'eau bouillante. En même temps, on poursuit activement l'étude des réacteurs à neutrons rapides. A mesure que les problèmes techniques trouveront des solutions satisfaisantes et que s'accumuleront les connaissances nécessaires pour l'exploitation de ces réacteurs, on envisage de construire des réacteurs à neutrons rapides de grande puissance en même temps que des réacteurs à neutrons thermiques, dans une proportion qui sera déterminée par les conditions de régénération du combustible nucléaire secondaire et par la circulation du combustible nucléaire dans le cycle du combustible de l'industrie nucléo-électrique. Dans l'étude des centrales nucléaires, le progrès scientifique et technique prend les formes suivantes: augmentation de la puissance des installations; accroissement de leurs paramètres initiaux; meilleure régénération du combustible; unification et normalisation des principaux éléments de l'équipement. Les auteurs examinent les filières qui offrent le plus d'intérêt, leur puissance et leurs performances possibles et leur approvisionnement en combustible nucléaire.

ПЕРСПЕКТИВЫ РАЗВИТИЯ ЯДЕРНОЙ ЭНЕРГЕТИКИ СССР.

Ядерная энергетика СССР, пройдя стадию экспериментальных работ, вступила на путь сооружения крупных атомных электростанций, по технико-экономическим показателям не уступающим современным конденсационным электростанциям, работающим на углях шахтной добычи. В докладе приводятся некоторые итоги строительства и эксплуатации атомных электростанций в СССР. Среди многих типов реакторов на тепловых (медленных) нейтронах для атомных электростанций в условиях СССР оказались эффективными и стали основой для развития ядерной энергетики СССР на ближайший период корпусные реакторы с обычной водой под давлением и канальные уран-графитовые реакторы с водяным кипящим теплоносителем. В то же время ведется широкая техническая отработка реакторов на быстрых нейтронах. По мере достижения удовлетворительных технических решений и накопления опыта эксплуатации этих реакторов предполагается строительство мощных энергетических реакторов на быстрых нейтронах в сочетании с реакторами на тепловых нейтронах в пропорциях, определяемых условиями воспроизводства вторичного ядерного горючего и циркуляцией ядерного горючего в топливном цикле ядерной энергетики. Научно-технический прогресс в развитии атомных электростанций осуществляется в направлении укрупнения мощностей агрегатов, повышения их начальных параметров, надежности, увеличения коэффициента использования горючего, его регенерации, унификации и стандартизации основных узлов оборудования. В докладе рассматриваются перспективные типы реакторов, их единичные мощности и возможные характеристики, обеспеченность ядерным топливом.

PERSPECTIVAS DE LA ENERGIA NUCLEOELECTRICA EN LA URSS.

La industria nucleoeléctrica en la URSS, superada ya la etapa experimental, se ha lanzado a la construcción de grandes centrales eléctricas atómicas que, desde el punto de vista técnico y económico, no son inferiores a las actuales centrales eléctricas de condensación alimentadas con carbón. En la memoria se exponen algunos resultados a que han conducido la construcción y explotación de las centrales eléctricas atómicas en la URSS. Entre muchos tipos de reactores térmicos (neutrones lentos) para centrales eléctricas, han resultado eficaces, en las condiciones de la URSS, y han pasado a constituir la base para el desarrollo de la energía nuclear en este país para el próximo período los reactores de vasija refrigerados por agua natural a presión y los reactores de tipo acanalado, de uranio-grafito, refrigerados por agua en ebullición. Al mismo tiempo, tiene lugar un amplio desarrollo técnico de los reactores rápidos. A medida que se va consiguiendo resolver satisfactoriamente los problemas técnicos y se va adquiriendo experiencia en la explotación de estos reactores, se proyecta la construcción de grandes reactores rápidos de potencia, junto con reactores térmicos, en una proporción que viene determinada por las condiciones de regeneración del combustible nuclear secundario y de la circulación del combustible nuclear dentro del ciclo de combustible de la industria nucleoeléctrica. El progreso técnico-científico en el desarrollo de las centrales eléctricas atómicas se encamina en la dirección de aumentar la potencia de las plantas, sus parámetros iniciales y la seguridad de funcionamiento, aumentar el coeficiente de utilización del combustible y su regeneración y unificar y normalizar las componentes principales de la instalación. En la memoria se consideran los tipos más prometedores de reactores, sus potencias individuales y posibles características, así como su abastecimiento con el combustible nuclear disponible.

ВВЕДЕНИЕ

IV Международная конференция ООН по использованию атомной энергии в мирных целях проводится в условиях, когда в ряде стран мира уже действуют крупные промышленные атомные электростанции и развернулось их широкое строительство. Прошедшие 7 лет после III Конференции были годами интенсивного и успешного экономического утверждения ядерной энергетики как нового источника производства электроэнергии. Можно считать, что 60-е годы в основном были периодом поисков наилучших типов реакторов и их отработки в условиях промышленной эксплуатации. Начался период использования АЭС, основанных на сравнительно ограниченном числе типов и модификаций тепловых реакторов (до 2-3 в стране).

Масштабы строительства, планы и прогнозы развития АЭС во многих странах свидетельствуют о все возрастающей, а для некоторых стран решающей роли ядерной энергетики уже в ближайшем будущем. Ядерная энергетика формируется в крупную отрасль энергетического производства [1].

Результативность и экономический эффект использования АЭС можно оценить уже на основе реальной энерговыработки промышленного масштаба. Полезный эффект от внедрения АЭС, очевидно, будет возрастать.

Не менее значимой является моральная сторона дела: успехи ядерной энергетики свидетельствуют о том, что атомная энергия – важное открытие нашей эпохи – может и должна быть широко использована в мирных целях на благо человечества.

ФАКТОРЫ, ОПРЕДЕЛЯЮЩИЕ ПОДХОД К РАЗВИТИЮ ЯДЕРНОЙ ЭНЕРГЕТИКИ СССР

Советский Союз относится к числу стран, хорошо обеспеченных природными энергетическими ресурсами. За последние годы были открыты новые большие запасы угля, нефти, газа. Интенсивно развивается топливно-энергетическая база. Производство электроэнергии ежегодно увеличивается на 7-8% и в 1970 году составило 740 млрд. кВт-ч. Мощность всех электростанций страны достигла к настоящему времени 170 млн. кВт.

Строятся экономичные тепловые электростанции мощностью 1200, 2400 и 3600 МВт. Они оснащаются энергоблоками 200, 300, 500 и 800 МВт, в том числе и на сверхкритических параметрах пара. Развиваются электросети напряжением 400, 500 и 750 кВ. Освоена передача постоянного тока при напряжении 800 кВ. Ведутся работы по созданию и освоению электропередачи напряжением 1000-1200 кВ переменного и 1500 кВ постоянного тока.

Запасы органического топлива в нашей стране позволяют решить задачу дальнейшего развития энергетических мощностей на основе классической энергетики. Однако в СССР наблюдается некоторое несоответствие между размещением экономичных энергетических ресурсов и потребителей энергии.

Огромным потенциалом топлива и энергии и исключительно благоприятными технико-экономическими показателями использования энергоресурсов располагают восточные районы страны. Велики энергетические ресурсы Казахстана, Сибири и Средней Азии.

Промышленность Европейской части СССР и Урала, имеющая материально-техническую базу, трудовые ресурсы и необходимое сырье, вместе с тем испытывает возрастающий дефицит экономичных топливно-энергетических ресурсов.

Таким образом, вопрос о масштабах и темпе роста мощностей ядерной энергетики в энергоснабжении нашей страны является экономическим вопросом и решается, в первую очередь, для Европейской части страны.

За последние годы проведен ряд расчетов применительно к изменившимся экономическим условиям и выполнены многие научно-исследовательские и проектно-конструкторские работы по усовершенствованию принятых к строительству в СССР типов реакторов для атомных электростанций (АЭС). Из этих работ видно, что экономические показатели, которые могут быть получены на АЭС в новых условиях, могут соответствовать требованиям экономичности.

АТОМНЫЕ ЭЛЕКТРОСТАНЦИИ СССР

После пуска первой в мире атомной электростанции в Обнинске, в Советском Союзе велись разработки крупных атомных электростанций, в максимальной степени безопасных и экономически эффективных, со сроком службы порядка 25-30 лет. Целью этих разработок была подготовка к созданию системы атомных электростанций, состоящей из АЭС первого этапа (с реакторами на тепловых нейтронах), обеспечивающих выработку электроэнергии на территории Европейской части СССР с меньшими затратами, чем на электростанциях с обычным топливом.

Эти АЭС, кроме выработки электроэнергии, создают топливную базу для ввода в действие в дальнейшем атомных электростанций второго этапа развития, а именно – с реакторами на быстрых нейтронах. Реакторы второго этапа должны обладать таким коэффициентом воспроизводства, который обеспечит необходимый для нашей страны темп роста для ядерной топливной базы создаваемых в последующее время быстрых реакторов, на которых может быть создана энергетика любого необходимого масштаба.

В ходе этих работ в Советском Союзе строились с целью накопления крупномасштабного инженерного опыта промышленные атомные электростанции различных типов как на тепловых, так и на быстрых нейтронах. Их проектирование, строительство и эксплуатация дали возможность накопить большой опыт, подготовить кадры и приступить к развертыванию атомного машиностроения, а также разработать проекты и приступить к строительству атомных электростанций крупного масштаба на тепловых нейтронах, входящих в систему АЭС первого этапа.

Благоприятная ситуация с обычным топливом в нашей стране (развертывание добычи открытым способом очень дешевых углей в Казахстане – Экибастузский угольный бассейн, открытие крупных нефтяных и газовых месторождений в Западной Сибири, использование мощных гидроэнергетических ресурсов) позволила вести в СССР работы по развитию атомной энергетики в спокойном темпе, без неоправданных затрат.

Учитывая быстрый рост установленной мощности классической электроэнергетики Советского Союза (удвоение мощностей за 8-8,5 лет) и высокую стоимость дальней транспортировки топлива с востока в западные районы нашей страны, можно сказать, что экономия в результате развития атомной энергетики в Европейской части Союза, на Кавказе, а в последующем и на Урале, будет по мере роста масштаба энергетики возрастать.

Поэтому в начавшемся пятилетии (1971-1975 гг.) предусмотрено значительное развитие атомной энергетики путем строительства крупных электростанций с реакторами единичной мощностью 1 млн. киловатт и выше и ввода в действие мощности на АЭС 6-8 млн. кВт с доведением в последующем пятилетии суммарных мощностей АЭС до 30 млн.кВт.

Атомные электростанции первого этапа после их ввода будут работать в основном в условиях базовой нагрузки с обеспечением их второй функции – подготовки к плутониевой загрузке для АЭС второго этапа с реакторами на быстрых нейтронах.

Строительство тепловых реакторов первого этапа будет продолжаться до 1980-1985 гг. с постепенным переходом к строительству АЭС с реакторами второго этапа, на быстрых нейтронах. Эти АЭС второго этапа по мере ввода их в действие будут брать на себя базовую нагрузку, а реакторы на тепловых нейтронах постепенно, по мере необходимости, будут переводиться в полупиковый режим регулирования. Сейчас трудно предсказать наиболее оптимальное сочетание тепловых и быстрых реакторов, а также конкретные масштабы этапов. Они будут зависеть от ряда факторов, таких, например, как цена на уран и экономика быстрых реакторов. Однако необходимо стремиться к тому, чтобы энергетика большого масштаба и скорость ее нарастания были бы не чувствительны к конъюнктурным изменениям цен на природный уран. Это возможно только при сбалансированном плутониевом топливном цикле, обеспечивающем нарастание энергетики за счет реакторов на быстрых нейтронах в нужном для нашей страны темпе, т.е. с удвоением мощностей порядка 8 лет или менее.

Приведенные выше соображения влияют на выбор перспективных для нашей страны типов реакторов.

АЭС С РЕАКТОРАМИ КОРПУСНОГО ТИПА

Как известно, конструкции реакторов на тепловых нейтронах корпусного типа развиваются в направлении одноконтурных, с кипением воды в активной зоне, и двухконтурных, с производством пара в парогенераторах. В Советском Союзе такие реакторы установлены на действующих Мелекесской АЭС, на первом и втором блоках Ново-Воронежской АЭС, на строящихся третьем и четвертом блоках этой АЭС, на Кольской и других АЭС.

Корпусные реакторы относятся к числу наиболее освоенных, они отличаются высокой компактностью, простотой схемы, малым количеством конструктивных материалов в активной зоне и относительно низкой стоимостью. По удельной энергонапряженности они в настоящее время являются одними из лучших. Однако, наряду с этими важными достоинствами, имеются и некоторые недостатки, значение которых возрастает при увеличении единичных мощностей. Первый недостаток – это сложность получения достаточных сведений, позволяющих во время эксплуатации станции прогнозировать возникновение дефектов в корпусе реактора и трубопроводах больших диаметров, особенно в районах вблизи корпуса. Этот недостаток, естественно, играет большую роль в крупных АЭС в связи с необходимостью сварки деталей все больших толщин при монтаже на месте строительства АЭС, а не в заводских условиях.

Потери нейтронов, связанные с необходимостью компенсации избыточной реактивности в начале кампании и с поглощением в шлаках в конце ее, особенно при глубоком выгорании, приводят к уменьшению воспроизводства топлива в реакторе. В целом топливный цикл этих реакторов является сейчас трудно регулируемым, так как изменять частоту загрузки горючего можно лишь в определенных пределах,хотя здесь и есть некоторые возможности прогресса, например использование плутониевого топливного цикла в перспективе или применение более плотных по урану загрузок.

Мы приступили к развитию первого этапа атомной энергетики. В настоящее время мы строим АЭС мощностью 880 МВт с двумя реакторами,по 440 МВт каждый.

Решению о серийном строительстве этих АЭС предшествовала длительная эксплуатация Ново-Воронежской АЭС и тщательная ревизия ее реакторов с проведением ремонтных работ. В осуществляемых типовых проектах учтен весь полученный опыт, и в настоящее время технически и экономически обоснованным является строительство АЭС с этими реакторами в центре России, на Кольском полуострове, на Кавказе, на Украине; несколько таких станций с помощью Советского Союза сооружается за рубежом. Экономические показатели этих станций во всех указанных районах несколько лучше, чем электростанций на обычном топливе [2].

Выгоднее всего для нашего народного хозяйства этими АЭС замещать конденсационные электростанции высоких параметров на угле и сланцах, которые предполагалось строить ранее.

Следующим шагом в развитии реакторов этого типа явится строительство станций с 2 реакторами мощностью по 1000 МВт. Первый такой реактор будет установлен на Ново-Воронежской станции, общая мощность которой при этом достигнет 2,5 млн. кВт.

Этот реактор будет представлять собой четырехпетлевой агрегат, с мощностью каждой петли по 250 МВт.

Корпус и крышка реактора, как и корпуса реакторов мощностью по 440 МВт, будут сделаны из высокопрочной тепло- и радиационно-стойкой стали, свойства которой у нас широко изучены. Структурное изменение этих сталей под действием радиации существенно меньше, чем у мягких, ибо эти высокопрочные стали обладают более растянутым интервалом пластичности и сохраняют надежную несущую способность до интегралов облучения, на порядок превосходящих получаемую дозу за 30 лет эксплуатации станции.

ТАБЛИЦА I. РАЗВИТИЕ ЭНЕРГЕТИЧЕСКИХ ВОДО-ВОДЯНЫХ РЕАКТОРОВ

Характеристика	ВВЭР-210	ВВЭР-365	ВВЭР-440	ВВЭР-1000
Мощность, МВт				
электрическая	210	365	440	1000
тепловая	760	1320	1375	3000
Давление насыщенного пара перед турбиной, атм	29	29	44	60
Давление в корпусе реактора, атм	100	105	125	160
Активная зона:				
энергонапряженность, кВт/л	46	80	83	111
число тепловыделяющих кассет	343	349	349	151
число твэлов в кассете	90	126	126	331
материал оболочки твэлов	циркониевый сплав			
загрузка урана, т	38	40	42	66
обогащение урана в топливе подпитки, %	2,8	3,0	3,5	4,4
глубина выгорания МВт·сут/т U:				
средняя	13000	27000	28600	40000
максимальная	19000	41000	42000	44000
Число циркуляционных петель на реактор	6	8	6	4
Число и мощность турбогенераторов (МВт)	3×70	5×73	2×220	2×500

В качестве конструкционного материала в активной зоне применяется высокопрочный, обладающий высокой коррозионной стойкостью в условиях облучения цирконий-ниобиевый сплав (2,5% Nb), а для оболочек топливных элементов сплав циркония с 1% ниобия.

Мы не предполагаем строить корпусные реакторы мощностью более 1 млн. кВт в одном корпусе. Промежуточные мощности, между 440 и 1000 МВт, не представляются необходимыми. В этом направлении, возможно, будет сделан постепенный переход от шестипетлевых и двухтурбогенераторных схем к блочной двухпетлевой однотурбогенераторной схеме мощностью 500 МВт. При этом все оборудование петель будет унифицировано с корпусной четырехпетлевой АЭС мощностью 1000 мегаватт. Это избавит от необходимости разработки и эксплуатации разнотипного оборудования (табл.I).

Ясно, что переход к блочному решению,(реактор-турбогенератор большой мощности) должен сопровождаться совершенствованием и увеличением надежности электрической части энергосистем с атомными электростанциями. До настоящего времени подавляющая часть кратковременных отключений АЭС была связана с нарушениями не в реакторной, а в электрической части, и это в известной степени определило нашу компоновку – один реактор на два турбогенератора. Однако такая компоновка приводит к некоторому удорожанию станции, что нежелательно при росте числа АЭС, и поэтому в дальнейшем будет использоваться блочная схема.

АЭС С РЕАКТОРАМИ КАНАЛЬНОГО ТИПА, С ГРАФИТОВЫМ ЗАМЕДЛИТЕЛЕМ

История развития энергетических реакторов этого типа началась с пуска Первой АЭС в 1954 году. Затем были построены и пущены: в 1958 году Сибирская АЭС (более 600 МВт), в 1964 – первый и в 1967 году – второй блоки Белоярской АЭС им.И.В.Курчатова (суммарная мощность 300 МВт). Эксплуатация двух реакторов Белоярской АЭС продемонстрировала их высокую радиационную безопасность и надежность. Длительная работа станции показала возможность осуществления ядерного перегрева пара в промышленных масштабах [1].

Канальный принцип конструкции, как альтернатива корпусному принципу, является перспективным с целого ряда точек зрения. Он обеспечивает возможность реализации весьма значительных единичных электрических мощностей (1000 МВт и выше), возможность повышения параметров теплоносителя (а значит к.п.д.), большую маневренность в эксплуатации и легкость перегрузки ядерного горючего, отсутствие сложного в изготовлении и транспортировке корпуса. Эти основные качества технически и экономически обуславливают реализацию планов внедрения мощных реакторов такого типа в ядерную энергетику СССР [3].

Следующим шагом развития канального конструктивного принципа была разработка проекта реактора РБМК-1000 мощностью 1000 МВт(эл). Он отличается от реакторов Белоярской АЭС следующим:

1) в активной зоне вместо нержавеющей стали основным конструкционным материалом служат циркониевые сплавы, существенно улучшающие баланс нейтронов, но требующие понижения параметров теплоносителя;

2) в рабочих каналах использованы стержневые твэлы;

3) значительно увеличена единичная мощность.

В активной зоне реактора РБМК-1000 существенно улучшено использование ядерного горючего. Применение в качестве конструкционного материала – циркониевого сплава, в качестве горючего – UO_2, а также оптимизация физических и теплотехнических параметров реактора позволили довести глубину выгорания ядерного горючего до 18 000 МВт·сут/т, а энергонапряженность горючего до 17,8 МВт/т.

Реактор РБМК-1000 принят в качестве серийного на нескольких строящихся двухреакторных АЭС, мощностью 2000 МВт каждая. Первая из этих АЭС – Ленинградская, находится в стадии монтажа оборудования [4].

Мы считаем преимуществом такого реактора то, что раздробленность активной зоны на отдельные каналы небольшого сечения делает неопасными нарушения герметичности отдельных каналов или даже группы их. Здесь возможна замена любого дефектного канала активной зоны. Коммуникации больших диаметров в канальных реакторах могут быть вообще исключены или вынесены в районы, легко доступные для контроля. Здесь допускается разгрузка любого канала на ходу реактора, без остановки станции, и, таким образом, топливный цикл является легко регулируемым. Недостатком является то, что эти реакторы имеют более развитые коммуникации активного теплоносителя. Они менее компактны, требуют бóльших строительных объемов, и поэтому капитальные затраты на них несколько выше, чем на АЭС с корпусными реакторами. Однако возможность легкого перестроения топливного цикла с целью его оптимизации, то, что активная зона комплектуется изделиями, производящимися крупносерийно, когда технология обеспечивает весьма высокое качество деталей, при низкой их стоимости, а также то, что из этих деталей могут быть созданы реакторы практически любой мощности, например в 2 млн. кВт, делают эти реакторы привлекательными.

В канальных реакторах возможен прогресс в смысле повышения их компактности.

Таким образом, мы пришли к заключению, что при единичных электрических мощностях около 1 млн. кВт и более канальные реакторы являются вполне конкурентоспособными с корпусными. Эксплуатация реакторов такого типа показала их высокую надежность и возможность удобного ремонта [5].

Так как эти реакторы опираются на более широкую промышленную базу и по топливному циклу гораздо лучше отвечают нуждам создания топливной базы для ввода реакторов второго этапа на быстрых нейтронах, то в СССР, наряду с развитием корпусных АЭС, большая часть крупных мощностей будет создаваться на канальных реакторах (строящиеся в СССР канальные реакторы представляют собой уран-графитовые системы).

Канальные реакторы дают возможность производить перегретый пар, как это показал наш опыт с двумя реакторами Белоярской АЭС.

Эту возможность будет экономически целесообразно реализовать, после того как будут созданы для каналов и оболочек перегревательных элементов сплавы на основе циркония, слабо поглощающие нейтроны. Но в отдельных случаях, – например, для получения промышленного пара высоких параметров в местах с затрудненной доставкой топлива или для теплофикации северных городов, – могут оказаться выгодными и перегревательные элементы со стальными оболочками. По мере нужды такие

ТАБЛИЦА II. РАЗВИТИЕ ЭНЕРГЕТИЧЕСКИХ РЕАКТОРОВ КАНАЛЬНОГО ТИПА С ГРАФИТОВЫМ ЗАМЕДЛИТЕЛЕМ И ОБЫЧНОЙ ВОДОЙ В КАЧЕСТВЕ ТЕПЛОНОСИТЕЛЯ

Характеристика	БАЭС-1	БАЭС-2	РБМ-1000	РБМ-КП-2000
Мощность, МВт				
электрическая	100	200	1000	2000
тепловая	286	530	3200	5620
Параметры пара перед турбиной:				
давление, атм	90	90	70	65
температура, °С	500	500	284	450
Активная зона:				
диаметр, м	7,2	7,2	11,8	13,5
высота, м	6	6	7	7
число рабочих каналов (в том числе перегревательных)	998(268)	998(266)	1690	1404(354)
число твэлов в канале	6	6	18	36-37
среднее обогащение урана, %	1,8	3,0	1,8	2,5
средняя глубина выгорания, МВт·сут/т U	4000	14600	18000	24000
энергонапряженность горючего, МВт/т	4,3	11,3	17,8	19,2
материал оболочки твэлов	нерж. сталь	нерж. сталь	циркониевый	перегревательных каналов — цирконий + нерж. сталь, испарительных — циркониевый сплав
Число и мощность турбин, МВт	1×100	2×100	2×500	2×1000

реакторы будут строиться, если реакторы на быстрых нейтронах с высокими параметрами пара не окажутся более экономичными.

В качестве следующего шага развития реакторов этого типа может рассматриваться проект реактора с перегревом пара типа РБМ-КП-2000 мощностью 2000 МВт(эл). Характеристики этого реактора приведены в табл.II.

Возможен также путь дальнейшего усовершенствования канальных реакторов без ядерного перегрева пара. Увеличение энергонапряженности горючего, оптимизация физических и тепловых характеристик активной зоны позволяет довести электрическую мощность такого реактора до 2000 МВт. Это открывает пути для дальнейшего повышения экономичности АЭС с канальными реакторами.

На первом этапе развития большая часть АЭС, как корпусного, так и канального типов, будет работать в режиме базовой нагрузки. Это обус-

ТАБЛИЦА III. ОСНОВНЫЕ ХАРАКТЕРИСТИКИ РЕАКТОРОВ НА БЫСТРЫХ НЕЙТРОНАХ

Характеристика	БОР-50	БН-350	БН-600
Тепловая мощность, МВт	60	1000	1450
Электрическая мощность, МВт	12	350 или 150 МВт(эл) и 120 тыс. $м^3$/сут·воды	
Глубина выгорания, %	10	5	10
Теплоноситель первого и второго контуров	Na	Na	Na
Расход по петле первого контура, $м^3$/ч	500	3200	9000
Время между перегруз-ками, сут	145	50	150
Диаметр активной зоны, см	40	160	205
Температура натрия на выходе из реактора, °С	550-600	500	550
Средняя энергонапряжен-ность, кВт/л	800	470	550
Параметры пара перед турбиной:			
температура, °С	500-540	440	500
давление, атм	90	50	130

ловлено не только чисто экономическими соображениями, но и целесообразностью (даже за счет некоторого повышения себестоимости топливной составляющей) максимального обеспечения топливного цикла реакторов второго этапа развития ядерной энергетики.

В районах с наиболее дорогим топливом, где, естественно, будут преобладать АЭС, постепенно возникнет необходимость перевода части АЭС в режим регулирования.

При этом необходимо будет переводить в режим регулирования те АЭС, которые дают наименьшую выработку плутония, и работа их должна быть оптимизирована на 4000-5000 час/год. При сохранении перегрузки один раз в год это даст возможность, например, перейти на менее обогащенное топливо. Не исключено, что окажется целесообразным создать специализированные АЭС, оптимизированные на 5000 час/год. Можно ожидать, что надобность в этом возникнет не ранее 1985 года, когда значительную часть базовой нагрузки примут АЭС второго этапа с реакторами на быстрых нейтронах (табл.III). Для этих АЭС чрезвычайно привлекательным будет использование уран-ториевого топливного цикла.

АЭС С РЕАКТОРАМИ НА БЫСТРЫХ НЕЙТРОНАХ

Решающее качество таких реакторов — более эффективное использование исходного ядерного горючего и возможность полного вовлечения в топливный цикл ^{238}U, а также тория — определяет ту важную роль, которая отводится в СССР реакторам на быстрых нейтронах в ядерной энергетике будущего. Исторически сложилось так, что тепловые реакторы существенно опередили более сложные быстрые реакторы по освоенности. Требуется решение многих научно-технических вопросов и накопление опыта эксплуатации головных образцов, прежде чем будут созданы и освоены мощные, высокоэкономичные и надежные энергетические быстрые реакторы. Как известно, эти реакторы особенно эффективны при плутониевой загрузке, и потому они могут хорошо сочетаться с тепловыми реакторами.

В СССР ведутся интенсивные работы по быстрым реакторам. Построена серия экспериментальных быстрых реакторов небольшой тепловой мощности (БР-1, БР-2, БР-3, БР-5, БФС).

После этих небольших экспериментальных реакторов на быстрых нейтронах в Мелекессе был построен реактор БОР-60, вышедший на электрическую мощность в 1970 году. Заканчивается строительство АЭС с реактором БН-350 в г.Шевченко, совмещенной с опреснительной установкой. Начато строительство третьей очереди Белоярской АЭС с реактором БН-600. Эксплуатация всех этих реакторов даст возможность получить необходимый опыт, отработать во всех деталях топливный цикл. Целью является достижение необходимого для нашей энергетики темпа удвоения мощности АЭС второго этапа с периодом порядка 8 лет без ввода или с минимальным вводом в топливный цикл системы этих АЭС горючего извне. Возможно, что вначале окажется необходимым вводить часть быстрых реакторов на урановом топливе [6].

Строительство АЭС второго этапа в больших масштабах будет осуществляться по мере накопления опыта работы первых АЭС и развертывания мощностей предприятий машиностроения и топливного цикла. При этом реакторы на быстрых нейтронах и их топливный цикл должны обеспечить доведение времени удвоения сначала до 8-9 лет, а затем до 6-8 лет. В этом направлении есть несколько перспективных путей, разрабатываемых нами совместно с социалистическими странами [7]. С этой целью ведутся проработки создания АЭС мощностью 1000-1500 МВт, оптимальных по технико-экономическим показателям и воспроизводству ядерного горючего.

Можно предполагать, что при успешном решении проблемы быстрых реакторов, начиная с 1985 года, во всей Европейской части СССР развитие электроэнергетики будет происходить преимущественно за счет строительства атомных электростанций с реакторами на быстрых нейтронах.

ОЦЕНКА ПЕРСПЕКТИВ ДО 2000 года

Успешное освоение крупных промышленных АЭС в СССР и начало осуществления широкой программы их строительства позволяют определить перспективы развития ядерной энергетики страны до конца столетия. Ядерная энергетика является частью общей и единой системы энергетического производства, поэтому при долгосрочном прогнозе ее развития должен быть учтен общий прогноз энергетики страны, характер и структура энергопотребления, режимы использования электрогенерирующих мощностей.

Очевидно, что количественные пропорции роста различных электрогенерирующих мощностей, в том числе и ядерных, на 30 лет вперед могут быть оценены лишь с известной степенью вероятности. На такой длительный срок в условиях исключительно быстрого прогресса в области ядерной энергетики невозможно достаточно точно определить масштабы изменения многих факторов, их величину и действие во времени. Поэтому в целом долгосрочный прогноз развития ядерной энергетики является задачей, в которой те или иные намечаемые пропорции могут изменяться под влиянием не известных в данный момент событий или факторов [8].

Основой энергетических ресурсов страны до 2000 года останется органическое топливо. Ядерная энергетика привлекается для энергоснабжения тех районов страны, где экономический эффект от ее применения будет максимальным. По прогнозам доля выработки электроэнергии на АЭС от общей выработки в стране может значительно увеличиться, в связи с чем практически должно прекратиться строительство новых конденсационных ТЭС в ряде районов Европейской части СССР.

В условиях Европейской части СССР запас экономической конкурентоспособности новых усовершенствованных АЭС с тепловыми реакторами является достаточно большим. Он допускает некоторое увеличение удельных затрат на добычу урана при условии, что вся экономия от действия других факторов, ведущих к улучшению экономики АЭС (увеличение единичной мощности, глубины выгорания, к.п.д., снижение затрат на изготовление твэлов, удешевление строительства и сокращение его сроков и т.д.), будет компенсировать это увеличение, и в целом экономическая конкурентоспособность ядерной энергетики сохранится.

Основной стратегией развития ядерной энергетики СССР является ориентация на всемерное и ускоренное развитие и внедрение быстрых реакторов с расширенным воспроизводством горючего.

К началу строительства серийных и мощных быстрых реакторов суммарные мощности АЭС с тепловыми реакторами достигнут в нашей стране десятков миллионов киловатт. Следовательно, АЭС с быстрыми реакторами будут фактически встраиваться в уже довольно развитую ядерную энергетику. Количество плутония, который будет накоплен к тому времени в тепловых реакторах и который будет использован для загрузки первых промышленных быстрых реакторов, обеспечит возможность ввода такого же порядка суммарной мощности быстрых реакторов. Соотношение между долями суммарных мощностей тепловых и быстрых реакторов будет постепенно изменяться в пользу последних.

Требование интенсивного наращивания ядерно-энергетических мощностей может быть выполнено при условии ввода весьма крупных энергоблоков АЭС. В этом отношении большими возможностями обладают канальные реакторы, единичная мощность которых в прогнозируемый период, по-видимому, может быть доведена до 2-3 млн.кВт(эл) и даже более. Доля таких реакторов в приросте мощностей ядерной энергетики может возрасти, так как доля корпусных реакторов по условиям транспортировки их корпусов по железной дороге разумно ограничится единичными мощностями не выше 1000 МВт(эл).

Что же касается оптимальных единичных мощностей быстрых реакторов, то этот вопрос должен решаться с учетом их важнейшего функционального назначения – поставки плутония для развивающейся ядерной энергетики. При чрезмерно больших единичных мощностях быстрых бридеров может оказаться затруднительным необходимое для этого размещение их в базисе графика нагрузки энергосистем.

На современном этапе важное значение приобретает вопрос о стандартизации и унификации конструктивных и строительных решений для АЭС и их компонентов. Ряд специфических требований, предъявляемых к материалам и оборудованию, особый характер эксплуатации, обслуживания и ремонта АЭС требуют дальнейшего развития специализированного машиностроения, что в решающей степени определяет надежность и экономические показатели АЭС.

Наряду с использованием конденсационных АЭС, насущными задачами уже сегодняшнего дня становится широкое использование ядерных реакторов для производства одновременно с электроэнергией других видов продукции – тепла, пресной воды, химических продуктов, холода. Среди этих задач, по-видимому, первоочередными следует считать развитие "атомной" теплофикации, а также получение методом дистилляции из соленой воды значительных количеств пресной воды с использованием реакторов как источников тепла.

Успешная эксплуатация первых АЭС, их радиационная безопасность [9,10] создают уверенность в возможности размещения атомных ТЭЦ (АТЭЦ) вблизи крупных городов. Это, кроме экономии на длине теплотрасс, одновременно позволит решить другую важную проблему – проблему борьбы с загрязнением воздуха и территории продуктами горения. Загрязнение воздуха крупных городов, происходящее в значительной степени за счет обычных ТЭЦ, снабжающих их теплом, не только наносит ущерб здоровью людей, но и меняет облик природы. Атомные конденсационные или теплофикационные электростанции исключают подобное загрязнение воздуха, обеспечивая при этом полную радиационную безопасность. С этой точки зрения наиболее предпочтительным техническим принципом представляется принцип конструкции рабочих каналов Белоярской АЭС. Конструкция твэла этой АЭС, как подтвердил длительный опыт эксплуатации, исключает попадание радиоактивных продуктов деления в контур и обеспечивает исключительно благоприятную радиационную обстановку как внутри АЭС, так и за ее пределами.

Другая весьма важная народнохозяйственная проблема – получение пресной воды с помощью атомных реакторов в промышленном масштабе – уже решается в Советском Союзе сооружением в г.Шевченко атомной электростанции. Этот город расположен на восточном берегу Каспийского моря, где отсутствуют природные источники пресной воды. С пуском атомной электростанции водоснабжение города и близлежащего района существенно улучшится. По сути дела здесь возникает крупный агропромышленный комплекс на базе использования атомной энергии.

Изучение перспектив развития ядерной энергетики показывает, что широкое строительство АЭС выгодно не только вследствие их более высокой экономичности по сравнению с электростанциями, работающими на органическом топливе. Не менее важным является то, что чрезвычайно высокая калорийность ядерного горючего приводит к существенной экономии трудовых ресурсов, занятых в сфере энергетического производства, особенно в добыче органического топлива и его транспорта.

Развитие народного хозяйства СССР в дальней перспективе (к 2000 году) потребует таких величин расходов топливно-энергетических ресурсов, которые приведут к необходимости коренного перелома в структуре приходной части этих ресурсов. Основой такого перелома может стать атомная энергетика, которая к 2000 году превратится в серьезную отрасль топливно-энергетического и электроэнергетического хозяйства страны.

Именно эти задачи и определяют масштабы, перспективу и пути развития атомной энергетики в Советском Союзе на период до 2000 года.

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PROSPECTS FOR ATOMIC ENERGY DEVELOPMENT IN JAPAN

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Abstract–Résumé–Аннотация–Resumen

PROSPECTS FOR ATOMIC ENERGY DEVELOPMENT IN JAPAN.

In April 1967, the Atomic Energy Commission of Japan drew up a long-range program on the peaceful uses of atomic energy in Japan. It looks at the future shape of the various areas of peaceful uses of atomic energy up to 1985, to clarify the policy for implementing priority measures for about ten years from fiscal 1967. Based upon this long-range program, the national ways to nuclear power generation, promotion of development of power reactors, procurement of nuclear fuels, construction of Japan's first nuclear ship "MUTSU", promotion of the use of radiation research on nuclear fusion and finally the safety measures, are discussed.

Since drawing up this long-range program the economic growth-rate in Japan has far exceeded any estimated figure and, reflected in this change of economic situation, the volume of energy demand has also increased remarkably. Therefore, to promote development and utilization of atomic energy in conformity with this trend, the Atomic Energy Commission of Japan considers revising its long-range program in 1971. The Economic Planning Agency has a long-range program of socio-economic development through 1980, concentrating primarily on the real growth-rate of the gross national product as the nation's economic index, and an estimate of the trend to increase the role of nuclear power in future power sources. In addition, the Japan Atomic Industrial Forum, Inc., a private organization, has estimated a long-term prospect of the volumes of energy and electricity demand with reference to the considerable changes in industrial structure to depict a nuclear power development prospect. Outlines of both programs are given, followed by a description of important problems which are likely to occur in the nuclear fuel cycle by extending the nuclear power program. Such problems are linked with the estimated quantity of nuclear fuel requirements, the development of advanced power reactors for the effective uses of nuclear fuels, the procurements of uranium resources and enriched uranium, fuel fabrication and reprocessing.

PERSPECTIVES DE DEVELOPPEMENT DE L'ENERGIE ATOMIQUE AU JAPON.

La Commission japonaise de l'énergie atomique a mis au point, en avril 1967, un programme à long terme d'utilisation de l'énergie atomique à des fins pacifiques au Japon. Ce programme visait surtout à préciser les moyens de mettre en œuvre des mesures prioritaires pendant 10 ans environ à partir de 1967, en tenant compte du développement prévisible des divers domaines d'utilisation pacifique de l'énergie atomique jusqu'à 1985. Le mémoire rend compte des mesures visant à faire progresser la production d'énergie nucléo-électrique et le développement des réacteurs de puissance; il aborde des problèmes tels que l'acquisition du combustible nucléaire, la construction du premier navire nucléaire japonais Moutsou, la promotion de l'utilisation des rayonnements, l étude de la fusion nucléaire, les mesures de sécurité.

Depuis le lancement de ce programme, la cadence de la croissance économique a largement dépassé les prévisions etablies, et ce changement de situation se reflète dans une augmentation importante de la consommation d'énergie. En conséquence, la Commission de l'énergie atomique a formé le dessein de reviser son programme à long terme en 1971, afin de hâter le développement et l'utilisation de l'énergie atomique conformément à cette nouvelle tendance. Le Bureau de planification économique, en se fondant surtout sur le taux de croissance réel du revenu national brut, qui est l'index de l'économie nationale, a mis au point un programme à long terme de développement socio-économique. Ce Bureau prévoit en outre la tendance à l'augmentation rapide de la production d énergie nucléo-électrique. D'autre part, le Forum atomique industriel japonais, une organisation privée, a fait, en tenant compte de l'évolution prévisible de la structure industrielle, une évaluation de la demande d'énergie à long terme ainsi que du développement futur de la production d'énergie nucléo-électrique. Le mémoire décrit les grandes lignes de ces deux programmes et examine les problèmes que posera le cycle du combustible par suite de l'élargissement du programme de production d'énergie nucléo-nucléaire.

Ces problèmes concernent entre autres la prévision des quantités nécessaires de combustible, le développement de réacteurs de puissance avancés pour l'utilisation efficace du combustible, l'approvisionnement en uranium naturel et uranium enrichi, la fabrication et le traitement des éléments combustibles.

ПЕРСПЕКТИВЫ ПРИМЕНЕНИЯ АТОМНОЙ ЭНЕРГИИ В ЯПОНИИ.

Комиссия по атомной энергии Японии разработала в апреле 1967 года национальную долгосрочную программу использования атомной энергии в мирных целях. Программа охватывает различные области мирного использования атомной энергии вплоть до 1985 года; излагается также политика принятия первоочередных мер приблизительно на 10 лет вперед, начиная с 1967 финансового года. Исходя из этой долгосрочной программы, обсуждаются национальные пути производства электроэнергии при помощи ядерной энергии, содействие разработкам энергетических реакторов, приобретение ядерного топлива, строительство первого японского атомного судна "MUTSU", содействие в использовании радиационных научных исследований в области термоядерного синтеза и, наконец, мероприятия в области безопасности.

С момента разработки этой долгосрочной программы рост японской экономики превзошел все предположения; отражением изменения в экономическом положении является значительное увеличение спроса на электроэнергию. Поэтому, стремясь содействовать развитию и применению атомной энергии в соответствии с этой тенденцией, Комиссия по атомной энергии Японии считает необходимым пересмотреть в 1971 году свою долгосрочную программу. Агентство по экономическому планированию имеет долгосрочную программу социально-экономического развития до 1980 года, в которой основное внимание сосредоточено на реальном приросте валового национального продукта как показателя национальной экономики и на оценке тенденции к увеличению роли ядерной энергетики среди будущих энергетических источников. Японский атомный промышленный форум, являющийся частной организацией, составил долгосрочный прогноз спроса на энергию и электроэнергию, уделив особое внимание значительным изменениям в промышленной структуре в целях определения перспектив развития ядерной энергетики. Излагаются основные принципы обеих программ и дается описание важных проблем, которые, вероятно, могут возникнуть в ядерном топливном цикле в результате расширения программы по ядерной энергетике. Эти проблемы связаны с потребностями в ядерном топливе, разработками усовершенствованных энергетических реакторов для эффективного использования ядерного топлива, обеспечением урановыми ресурсами и обогащенным ураном, изготовлением и переработкой топлива.

PERSPECTIVAS DEL DESARROLLO DE LA ENERGIA ATOMICA EN JAPON.

En abril de 1967, la Comisión de Energía Atómica del Japón redactó un programa a largo plazo sobre el empleo pacífico de la energía atómica en el Japón. El programa considera la configuración futura de los distintos campos de utilización pacífica de la energía atómica hasta 1985, poniendo en claro la política referente a las prioridades a que han de ajustarse durante diez años, a partir del año fiscal de 1967. Basándose en este programa a largo plazo, se explican la política de construcción de centrales nucleares, la promoción del desarrollo de los reactores, la obtención de combustibles nucleares, la construcción del primer barco nuclear japonés « MUTSU », el incremento de la investigación sobre fusión nuclear y finalmente las normas de seguridad.

Desde la redacción del programa a largo plazo, el ritmo de crecimiento económico del Japón ha sobrepasado, con mucho, cualquier estimación, y como consecuencia de esta evolución económica la demanda energética también ha aumentado de forma considerable. Por lo tanto para favorecer el desarrollo y la utilización de la energía atómica de acuerdo con esta tendencia, la Comisión de Energía Atómica del Japón está considerando la revisión del programa a largo plazo en 1971. La Agencia de Planeamiento Económico tiene un programa de desarrollo socioeconómico hasta 1980, que toma fundamentalmente la tasa real de crecimiento del producto nacional bruto como índice económico de la nación, y hace una estimación de la tendencia del papel creciente de la energía nuclear entre las fuentes de energía. Además, el Forum Industrial Atómico del Japón, que es una organización privada, ha estimado las perspectivas a largo plazo de la demanda de energía y electricidad con referencia a los grandes cambios en la estructura industrial y ha descrito unas perspectivas de desarrollo de energía nuclear. En la memoria se dan las líneas directrices de ambos programas siguiendo con una descripción de los problemas principales que probablemente han de presentarse en el ciclo del combustible en vista de la importancia del programa de energía nuclear. Tales son las estimaciones de las necesidades de combustible nuclear, el desarrollo de reactores avanzados de potencia para el uso eficaz del combustible, la búsqueda de recursos de uranio y la obtención de uranio enriquecido, la fabricación y la reelaboración del combustible.

INTRODUCTION

In April 1967, the Atomic Energy Commission of Japan prepared a long-range program on the peaceful uses of atomic energy which outlines the future of the peaceful uses of atomic energy in Japan for twenty years through 1985, with stress on the policy for promotion, and major measures for the effective development and utilization of atomic energy during the ten-year period beginning 1967.

Since the long-range program was formulated in 1967, Japan's economy has expanded remarkably and the volume of energy demand has also increased at an astonishing rate. Fossil fuels, which have been the major sources of this energy supply, are now handicapped by problems of air pollution and international price increases, affecting, for example, crude oil.

Therefore, the role of atomic energy, which has for years been looked upon as a future stable energy source, has increased greatly. The Commission concerned with this new socio-economic situation plans to revise the current long-range program during 1971 in order to promote further the development and utilization of atomic energy, while the Government of Japan has already drawn up the Long-Term Electric Power Development Program up to the year 1980, and the Japan Atomic Industrial Forum has made "Forecast of Nuclear Power Development Prospects for the Year 2000". Both estimate the increasing role of nuclear power in supplying energy to satisfy future demand.

In this situation, the acquisition of nuclear fuels, the development of advanced power reactors, and the matter of environmental protection are becoming questions of urgency. The counter-measures to deal with these problems are discussed in this paper.

1. OUTLOOK FOR ATOMIC ENERGY DEVELOPMENT

1.1. Long-term estimate of the energy supply and demand

The Economic and Social Development Plan, on which the Commission's Long-Range Program for the Development and Utilization of Atomic Energy, was based, was prepared by the Government in 1967. The former Plan was designated as the general blueprint for our national economic plan, aiming at the stable growth of Japanese economy and it sets a target for the annual growth-rate of the gross national product (GNP) at 8.2%. According to this plan, the total energy demand for 1970 would be 1.3 times greater than that for 1967, increasing to 1.8 times in 1975 and 3.2 times in 1985.

In 1970 the Energy Advisory Committee to the Minister of International Trade and Industry (MITI) estimated that the annual growth-rate of the GNP will be 10.6% during 1969 - 1975 and 8.5 - 9.5% in 1976 - 1985. This indicates that the volume of energy demand for 1975 will be 2.5 times more than that for 1967, increasing to 5.4 - 6.0 times for 1985 (Table I).

This remarkable increase in energy and electricity demand indicates the future industrial structure of Japan and points to an improvement in living standards.

TABLE I. ESTIMATE OF ENERGY DEMAND (10^{13} kcal)

	Year	1967 Actual	1970 Projected[a]	1975 Projected[a]	1975 Latest estimate[b]	1985 Projected[a]	1985 Latest estimate[b]
Volume of energy demand	Total energy	172.9	219.5	309.2	438.5	550.1	933.3--1,028.9
	Electricity	53.1	68.1	102.3	135.4	212.2	310.0--340.2
	Others	119.8	151.4	206.9	303.1	337.9	623.3--688.7
	Years	-	1970/1967	1975/1967	1975/1967	1985/1967	1985/1967
Growth-rate (per cent)	Total energy	-	127	179	254	318	540--595
	Electricity	-	128	193	255	400	583--641
	Others	-	126	173	253	282	520--575

[a] Projections were made in 1967.
[b] Latest estimate made in 1970.

1.2. Development of nuclear power generation

The Commission's Program of 1967 predicts that, taking into account the expected role of nuclear power in supplying future energy, the volume of nuclear power generation will be 30 000 - 40 000 MW in 1985.

By the end of March 1971, four commercial nuclear power stations (total output: 1323 MW) were in operation in Japan – Tokai (Magnox 166 MW), Tsuruga (BWR 357 MW), Fukushima-1 (BWR 460 MW) and Mihama-1 (PWR 340 MW). Nine more nuclear power stations were then under construction, which would total 5803 MW, exceeding the projected capacity. In addition, in 1970 the Government formulated a Long-Term Electric Power Development Program up to 1980, which calls for a generating capacity of 27 000 MW of nuclear origin to be installed by that year. In March 1971, the Japan Atomic Industrial Forum prepared a long-term forecast for nuclear power development for the year 2000, which estimated volumes of nuclear power generation that would reach 110 000 MW in 1990 and 220 000 MW in 2000. Outlines of both projections are discussed briefly.

(1) The Government's Long-Term Electric Power Development Program

Giving due consideration to the importance of the real growth-rate of the SNP as a national economic indicator, in May 1970 the Government

TABLE II. THE GOVERNMENT'S ELECTRIC POWER DEVELOPMENT PROGRAM

Power source \ Fiscal Year	1969 (MW)	1975 (MW)	1980 (MW)
Hydro	18 190 (35%)	23 760 (22%)	32 860 (20%)
Thermal	33 150 (65%)	75 140 (70%)	100 640 (63%)
Nuclear	500 (1%)	8 660 (8%)	27 020 (17%)
Total	51 840 (100%)	107 560 (100%)	160 520 (100%)

Note: Percentages shown in parentheses indicate the installed rate of each source at the end of fiscal year.

TABLE III. JAIF'S PROTECTION FOR GENERATING CAPACITIES

Year	1990 (GW)	2000 (GW)
Hydro	57 (20%)	86 (20%)
Thermal	119 (41%)	134 (30%)
Nuclear	110 (39%)	220 (50%)
Total	286 (100%)	440 (100%)

forecast socio-economic development for 1971-1980. This foresees an increasing role for nuclear power in the development of future power sources. Electricity demand for 1980 will total 820×10^9 kWh.

To ensure a stable supply of electricity to keep pace with this growing demand, a comprehensive economic operation of hydro, thermal and nuclear power plants is advocated together with the promotion of a large area co-ordination system for electric utilities, aiming at a gross margin of 8 or 10% in over-all generating capacity. In this project, the total installed capacity at the end of 1980 will be about 161 000 MW (hydro: 33 000 MW (20%), thermal: 101 000 MW (63%); nuclear: 27 000 MW (17%) (see Table II).

(2) Japan Atomic Industrial Forum's Projection for nuclear power development for the year 2000

While the New Economic and Social Development Plan for 1975 predicts that Japan's economy will grow at an average rate of 10.6% annually, the Forum's Projection estimates the growth-rate of SNP at 9.9% during 1969 - 1980, 7.6% for 1981 - 1990 and 4.8% for 1991 - 2000, and points out the gradual downward trend.

To satisfy the future electricity demand, the nine electric utilities will need 286 GW by 1990 and 440 GW by 2000 (Table III), which amounts respectively to six and nine times the 50-GW capacity at the end of 1969.

As a result of a study of an ideal combination of power sources, estimating the annual installed capacity of hydro, thermal and nuclear energy in the development of power sources, the Forum predicts the percentage for installed nuclear capacity will be about 40% in 1990 and 50% in 2000.

However, several problems have arisen which may slow down the increasing trend of energy demand, such as problems caused by air pollution as well as that of the supply of a vast amount of crude oil, and if the possible growth of the importance of "non-energy intensive industries" in the future industrial structure of Japan is considered, it could be anticipated that volume of energy demand in the coming decades be smaller than the estimate of the MITI Advisory Committee. In spite of this, the actual increase in the volume of nuclear generating capacity will be not less than indicated by the above MITI report.

Nuclear power generation, being excellent for stabilizing supply, and because of the simplicity of the transport and storage of its fuels, could be the most reliable energy source for the large demand to support the future economy; therefore, its early commercialization has been steadily pushed forward.

(3) Securing of nuclear fuel

Judging from the recent constructions of nuclear power plants in rapid succession in Japan, it is expected that the cumulative total of U_3O_8 required between now and 1975 will be about 18 000 t, and may be as much as 120 000 t by 1985, while by 1990 it may jump to approximately 170 000 - 200 000 t.

The Power Reactor & Nuclear Fuel Development Corporation (PNC), after ten years investigation and prospecting, has so far discovered only 8000 t U_3O_8 in the Ningyo-Toge and Tono area.

It is of vital importance to Japan to secure a reliable source of uranium supply; therefore, it has been decided that a substantial amount of uranium should be secured by private enterprises through overseas resources development together with long-term purchase contracts.

For example, a company, the Overseas Uranium Resources Development Co., Ltd., was organized by interested parties in the mining and electric power industries and it is now developing uranium resources in Niger, Africa, in co-operation with the Niger Government and Commissariat à l'Energie Atomique of France.

The Japanese Government, in order to assist and expedite these private enterprises in uranium resources development, has entrusted the PNC and other governmental organs with the task of conducting basic surveys for uranium resources in potentially promising areas throughout the world.

The future requirements of enriched uranium for nuclear power plants in Japan will, it is estimated on the basis of present plans for the construction of nuclear power plants, amount to some 5000 t separative work units (s.w.u.) in 1980, and about 9000 t s.w.u. in 1985. From the point of view of ensuring a stable supply of nuclear fuels, it is undesirable that Japan should rely solely upon the United States of America for the supply of such large quantities of enriched uranium.

From this aspect, and in view of the importance of research and development work on uranium enrichment, since August 1969 the Atomic Energy Commission has been forging ahead with the research and development work on both the centrifuge and the gaseous diffusion processes, which are the major research areas under the current Specific Development Project on Atomic Energy, with the aim of discovering by 1972 possible solutions to a number of technical problems relating to uranium enrichment.

The Atomic Energy Commission is also continuing its studies on the situation concerning the world supply and demand of enriched uranium and long-range plans for securing a continuing stable supply, mainly dealing with international co-operation in this sector.

To achieve the effective utilization of nuclear energy, the Commission is also working on the problems involved in making possible the use of advanced thermal reactors and breeder reactors, development of nuclear fuel fabrication, setting up of a spent fuel reprocessing system, promoting recycling as nuclear fuel the recovered plutonium from spent fuels, as well as setting up the nuclear fuel cycle most suitable to Japan's needs.

The PNC began the construction of a spent-fuel reprocessing plant with a capacity of 210 t/yr U in mid-1971 at Tokai Mura, Ibaragi Pref., to be completed and to go into operation in 1974. As for nuclear fuel fabrication, several plants are already in operation, and its industrialization is progressing remarkably.

(4) Development of power reactors

From the standpoint of securing a continuing stable supply of nuclear fuel as well as its effective long-term utilization, it is undesirable, on a long-range basis, to rely upon the light-water power reactors alone. Therefore, since available domestic resources are extremely scarce, it is very important for the sound progress of Japan's nuclear power industry as well as for the establishment of its energy policy, to develop the most suitable type of power reactor to make use of the advantages and special characteristics offered by the nuclear power generation.

The PNC, as the principal promotor, is working in close co-operation with the Japan Atomic Energy Research Institute and private organizations on the national project to develop a fast-breeder reactor and an advanced thermal reactor (a heavy-water-moderated reactor).

The construction of the experimental fast-breeder reactor "JOYO", which is expected to reach criticality in 1974, has already been started. The designing of the prototype fast-breeder reactor "MONJU" is also progressing. This project is expected to be completed in the second half of the 1980s when the reactor will be in commercial operation.

The advanced thermal reactor is expected to be in commercial use in the late 1970s, and construction of the prototype reactor "FUGEN" will be started in 1971 and is expected to reach criticality in 1975.

(5) Development of nuclear ships

With the aim of raising the level of nuclear ship technology in Japan, the first nuclear ship "NS Mutsu" is under construction as a demonstration ship using domestic technology. The Japan Nuclear Ship Development Agency is responsible for the construction of "NS Mutsu" based upon the Basic Program for the Development of the First Nuclear Ship.

In July 1970, construction of its hull was completed and the "NS Mutsu" was brought to the home port at Mutsu City, Aomori Prefecture, in the northern area of the main island of Japan. At present, its reactor components are being installed for commission scheduled for March 1973.

It is expected that the shipbuilding industry will construct and operate a second nuclear ship and the Government will assist the industrial development of economic maritime reactors.

Furthermore, in view of the approaching completion of "NS Mutsu" as well as possible future calls by foreign nuclear ships, a system providing for compensation for nuclear damage has been carefully studied and revised.

(6) Promotion of the radiation utilization

Regarding radiation utilization, the techniques for large-scale irradiation and activation analysis have been perfected steadily in parallel with advances in the domestic production of short-lived nuclides and labelled compounds, and also with the development of relevant equipment such as radiation counters and particle accelerators.

Concerning the research and development of food irradiation, which was authorized by the Atomic Energy Commission in 1967 as a Specific Development Project on Atomic Energy, wheat and boiled fish pastes were added in 1969 to the formerly approved items to be irradiated such as potatoes, onions and rice. Tests on the use of irradiation to preserve foodstuffs longer have been made with favourable results. As part of this experimental program work has been done for the possibilities of the commercial use of irradiation to prevent the germination of potatoes.

Research and development in radiation chemistry are carried out mainly at the Takasaki Establishment of the Japan Atomic Energy Research Institute. Progress has been made in the studies of radiation graft-polymerization of fibres, radiation vapour phase polymerization of ethylene, radioactive solid polymerization of trioxane, etc. and these are considered to be processes with promising industrialization possibilities.

(7) Research on nuclear fusion and multi-purpose use of nuclear reactors

Basic research in plasma physics relating to controlled nuclear fusion which it is hoped will be the main future energy source, has been pursued as another Specific Development Project on Atomic Energy.

In 1969, JAERI obtained favourable results in its work on the stable confinement of plasma by using the axially symmetric toroidal system for low-beta plasma (JFT-1). JAERI is now constructing the axially symmetric toroidal system for plasma current (JFT-2). At the electrotechnical laboratory of MITI, research on high-beta plasma has been conducted by using a large theta-pinch unit. In addition to these projects, related technical studies have been undertaken at the Institute for Physical and Chemical Research and at universities where extensive basic research has been undertaken.

The iron and steel industries have been pressing for studies of the multi-purpose use of nuclear reactors and at JAERI the Commission started a survey on the technical feasibility of acquiring by HTGR coolant temperatures of about 1000°C for use in the iron and steel industry. The basic studies on reactor characteristics and fuel for HTGR are advancing at JAERI.

(8) Nuclear safety

With respect to safety measures for reactors, experimental research to demonstrate safety has been given serious attention. As a result of the industrialization of atomic energy, safety measures involving precise and practical standards and the execution of a strict reactor safety assessment have been implemented.

Furthermore, to cope with the question of environmental radioactivity, a survey program on radioactive levels has been conducted on a nationwide basis and, simultaneously, radiation effects on marine life have been studied.

The National Institute of Radiological Sciences is taking the initiative in researches on the radiation effect, and will carry out intensive research on the effect of low-level radiation.

JAERI and industrial organizations have so far conducted the research and development work on the treatment and disposal of radioactive wastes and, in view of the considerable volume of radioactive wastes to be discharged in the future, a committee of experts is discussing concrete methods of treatment and disposal.

(9) Training of personnel

The development of nuclear energy requires the training of personnel in almost all scientific fields. For this, we are promoting the expansion of university faculties for basic training, and of training organizations for higher education.

There were about 10 000 nuclear scientists and engineers in 1965 and about 14 000 in 1969. However, according to the current long-range program, it is estimated that about 27 000 - 29 000 scientists and engineers will be required in 1975 owing to the future level of growth of nuclear energy development.

Faced with this large demand for nuclear scientists and engineers, it has been necessary for universities, playing the most important role in this sector, to increase the number of related subjects and courses offered and to expand their educational and research facilities.

In addition to the universities, JAERI, the National Institute of Radiological Sciences, Japan Atomic Power Co., etc. have been undertaking the training of high-level scientists and engineers including those from overseas.

2. FUTURE TASKS RELATING TO THE DEVELOPMENT AND UTILIZATION OF ATOMIC ENERGY

For the reliable acquisition of large amounts of uranium and enriched uranium Japan must urgently work to establish a domestic nuclear fuel cycle.

As for uranium, Japan must import it under long-term purchase contracts with the producing countries and much emphasis is placed on the importance of the development and import of overseas uranium resources. Although it is considered that we must increasingly rely on the latter, the economic risk is great so the Government is considering taking positive measures to assist private enterprise.

In the light of the unexpectedly rapid expansion of nuclear power, uranium enrichment, which could be the hub for the whole fuel cycle, is a vital problem now urgently requiring solution. Currently, the international situation in this field is very fluid and it is necessary for Japan to decide, from an international point of view, on the formula of procuring enriched uranium. After carefully considering the estimate of supply and demand of enriched uranium available, we are extremely interested in the possible increase of separation capacity in the United States and the enrichment plant construction programs of European countries. Japan will steadily promote the research and development of uranium enrichment technology.

Japan area is small and densely populated; therefore, it is very difficult to procure sufficient extensive sites for industrial facilities. In addition, there still remains anxiety on the part of the general public about the safety of nuclear facilities and the loss of coastal fishing grounds because of the thermal effluent from fossil and nuclear power plants.

To ensure the successful promotion of the development and utilization of atomic energy once these difficulties have been overcome, efforts to educate the public on the safety of nuclear facilities as well as those to complete monitoring and assessment systems for environmental radioactivity should be increased.

Also, the treatment and disposal of the considerable amount of radioactive wastes from nuclear power stations and spent fuel reprocessing plants will be a serious problem. It is considered that solid radioactive wastes of high level should be stored on land for a long period but that, concerning the treatment and disposal of intermediate- and low-level solid radioactive wastes, which account for the greater part of all wastes, though each country may have peculiar conditions for selecting disposal methods, the problem of marine disposal should be solved through international study and discussion. Japan, for its part, is working on the technical development necessary to ensure the safety of marine disposal.

Finally, the question of the IAEA safeguards system must be referred to. The Agency's safeguards system should be rationalized and simplified as far as possible in line with the decision made by the Safeguards Committee in February, 1971. For this purpose, as the Committee pointed out, it is important to apply in a most effective way the national safeguards system of member countries. When making efforts to complete its national safeguards system based upon our regulatory laws and developments in safeguards technology, Japan will conform to the new guidelines for the Agency's safeguards system.

We understand that the tasks and problems involved in the development and utilization of atomic energy mentioned so far cannot be solved by one nation alone and that international co-operation is therefore essential, and this will be given the highest priority in Japan.

A NUCLEAR POWER FORECAST FOR BRAZIL

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Abstract–Résumé–Аннотация–Resumen

A NUCLEAR POWER FORECAST FOR BRAZIL.

The paper forecasts nuclear power development in Brazil up to the end of the century and outlines the main requirements to back up such a nuclear program. Owing to its overwhelming importance in the electric energy market in Brazil, the South-Central Region is chosen as the area under study and the results are largely representative of the country as a whole. The generating capacity of the region relies heavily on hydro power, but both the coming exhaustion of economic sites and the need to ensure the continuous energy of the system point out to the necessity of a program of thermal power plants, in which a considerable portion could be nuclear. A mathematical model of the expanding electric system is used to determine the optimum mix of hydro, conventional and nuclear power plants. The relative location of hydro sites along a river basin is taken into account in order to assess their mutual influence through the regulation of the river. A parametric study is made to assess the influence of input data on the resulting nuclear program. Taking one of the thermal complementation programs as a reference case, different reactor strategies are analysed. The industrial support necessary to carry out the reference nuclear program is discussed.

DEVELOPPEMENT PREVU DE LA PRODUCTION D'ENERGIE NUCLEO-ELECTRIQUE AU BRESIL.

Le mémoire rend compte du développement prévu au Brésil jusqu'à la fin de ce siècle en matière de production d'énergie nucléo-électrique et des mesures nécessaires pour appuyer un tel programme. Etant donné son importance prépondérante dans le marché de l'énergie électrique au Brésil, la région centre-sud a été choisie pour l'étude; les résultats sont très représentatifs de l'ensemble du pays. La capacité de production d'énergie de la région repose essentiellement sur l'énergie hydraulique; cependant. tant l'épuisement des sites économiques que le besoin d'un approvisionnement continu du réseau confirment la nécessité d'un programme de centrales thermiques, où le nucléaire pourrait prendre une place importante. On emploie un modèle mathématique du système électrique en expansion pour déterminer la combinaison optimale de centrales hydrauliques, classiques et nucléaires. La position relative des sites hydrauliques le long du bassin est indiquée pour déterminer leur influence réciproque par suite de la régularisation du cours d'eau. Une étude paramétrique permet d'analyser l'influence des données de base sur le programme nucléaire. Sur la base d'un programme de centrales thermiques complémentaires on analyse différentes stratégies de réacteurs. On analyse aussi le support industriel nécessaire pour mener à bien le programme nucléaire de référence.

ПЕРСПЕКТИВЫ РАЗВИТИЯ ЯДЕРНОЙ ЭНЕРГЕТИКИ В БРАЗИЛИИ.

В докладе делаются прогнозы развития ядерной энергетики в Бразилии на период вплоть до конца этого столетия и описываются основные требования, необходимые для осуществления такой ядерной программы. Ввиду того что центрально-южный район Бразилии имеет исключительно важное значение с точки зрения обеспечения электроэнергией, он был выбран в качестве объекта исследования, поэтому полученные результаты в значительной степени характерны для страны в целом. Генерирующая мощность электростанций этого района обеспечивается главным образом за счет гидроэлектростанций, однако сокращение экономически выгодных мест для строительства ГЭС и необходимость обеспечения непрерывного производства электроэнергии говорят о необходимости осуществления программы строительства тепловых электростанций, где значительное место могло бы принадлежать АЭС. Для определения оптимальной комбинированной системы, состоящей из гидростанций, тепловых и атомных электростанций, использовалась математическая модель развивающейся энергосистемы. Учитывается тот факт, что ГЭС располагаются вдоль бассейна реки; это необходимо для определения их взаимного влияния путем регулирования уровня воды. Проводится параметрическое исследование с целью оценки влияния исходных данных на выполняемую ядерную программу. Анализируются варианты использования различных реакторов на основе одной из программ эксплуатации тепловых станций. Обсуждается помощь со стороны промышленных предприятий, необходимая для выполнения указанной ядерной программы.

PREVISION DEL DESARROLLO DE LA ENERGIA NUCLEOELECTRICA EN EL BRASIL.

Se formula en la presente memoria una previsión del desarrollo de la energía nucleoeléctrica en el Brasil hasta finales de siglo, y se esbozan los principales requisitos para apoyar un programa de esta naturaleza. Por su destacada importancia en el mercado de la energía eléctrica en el Brasil, se ha escogido la región sur-centro para este estudio, siendo los resultados obtenidos ampliamente representativos del país en conjunto. La capacidad de generación de esta región se basa fundamentalmente en la energía hidráulica, pero, tanto el próximo agotamiento de emplazamientos económicos como la necesidad de asegurar el suministro continuo de energía a la red ponen de relieve la precisión de un programa de centrales térmicas, de las que podrían ser nucleares una porción considerable. Se utiliza un modelo matemático de la red eléctrica en expansión para determinar la combinación óptima de centrales hidroeléctricas, térmicas clásicas y nucleares. Se tiene en cuenta la ubicación relativa de las centrales hidroeléctricas a lo largo de la cuenca de un río, con objeto de evaluar la influencia mutua que entre ellas se ejerce al regular el río. Se presenta un estudio paramétrico con el fin de analizar la influencia de los datos de partida sobre el programa nuclear resultante. Adoptando como punto de referencia un programa complementario de centrales térmicas, se analizan diferentes sistemas de reactores nucleares. Se estudia igualmente el apoyo industrial necesario para ejecutar el programa nuclear de referencia.

1. INTRODUCTION

The Brazilian economy shows a rhythm of continuous and considerable expansion, as indicated by the data in Table I for recorded and programmed economic indices for the 1969/73 period. The supply of energy that is necessary for such an expansion has been adequately assured and is reflected in the importance of the energy sector in Brazilian economic life. Indeed, the two largest corporations in the country are related to energy: PETROBRÁS (Federal oil monopoly) and CESP (electric power utility, São Paulo State), both with a US $800[1] million capital.

As regards the electricity sector, a systematic expansion program is being carried out. Total resources invested in 1966/70 reached 2900 million, of which 80% were of domestic origin.

The generating capacity has been predominantly hydro in origin, owing to the vast undeveloped potential. However, forecasts of electricity consumption have indicated the need for a growing complementary thermal program. As early as 1960 CNEN technicians began to analyse the economic advantages of making nuclear power a sizeable part of this thermal program [1-4]. As the economic outlook for nuclear power introduction in Brazil shown by these studies began to take a more definite shape, in 1967 the Brazilian Government proceeded to initiate the necessary steps to introduce the first nuclear plant into the grid. The technical and economic aspects of the problem were reappraised carefully and systematically by a joint study team from the CNEN, ELETROBRÁS[2] and IAEA (1968), in which the previously developed models were used to obtain an up-dated forecast

[1] US dollars used throughout this paper.

[2] ELETROBRÁS is a Federal owned holding electric power company that is responsible for coordinating and financing electric power in the country.

TABLE I. BRAZILIAN ECONOMY - 1969/73

Global value	Unit	1969	1973	1969/73 Increase (%)
1. Gross national product (GNP)	10^9 $	33.5	47.1	41
2. GNP per capita	$	368	465	26
3. Employment	Million workers	29.6	33.5	13
4. Gross investment (fixed)	10^9 $	5.4	8.5	58
5. Industrial product	10^9 $	9.5	14.4	51
6. Exports	10^9 $	2.27	3.32	46
7. Installed capacity	GW	10.4	15.8	52
8. Electricity consumption	GWh	34.3	54.5	59

Source: "Metas e Bases para a Ação do Govêrno"

Values in 1970 Cruzeiros (Cr.)

1 US $ = Cr $4.622 (average for 1970)

US dollars used throughout

which confirmed the benefit of having a 500-MW(e) nuclear plant in the mid-'seventies as the first of a complementary nuclear power program in the expanding generating system. This will be the Angra Nuclear Power Plant, scheduled to enter the grid in 1976 [5].

Meanwhile, with the short-term program of actually constructing the first nuclear plant handed over to the particular utility in charge of it, CNEN gradually shifted its attention to the more general problem of preparing the country for an over-all long-range nuclear program. This task was initiated by an IAEA Report [6]. It was later developed to some extent by CNEN in a short study [7] and now is the object of a systematic study scheduled for 1970-72. This paper summarizes the results obtained up to April 1971.

2. THE SOUTH-CENTRAL REGION POWER SYSTEM

The Brazilian economic expansion mentioned earlier has been unequal in the different regions, for historical reasons.

In particular, 80% of total electricity consumption is concentrated in the South-Central Region (SCR), formed by the States of Guanabara, Rio de Janeiro, São Paulo, Minas Gerais, Espírito Santo and small parts of Goiás and Paraná. This region, with a population of 39.6 million spread over 925 000 km^2 is the economic, demographic and cultural centre of the country. Its determining importance has made it the object of detailed studies on power supply. An exhaustive study on hydroelectric resources of the region was made in 1963-66 under the sponsorship of UNDP, by the CANAMBRA firm of consultants. The resulting report [8] provided a sound basis for power systems expansion program through 1980.

By December 1970, SCR had a total installed capacity of 8400 MW, of which 7700 MW was in hydro power and 700 MW in thermal. Its main assets in terms of generating potential are the rivers of the Paraná basin, which flow inland, and to a lesser extent, a certain number of rivers that flow to the Atlantic. The total remaining hydro potential of the region is about 31 000 MW of which 2400 MW would be derived from river regularization.

Because of the importance of the region, the present CNEN study on a forecast of nuclear power was initially limited to this area, and the results reported in this paper are restricted to the SCR. Work on the Southern Region is already under way [9] while that relative to the other regions is planned. Previous CNEN works on other Brazilian regions [10-12] indicated that during the 'eighties and 'nineties, the nuclear market will certainly not be limited to the SGR, which rendered this forecast correspondingly lower for the whole country.

3. THE MATHEMATICAL MODEL

A computer program [13], which allowed the establishment of the optimum sequence of construction of power stations in an expanding electrical system, was written for a small computer (IBM-1130, 16K memory) and was based on the mathematical model described below.

Its main feature was the taking into account of the geographic distribution of producing and consuming regions.

The first step of the program was to find separately the optimum sequence of hydro power stations, chosen from a given list of sites. The criterion is to choose sequentially the power station which expands the system at the lowest cost per kilowatt. This cost takes into account the mutual influence of hydro stations along the same river basin in upgrading the firm energy through regularizations of the water flow. Due economic allowance is made of the time the system takes to absorb the additional capacity.

The second step is to find the optimum sequence (in time) of hydro and thermal stations (nuclear and conventional). To do this, a given thermal station is introduced in the first, second, etc., place in the optimum hydro sequence, the remaining hydro stations being duly shifted in time; the present-worth of such a system is calculated, referring to a common fixed date, and including investment, operation, maintenance, and fuel costs. The expansion mode with the lowest present-worth cost determines the best timing for building the thermal station. The procedure is repeated for all thermal stations.

The cost to the system of an additional thermal plant is determined as the sum of investment and the present worth of operation and maintenance plus fuel expenses during its 30-year life. Fuel costs are calculated as the sum of fuel expenditure of the new plant and the variation of fuel expenditure of existing plants resulting from the insertion of the new plant. The mathematical model is a marginal model of complementary thermal power [1-2] in which thermal plants are substituted in their order of merit for hydro plants in the base of the load curve during dry periods. Therefore, the introduction of a new plant may alter the position of existing plants in the load diagram. The distribution in time of hydro generation ("hydro productivity curve" - see Fig. 1) is assumed as constant with the expansion of the system, which has proved a reasonable first approximation. The capacity factor of thermal plants is calculated between a minimum of 20% (peaking operation) and a maximum of 85% (base-load operation).

The total added capacity to the system equals the new thermal capacity plus additional peaking capability which is a characteristic of the system (54.5% of base thermal in the present case).

Transmission was taken into account by including in the investment of the stations the transmission costs to one of the three presumed big load centres, Rio de Janeiro, São Paulo, Belo Horizonte. A more complex model for dealing with transmission is available and was applied to the special case of the State of Minas Gerais, for which the program was originally conceived [14]. Owing to the complexity of the SCR grid this advanced aproach was left for future studies.

4. THE INPUT DATA

Based on the projected energy and peak demand from the SCR market study by ELETROBRÁS [15] and on the present firm construction programs, the starting point for the forecast in this paper was determined as that beyond which no firmly decided plant is scheduled to enter the grid. This date is January 1977 by which time the installed capacity will be 12 000 MW hydro, 1000 MW thermal and 500 MW nuclear. To this starting point, the growth-rates of the ELETROBRÁS market study [15] were applied, as indicated in Table II, furnishing the low, medium and high projections of total installed capacity. January 1977 was taken also as the reference date for calculating present-worth values of expansion alternatives, at a discount rate of 10% p.a. The system characteristics, hydro-power-station costs and performance data were those given by CANAMBRA [8], with the following modifications: (a) Costs were all escalated to January 1970; (b) if a more recent design made by the utilities existed for a proposed hydro plant, this replaced the CANAMBRA one; (c) in a few cases lack of published data led to the use of our own estimates.

All feasible available hydro sites (a total of 32) for the South-Central Region were considered. Their price bracket ranged from \$225 to 560/kW of "first added" capacity[3], including transmission, and their capacity ranged from 70 to 9600 MW (Sete Quedas). The unit cost of expanding existing capacity through river regularization ranged from \$86 to 215/kW, including additional transmission. The "hydro productivity curve" of the system is that shown in Fig. 1.

Three kinds of thermal plants were taken as representative of the possible spectrum of cost structure: advanced thermal reactors (ATR),

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[3] "First added" capacity of a hydro plant being that that does not include the benefits of upstream river regularization.

TABLE II. GROWTH-RATES OF INSTALLED CAPACITY - BRAZIL, SOUTH CENTRAL REGION [15]

Period	Low	Medium (%)	High
1975 - 80	8.9	9.55	10.2
1980 -	9.3	9.85	10.6

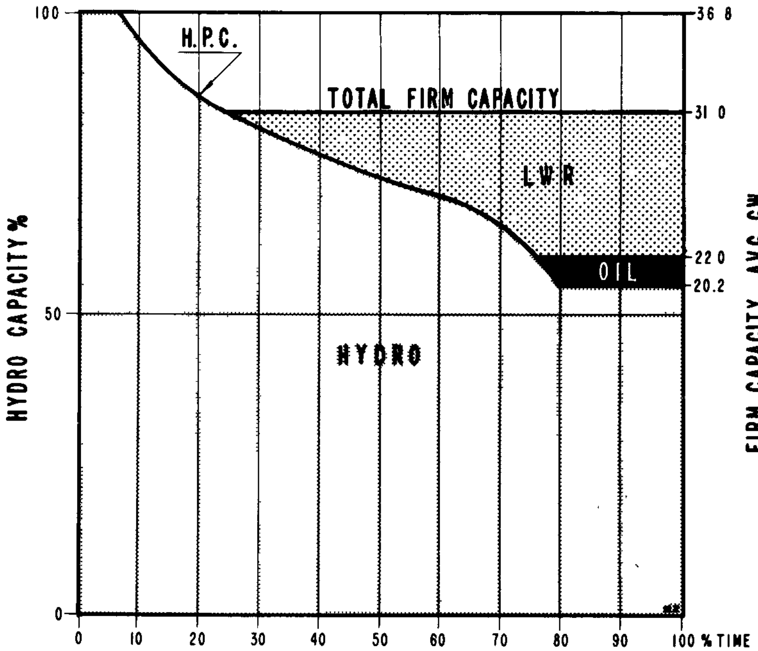

FIG. 1. Hydro productivity curve (HPC) for SCR system as of 1992.

light-water reactors (LWR) and oil plants, in their order of merit (increasing fuel costs). The unit size was assumed as constant for all plants (1000 MW(e)). Costs were taken as representative of those prevailing in 1970 and are presented in Table III. The problem of introducing fast-breeder reactors is treated separately in the strategy studies described further in section 6.

The peaking capacity associated with each thermal plant (545 MW for each 1000 MW) was only specified by its cost of $125/kW, which represents typical peaking plants of the hydro type (pumped storage, etc.), and are not included in the inventory of the 32 base-load hydro plants.

TABLE III. ECONOMIC DATA FOR THERMAL POWER STATIONS (1000 MW(e))

Item	Unit	Oil	LWR	ATR
Investment [a]	$/kW(e)	175	260	320
Fuel consumption (100% c.f.)	$/kW(e) - yr	39.3 [b]	12.2 [c]	7.0
Operation and maintenance (100% c.f.)[d]	$/kW(e) - yr	1.7	2.5	2.5

[a] Includes first fuel load and interest during construction

[b] Fuel-oil price in Brazil in 1970: $19/t

[c] $28.7/kg s.w.u.

[d] c.f. = capacity factor

The installed capacity of the new hydro plants was taken as [firm energy]/0.55, i.e., each plant is assumed to have a 55% capacity factor, which is the capacity of the system as a whole.

As said in footnote 3 the firm energy of a hydro plant is defined as the average generation of this plant during a critical hydrological period, during which the reservoir is completely empty. In this program, taking into account the fact that the system is completely interconnected, the critical period of each plant is taken as equal to the critical period of the system, defined as that when all the reservoirs of the region are completely depleted. Simulation studies of the system during the hydrological series of 1931-1960, showed that the critical period does not vary considerably as the system expands, and that it can be assumed that the critical period for the whole scope under study is the time interval of 54 months which corresponds to June 1952 - November 1956 in the hydrological series [16].

5. RESULTS

The reference result was that obtained with the medium load projection and the thermal stations cost data indicated in section 4. Certain dates were also imposed on three particular hydro plants whose construction has been fairly well decided. These were to be the first, third and fifth hydro plants in the sequence. This reference case is indicated in Fig. 2. Several observations may be drawn from this figure.

The total capacity attains 116 000 MW by the year 2000. Up to 1990, the growth is assured mainly by hydro power which, however, levels off at about 37 000 MW from 1992 onwards. From this date, the total expansion is assured almost exclusively by LWR nuclear stations, which are competing with ATRs and oil-fired stations. The distribution of power stations in the hydro productivity diagram for the system in 1992 is shown in Fig. 1 as an example.

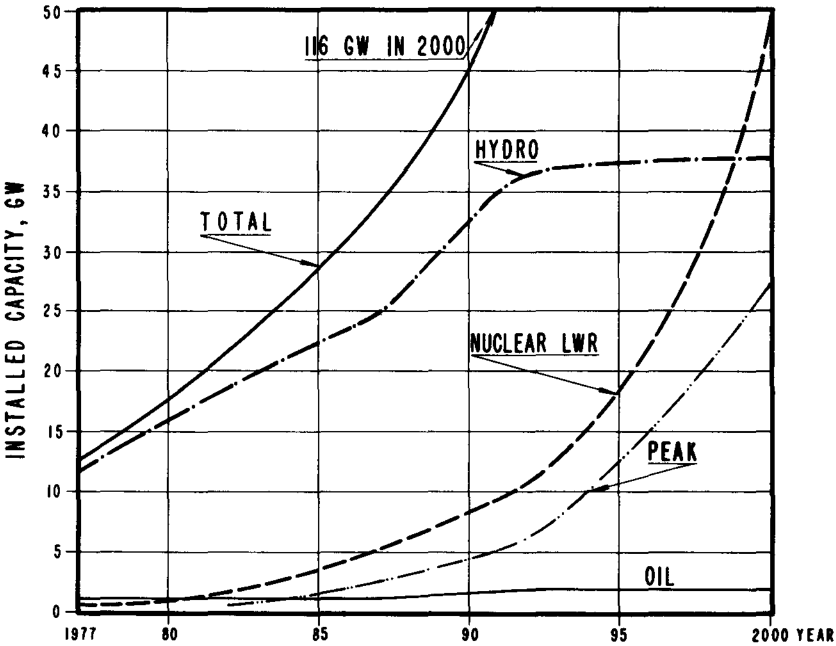

FIG. 2. Reference case.

The nuclear program reaches 50 000 MW (44% of the total) in the year 2000, which means an average of about 2200 MW/yr in the period under study. The introduction rate is low at the beginning - 8500 MW up to 1990 - but sufficient to ensure a continuous rhythm of construction of about one plant per year (average size 850 MW). In contrast, the period 1990/2000 will need about 4100 MW/yr.

The low-investment peaking plants will reach 27 500 MW in the year 2000.

Starting from the reference case, a parametric study was made. First the investment cost of LWRs was increased by 10% and the corresponding result is shown in Fig. 3. The picture is quite different from that of Fig. 2. The overall nuclear capacity drops by 4500 MW (10%). After 1992, when the capacity factor is sufficiently high (0.65 and above), ATRs become competitive and take over the nuclear market. Oil stations also become more competitive and their total capacity is increased from 2000 MW (reference case) to 6000 MW. At the end of the period there is 37 500 MW hydro, 39 000 MW ATRs, 6500 MW LWRs, 6000 MW oil and 27 800 MW peaking capacity (not indicated in the figure, for the sake of simplification). In conclusion, the assumed increased investment in LWRs has a strong effect in the beginning of the program, where 50% of thermal capacity is taken over by oil stations; it also has a strong effect on the structure of the nuclear program, justifying ATRs with their high capital but low fuel-cycle cost. However, the effect on the overall nuclear capacity is small (10%).

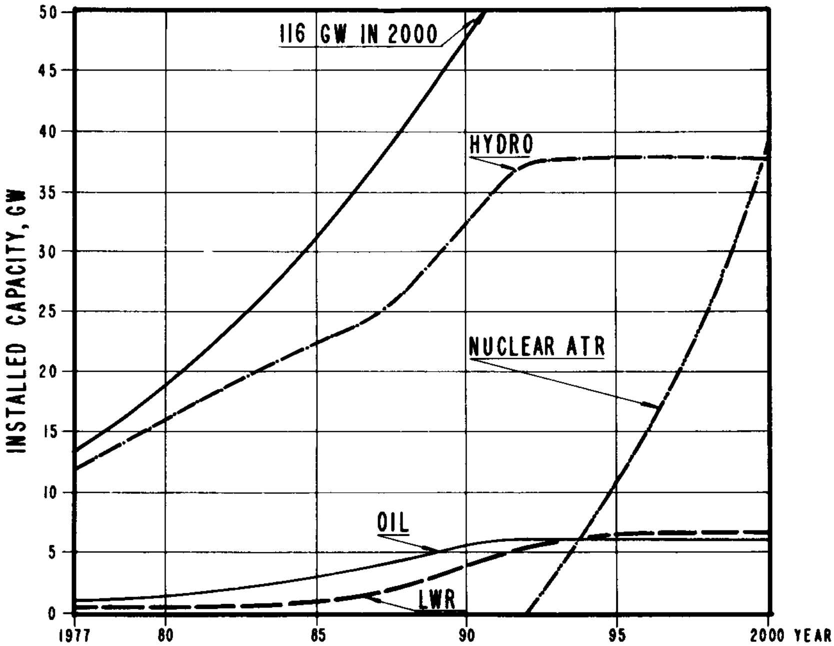

FIG. 3. LWR investment increased by 10%.

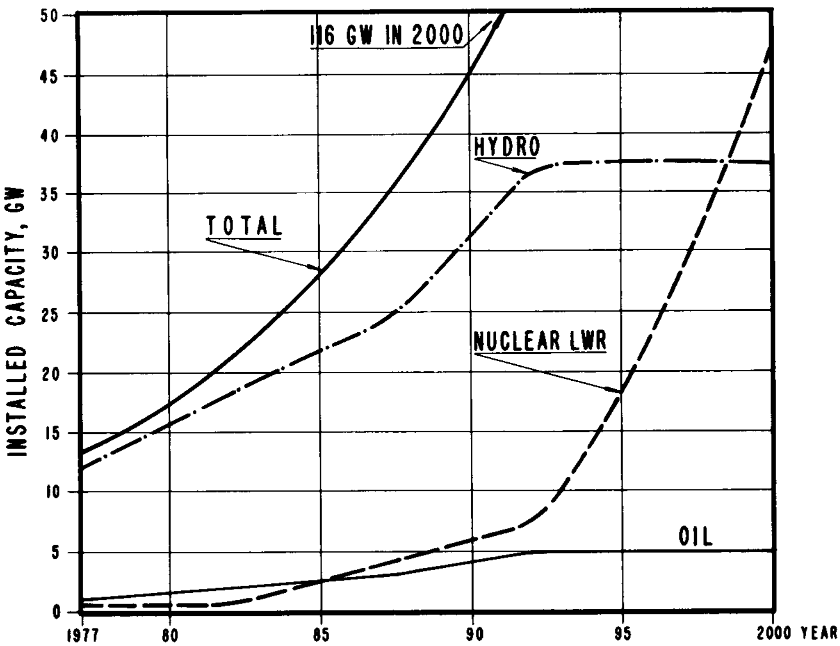

FIG. 4. Oil stations investment (or fuel oil cost) lowered by 10%.

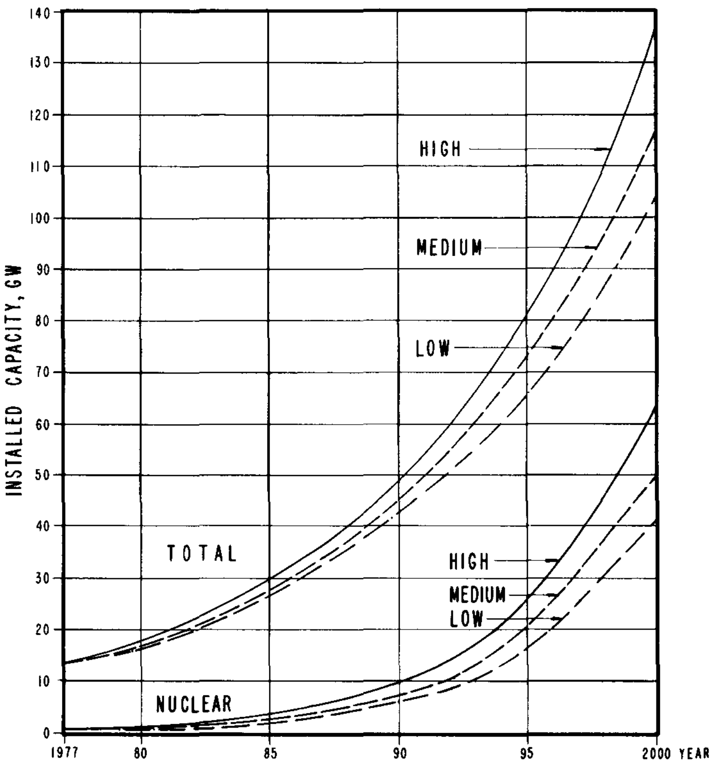

FIG. 5. Effect of capacity projection.

If the investment of oil-fired stations is lowered by 10% the effect on the program is practically the same as that of lowering the cost of the fuel oil by 10%, and the corresponding result is indicated in Fig. 4 (where peak capacity was also left out for the sake of clarity). The program is less altered compared with the reference one than in the preceding case. The total nuclear program is slightly lowered (by 7%), but its structure remains unchanged (only LWRs). In 1982/92, some 3000 MW of oil stations will be introduced instead of nuclear stations.

Of course, as nuclear power is responsible for ensuring the growth of installed capacity after about 1990, the nuclear power program is very sensitive to the total capacity projections. Figure 5 shows the corresponding effect for the three projections of Table II. For the reference costs, nuclear capacity will assume 41 000 MW, 50 000 MW or 62 500 MW, respectively, for the low, medium and high projection.

6. STRATEGY STUDIES

From the results of the preceding section, one sees that the non-hydro share of generating capacity contains a considerable proportion of peaking capacity, which was assumed, in the mathematical model, as

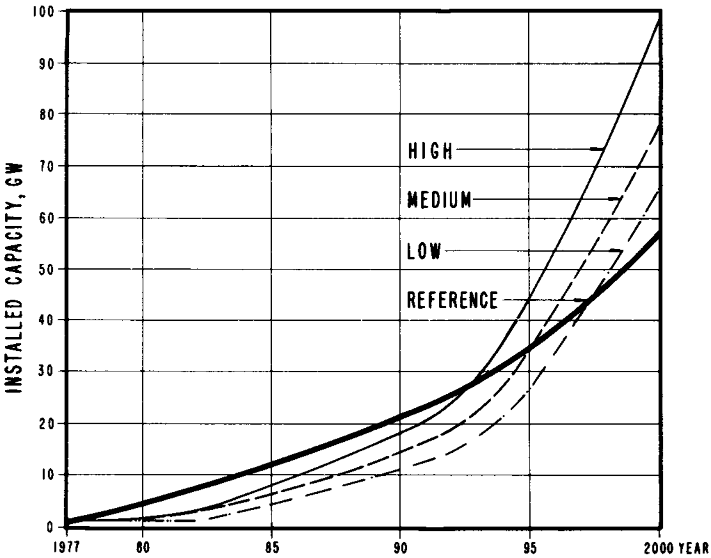

FIG. 6. Non-hydro capacity.

being a fixed percentage of the base-load thermal generating capacity. On the other hand, the preceding model did not allow a true strategy study to be made, as its main purpose was to optimize the introduction rate of thermal stations in an expanding hydro system. In particular, fast-breeder reactors were not considered.

Therefore, to make a more detailed strategy study, another model was used. This was a computer program developed by KFA Jülich, described in Refs [17, 18].

The program input is the non-hydro capacity and the technical and economic data for the stations. For the capacity projection an adequate average of the preceding results was chosen, as indicated in Fig. 6. The economic data are those of Table III. FBRs were assumed to have an investment of $300/kW.

The main output of the program is the optimum mix of stations that leads to the lowest generating cost for the system.

In particular, the peaking capacity is assumed to be taken over by oil stations in contrast with the model of the preceding sections. Also, fast-breeder reactors are allowed to compete, having as one of the input data the plutonium price. Uranium ore, separative work, fuel fabrication and reprocessing requirements are also given in the output for each strategy studied.

To satisfy the thermal station program shown in Fig. 6, five different combinations of oil, LWR, ATR and FBR were applied.

The results for oil + LWR + FBR strategy are shown in Figs 7 to 9. This particular strategy indicates what share of the LWR capacity could be taken over by FBRs. Two results are particularly important.

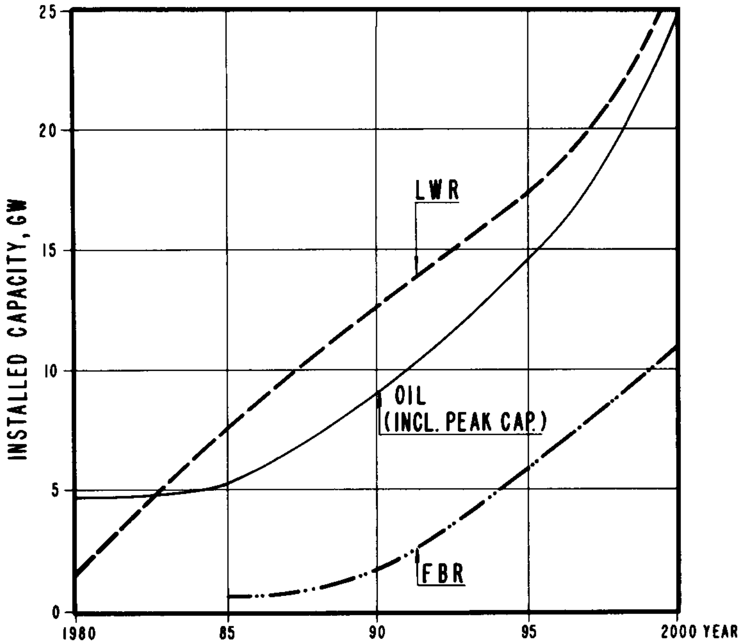

FIG. 7. Strategy study: Oil + LWR + FBR.

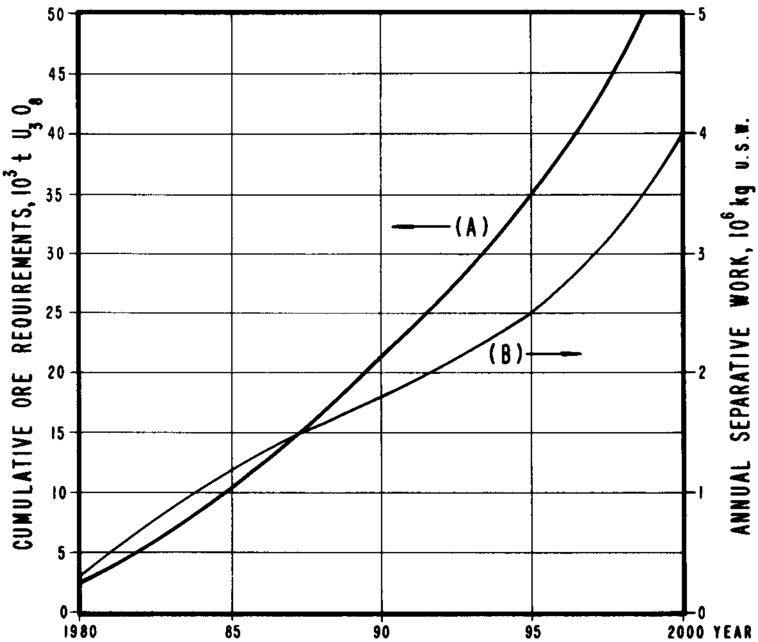

FIG. 8. Ore (A) and separative work (B) requirements for program of Fig. 7.

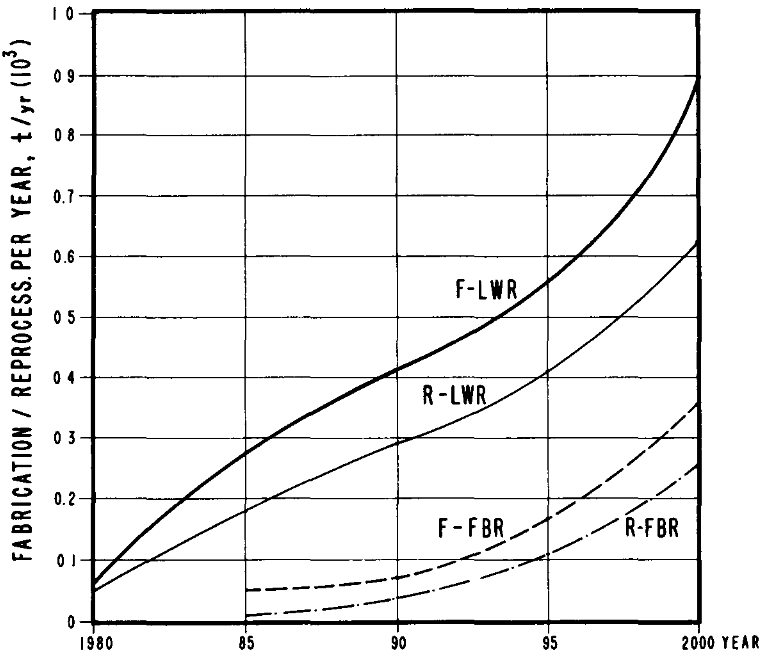

FIG. 9. Fuel-element fabrication (F) and reprocessing (R) for program of Fig. 7.

The first one relates to FBRs. They are allowed to compete from 1985 onwards, constrained both by a condition of system cost minimization and by plutonium availability (no external supply of plutonium is assumed). Results show that the second condition is not a restriction in this case, and that on purely economic competition, 11 000 MW from FBRs might be installed between 1985 and 2000.

The second one relates to peak plants. As it is assumed that their role is taken over by oil stations, their share in the program is greatly increased compared with the reference case of the preceding section (Fig. 2).

7. NUCLEAR INDUSTRY PERSPECTIVES

Figures 8 and 9 show the resulting requirements on the fuel cycle, which indicate the economic interest in establishing a complete fuel-cycle industry in the country from the 'eighties onwards. Preliminary feasibility studies are underway to better define the timing and size of the corresponding industrial installations [19-22].

As regards the electromechanical industry, a preliminary appraisal is being made by a joint IAEA-Brazilian team. The resulting report [23] will provide a basis for future studies to orientate Government policy in the area. Preliminary results are encouraging as to the possible extent of Brazilian industry's participation in the nuclear field.

8. CONCLUSION

From the hypotheses submitted in this paper and applying the mathematical models indicated, the South Central Region of Brazil will need about 50 000 MW (± 20%) of nuclear power stations up to the year 2000. The rhythm of construction will be rather slow in the 'eighties (1000 MW/yr), but will increase considerably in the 'nineties (4000 MW/yr). Such a market underlines the interest in establishing a national nuclear industry, to cover both fuel-cycle and electromechanical components. Additional studies on reactor strategies and feasibility studies on the nuclear industry are being carried on as part of an over-all analysis on the introduction of nuclear power to Brazil, scheduled for 1970-72, and will provide guidelines for future decisions.

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PROJECTED ROLE OF NUCLEAR POWER IN KOREA

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Abstract–Résumé–Аннотация–Resumen

PROJECTED ROLE OF NUCLEAR POWER IN KOREA.

Rapid economic development together with the natural growth of the population in Korea is contributing to an enormous consumption of energy. Korea is increasingly dependent on imported energy resources. Therefore, an economic and stable policy-making in relation to the importation of energy sources plays a significant role in the continuous development of the national economy. Local energy resources – anthracite coal, petroleum and hydro power – are reviewed. Although no resources exist in Korea, petroleum occupied 35% of the energy supply in 1970 and is expected to exceed 60% of the energy supply in 1980. Such a rapid growth of petroleum consumption will be out of control unless it can be met by another form of energy such as nuclear power, which should be a main source of power by the late 1980s.

A study of the future total energy demand and supply reveals that Korean energy needs have to be met economically by nuclear power. With the assumption that annual growth-rates of electric power demands are 9 to 13% for the period 1981 to 2000, and fractions of nuclear power share of total power generation are 9 to 13% for the same period, nuclear power is expected to contribute more than half the electricity power generation by the year 2000.

PREVISIONS RELATIVES AU ROLE DE L'ENERGIE D'ORIGINE NUCLEAIRE EN COREE.

En Corée, la rapidité du développement économique combinée à l'accroissement démographique naturel contribue à accroître la consommation d'énergie dans de grandes proportions. Ce pays doit faire de plus en plus appel aux importations de ressources énergétiques. C'est pourquoi une conception économique et stable de l'importation des ressources d'énergie joue un rôle important dans le développement de l'économie nationale. L'auteur étudie les ressources locales en énergie – anthracite, pétrole et énergie hydraulique. Bien qu'il n'existe pas de ressources pétrolières en Corée, le pétrole représentait 35% de l'énergie consommée en 1970; cette proportion devrait dépasser 60% en 1980. Un développement aussi rapide de la consommation de pétrole échappera à tout contrôle s'il ne peut s'accompagner de la production d'énergie sous une autre forme, l'énergie d'origine nucléaire par exemple, qui devrait devenir la principale source d'énergie avant la fin des années 1980.

Il ressort d'une étude de la demande et de la production énergétiques globales pour les années à venir que l'énergie d'origine nucléaire devra satisfaire de manière rentable les besoins énergétiques en Corée. A supposer que le taux de croissance annuelle de la demande d'énergie électrique soit de 9 à 13% pour la période comprise entre 1981 et l'an 2000 et que la part de l'énergie d'origine nucléaire dans la production totale d'énergie soit de 9 à 13% pendant la même période, on prévoit que d'ici à l'an 2000 plus de la moitié de l'électricité produite sera d'origine nucléaire.

ПЕРСПЕКТИВЫ РАЗВИТИЯ ЯДЕРНОЙ ЭНЕРГЕТИКИ В КОРЕЕ.

Быстрое экономическое развитие, а также естественный рост населения Кореи требуют огромного потребления энергии. Корея все больше зависит от импортируемых энергетических ресурсов. Поэтому экономически оправданная и твердая политика в отношении импорта энергетических ресурсов играет значительную роль в дальнейшем развитии национальной экономики. Местные энергетические ресурсы – антрацит, нефть и гидроэнергия – пересматриваются. Хотя Корея не располагает запасами нефти, ее доля в производстве энергии составляла 35% в 1970 году и ожидается, что она превысит 60% в 1980 году. Столь быстрый рост потребления нефти нельзя будет удовлетворить; необходимо переключение на такой вид энергии, как ядерная энергетика, которая должна стать основным источником энергии к концу 1980 годов.

Изучение вопроса о будущей общей потребности в энергии и ее производстве показывает, что потребности Кореи в энергии могут быть экономично удовлетворены за счет ядерной энергии. Если предположить, что ежегодный темп роста спроса на электроэнергию на

период 1981-2000 годов составит 9-13%, а доля ядерной энергии в общем производстве энергии за тот же период – 9-23%, то можно ожидать, что ядерная энергия будет составлять к 2000 году более половины производимой электроэнергии.

FUTURO DE LA ENERGIA NUCLEAR EN COREA.

El rápido desarrollo económico, junto con el aumento natural de la población de Corea, está originando un enorme consumo de energía. Corea depende cada vez más de los recursos energéticos importados. Por consiguiente, la fijación de una línea de conducta estable y rigurosamente económica, en relación con la importación de recursos energéticos, constituye un elemento decisivo para el desarrollo continuado de la economía del país. Se consideran los recursos energéticos locales, antracita, petróleo y potencial hidroeléctrico. Aunque Corea carece de petróleo, éste representó el 35% del aprovisionamiento total de recursos energéticos en 1970, y se espera que supere el 60% en 1980. Un crecimiento tan rápido del consumo de petróleo terminará por ser incontrolable a menos que se pueda contener recurriendo a otra forma de energía como la electricidad nuclear, que debe llegar a constituir uno de los principales recursos energéticos a finales de los años ochenta.

Un estudio sobre la demanda y oferta futuras totales revela que para responder económicamente a las necesidades de la República de Corea en materia de energía es preciso recurrir a la electricidad nuclear. En la hipótesis de que la tasa de crecimiento anual de la demanda de energía eléctrica sea del 9 al 13% durante el período 1981-2000, y de que la proporción de la electricidad de origen nuclear sea del 9 al 13% de la producción total durante el mismo período, se espera que la energía nucleoeléctrica represente para el año 2000 más de la mitad de la electricidad total generada.

During the past decade, and specially since the inauguration of the first five-year development plan that began in 1962, the economy of the Republic of Korea has enjoyed a sound and rapid growth. The effect of the rapid economic increase and industrial development during these two five-year plan periods has resulted in a considerable increase in the amount of exports and in their quality and type.

Such a rapid economic development together with the natural population growth has caused an enormous consumption of energy, thus forcing us to expend more foreign exchange for the import of foreign energy sources. The future growth of energy consumption is expected to follow the trends evident so far, which means that local energy resources will decrease whereas the imported energy resources will increase as time goes on.

It is, therefore, visualized that the most economic and stabilized policy concerning the import of energy resources will play a significant role in the continuous development of Korean economy. The present task is how to develop a means of saving foreign exchange for the import of energy resources.

1. KOREA'S ENERGY RESOURCES

1.1. Anthracite coal resources

The development of anthracite coal has been in operation since the 1930s. Since bituminous coal, which used to be the main type of coal, is deposited in northern Korea, the mining of anthracite coal was not started until the outbreak of the Korean war. The main reason for the rapid growth in anthracite supplies up to now is due to the government's policy of controlling the uses of firewood in order to protect forestry, together with import restrictions of foreign energy resources because of foreign exchange shortage. Also, more important, the coal industry could produce much cheaper coal in comparison with the relatively expensive imported energy resources.

In fact, in the early stages the production of cheap and abundant coal was due to geologically shallow coal deposits. Above all, a cheap labour force, which was available only in the pre-industrialized era, contributed considerably to savings in capital investment. Such advantageous conditions led to a coal production increase from 1.3 million tonnes in 1955 to 12 million tonnes in 1966. Nevertheless, the coal industry has remained in a backward state. To enhance coal production in the future, therefore, the coal industry must overcome two challenges, namely, the gradual deterioration of the existing situation in producing from deep coal deposits, and the rapid increases in labour wages.

The largest coal consumer is the household sector which was 43% in 1952 and 72% in 1966. In the developed countries, however, the consumption of coal by household sector is only 20%. This wide gap in the anthracite coal consumption between Korea and the developed countries is explained not only by the level of industrialization but also by the low caloric value of Korean anthracite coal. Coal production has increased substantially in the recent years, with an average annual growth-rate of 14.2% in the years 1961 through 1966.

Korea is estimated to have 500 million tonnes of mineable coal reserves, which reach to a depth of 750 m and have a minimum seam thickness of 70 cm. The reserve tonnage represents the estimated recoverable coal, adjusted for expected losses in mining. These reserves could not be the exact amount of deposit, since some areas are reported to have promising coal-bearing formations which are either known or believed to exist, but have so far not been explored or assessed.

Even if the coal production is calculated at an upper limit of 24 million tons per annum in the years to come, its share in the energy market will not exceed 22% in 1980, while it will drop to 5% by the end of this century.

1.2. Petroleum resources

No petroleum deposits have yet been confirmed anywhere in Korea, except for recent indications of some deposits on the continental shelf.

Owing to the government's restriction of petroleum imports, petroleum's share in the energy structure was not significant up to 1965. Until 1964 its share in the energy market was less than 10% of the total. However, on the occasion of the so-called "energy wave", which took place in the winter of 1966, the government turned the tide from solid to liquid fuel, by encouraging people to use imported fuel, which then resulted in rapid growth of petroleum consumption. It represented 35% of the energy supply in 1970, and it is expected to increase to more than 60% in 1980.

Such a rapid growth of petroleum consumption seems to be out of control unless it is replaced by another form of energy such as nuclear power, which will be the main source of power from the late part of 1980s.

1.3. Hydro power

Of about 2×10^6 kW of hydro potential 327 000 kW has already been harnessed in the southern part of Korea, and its status is as follows:

Han River Basin	Capacity (kW)
Hwachon	108 000
Chunchon	57 600
Chongpyong	79 600
Uiam	45 000
Kwaesan	2 600
Sumjin River Basin	
Sumjin	28 800
Bosung	3 120
Unam	2 560

Three more hydro dams are now under construction, namely, Paldang (80 000 kW), Namkang multi-purpose dam (12 600 kW), and Soyang-kang (195 000 kW). It is presumed that about half the entire hydro potential could be tapped by various means.

There is a prospect of rapidly increasing future requirements for water for various uses, with the possibility that a nearly complete utilization of the water supply may eventually be required. Water development planning must therefore be done with due regard to the co-ordination of all water needs, and planning for additions to the hydroelectric generating capacity must be accomplished within this context. Current planning for future dams, in which virtually all new dams are foreseen as multi-purpose structures, is in accord with this need for co-ordination of water usage.

1.4. Nuclear resources

An important nuclear source in Korea is monazite placer, mainly composed of thorium. Pegmatite and graphite, containing small quantities of uranium, are also found, but both are not economically suitable for uranium extraction. The quality of monazite found in 22 areas ranges from 0.03 - 0.08% and contains about 5.0 - 8.0% ThO_2. In some areas, not only monazite but also fergusonite is found in the placer. The quality of this fergusonite is 7 - 15 g/cm^3 and is composed of 3.5% U_3O_8 and 2.1% ThO_2. It is estimated that the amount of monazite deposit in Korea is about 150 000 t, and it is expected that more monazite placer will be found in further investigations.

2. PROJECTED NUCLEAR POWER DEVELOPMENT PLAN

To estimate the total future energy and supply demands, the following assumed annual growth-rate was employed:

Period	Assumed annual growth-rate of total energy demand (%)
1966 - 1971	11
1972 - 1976	10.2
1977 - 1980	8.8

The projected nuclear power development, together with that of hydro, coal and oil power development from 1966 to 1980, are given in Table I.

An attempt was also made to estimate the role of nuclear power after 1981. The assumptions upon which the estimates were based are as follows.

Period	Assumed annual growth-rate of total energy demand (%)	Assumed annual growth-rate of electric power demand (%)
1981 - 1985	10	13
1986 - 1990	7.5	11
1991 - 2000	6.5	9

In this estimate it was also assumed that the fractions of 70, 85 and 95% of the projected increases in demand of electric power would be met by nuclear power from 1981 to 1985, from 1986 to 1990 and from 1990 to 2000, respectively. It should be noted that nuclear power's fraction of total power generation depends on the assumptions of how much of the projected increase will be met by nuclear power. Anyway, under the assumptions we have already made, the nuclear share will reach about 66% of the total power generation by the end of 2000.

In the total energy structure petroleum will be dominant for the time being; however, its share and the growth-rate will gradually decline from 1985. On the other hand, coal and firewood will contribute only 5 and 1% to the total energy requirement by the end of this century.

3. NUCLEAR POWER COST

It can be estimated that a nuclear station of about 600 MW would give cheaper power for meeting the base load (80% load factor). The comparison of cost of power from Kori Nuclear power plant, which is the first nuclear power plant in Korea, and that from a conventional power plant, is given in Table II.

TABLE I. PROJECTED POWER DEVELOPMENT PLAN (1966 - 1980) (MW)

Year	Installed capacity (at year's end)					Peak demand (at year's end)	Installed capacity / Peak demand
	Hydro	Coal	Petroleum	Nuclear	Total		
1966	215	486	68	0	769	765	1.00
1967	327	486	131	0	944	930	1.01
1968	327	561	431	0	1320	1115	1.18
1969	327	700	890	0	1920	1380	1.39
1970	540	830	1090	0	2240	1670	1.34
1971	540	830	1540	0	2910	2000	1.45
1972	870	790	1840	0	3170	2300	1.38
1973	870	790	1840	0	3500	2550	1.37
1974	870	790	1840	0	3500	3070	1.14
1975	870	790	2440	600	4700	3550	1.32
1976	870	790	2440	1000	5100	4050	1.26
1977	870	790	3040	1000	5700	4600	1.24
1978	870	790	3340	1500	6500	6210	1.25
1979	870	790	4040	1500	7200	5940	1.21
1980	870	790	4440	2000	8100	6780	1.19

TABLE II. COMPARISON OF POWER COST FROM KORI NUCLEAR POWER STATION WITH THAT OF A CONVENTIONAL POWER PLANT

1. Construction cost	Conventional	Nuclear
Installed capacity (MW)	300 × 2	595
Load factor (%)	80	80
Construction cost (10^3 $)	44 570 × 2	150 674
Unit price for construction ($/kW(e))	155	267
2. Generation cost (mills/kWh)		
Fixed charge (10.16%)	2.247	3.870
Fuel cost	3.800	1.800
Operation and maintenance	0.252	0.298
Insurance	0	0.052
Unit price (mills/kWh)	6.299	6.020

The fixed charge-rate of 10.16% p.a. is composed of the following.
(unit % p.a.)

Cost of money	5.92	
Depreciation	3.33	
Insurance and local taxes	0.27	
Income tax	0.64	
Total:	10.16	

CONCLUSION

It is well known that the history of world energy is the continuous replacement of one energy by another. As shown in Table I, the pattern of energy supply continually changes. To the Republic of Korea, which is a country that is obliged to import a considerable amount of the energy required from abroad, nuclear power is very attractive. Although it depends on assumptions upon which the estimate is to be made, nuclear power is expected to take over half the electric power generation by the year 2000.

ОПЫТ, НАКОПЛЕННЫЙ В ЧССР, В ОБЛАСТИ РАЗВИТИЯ ЯДЕРНОЙ ЭНЕРГЕТИКИ

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Чехословацкая комиссия по атомной энергии,
Прага,
Чехословацкая Социалистическая Республика

Abstract–Résumé–Аннотация–Resumen

EXPERIENCE GAINED FROM CONSTRUCTION WORK IN CONNECTION WITH NUCLEAR POWER ENGINEERING IN THE CZECHOSLOVAK SOCIALIST REPUBLIC.

The Czechoslovak Socialist Republic is a country with highly developed industry and a tradition of manufacturing power generation equipment for its own use and for export. At present, it cannot develop its own primary energy resources to the extent necessary for the further growth of the national economy and the consolidation of the scientific and technological revolution which has taken place. For this reason, the Czechoslovak Socialist Republic has from the outset been very interested in the use of atomic energy for power generation. The country's initial plans were very far-reaching. Nuclear power generation was to be developed rapidly on the basis of gas-cooled, heavy-water reactors burning natural metallic uranium. The construction of a prototype gradually gave rise to technological problems which could be overcome only by creating an appropriate scientific and manufacturing base. Through concentration of the efforts of the country's main engineering enterprises, the first Czechoslovak nuclear power station is now ready for operation. The delay in completing the construction of the prototype station and the experience gained during construction have made it clear that a prerequisite for the rapid growth of nuclear power in a country with the economic and industrial potential of the Czechoslovak Socialist Republic is wider international co-operation in the manufacture of equipment for nuclear power stations. With regard to the role of nuclear power stations in the Czechoslovak electric power system, it is expected that reactors with a total capacity of 1.8 GW will have been installed at nuclear power stations by 1980 and with a total capacity of 5 GW by 1985.

From the above-mentioned experience it is concluded that the basic reactor type will be the Soviet VVER pressurized-water reactor burning enriched uranium. The Czechoslovak Socialist Republic will contribute 77.5% of the capital equipment for the first two stations, which will have a total capacity of 1.8 GW and on which construction work began in 1970 following the conclusion of an inter-governmental agreement. It is expected that the Czechoslovak contribution will be even higher in the case of subsequent stations. Czechoslovak industrial enterprises are concentrating on the manufacture of certain units for the primary and secondary circuits of nuclear power stations, for which there are increasing commercial opportunities not only within the Czechoslovak Socialist Republic but also in the other member countries of the Council for Mutual Economic Assistance (CMEA). The technological experience gained by Czechoslovak enterprises in building the prototype of the first Czechoslovak nuclear power station is being drawn upon in this process of integration. The basis for further development is a co-ordinated plan of scientific research within the framework of CMEA directed at the construction of pressurized-water reactors of high unit capacity. As part of the integration process it will be necessary to discuss the further role of heavy-water systems in the light of a careful analysis of experience gained in operating the first Czechoslovak nuclear power station. It is generally recognized that in the longer term fast reactors will form the basis for nuclear power generation. Here, the tendency towards integration on the part of countries with an industrial potential similar to that of the Czechoslovak Socialist Republic is strongly marked.

EXPERIENCE ACQUISE PAR LA TCHECOSLOVAQUIE DANS LA CONSTRUCTION DE CENTRALES NUCLEAIRES.

La Tchécoslovaquie est un pays fortement industrialisé qui construit depuis longtemps des installations énergétiques pour ses propres besoins et pour l'exportation. A l'heure actuelle, l'ampleur de ses réserves primaires ne lui permet pas de produire suffisamment d'énergie pour assurer l augmentation du revenu national et faire bénéficier son économie de la révolution scientifique et technique. C'est pourquoi, la Tchécoslovaquie s'est intéressée dès le début à la production d'énergie d origine nucléaire. Les plans initiaux étaient très ambitieux. On envisageait de développer très activement l'énergie atomique en construisant des centrales nucléaires équipées de réacteurs à eau lourde, refroidis par un gaz, qui utiliseraient de l uranium métallique naturel. La réalisation d'un prototype a suscité peu à peu divers problèmes techniques dont la solution a exigé la création d'une infrastructure scientifique et industrielle. Les efforts

conjugués des principales usines tchécoslovaques de constructions mécaniques ont permis de créer la première centrale nucléaire du pays qui est maintenant prête à fonctionner. Les délais nécessaires à la construction du prototype de centrale nucléaire et l'expérience acquise au cours de ces travaux ont montré clairement que dans un pays ayant le potentiel économique et industriel de la Tchécoslovaquie, le développement de l'énergétique nucléaire exige un resserrement de la coopération internationale dans le domaine de la production du matériel destiné à ces centrales. Quant au rôle des centrales nucléaires dans le réseau électrique tchécoslovaque, on peut maintenant affirmer qu'en 1980 la puissance nucléaire installée s'élèvera à 1,8 GW et qu'en 1985 elle atteindra 5 GW.

Compte tenu de l expérience susmentionnée, le programme de construction sera fondé sur des centrales nucléaires équipées de réacteurs soviétiques du type VVER, refroidis à l'eau sous pression et utilisant de l'uranium enrichi. Pour les deux premières centrales d'une puissance globale de 1,8 GW, qui sont actuellement construites dans le cadre d'un accord bilatéral conclu l'an passé, les fournitures d'origine tchécoslovaque atteignent déjà 77,5% du montant total des investissements. On estime que pour les autres centrales qui seront construites en Tchécoslovaquie, ce pourcentage sera encore plus élevé. L'industrie tchécoslovaque concentre ses efforts sur la production d'ensembles de circuits primaires et secondaires pour centrales nucléaires, qui offrent un intérêt commercial non seulement pour le marché intérieur, mais aussi pour celui des pays membres du Conseil d'assistance économique mutuelle. L'expérience technique acquise dans la construction de la première centrale nucléaire tchécoslovaque est mise à profit au cours du processus d'intégration. La Tchécoslovaquie compte aussi participer à un programme de travaux scientifiques coordonnés dans le cadre du CAEM pour la construction de réacteurs de grande puissance unitaire, refroidis à l'eau sous pression. Dans le processus d'intégration, il sera nécessaire d'examiner le rôle qui incombera aux filières à eau lourde, compte tenu de l expérience acquise dans l'exploitation de la première centrale nucléaire tchécoslovaque. En ce qui concerne l'évolution à long terme, on estime généralement que l'avenir appartient aux réacteurs à neutrons rapides. Dans ce domaine, il est parfaitement normal qu un pays aussi industrialisé que la Tchécoslovaquie favorise les tendances d intégration.

ОПЫТ, НАКОПЛЕННЫЙ В ЧССР, В ОБЛАСТИ РАЗВИТИЯ ЯДЕРНОЙ ЭНЕРГЕТИКИ.

Чехословацкая Социалистическая Республика – страна с развитой промышленностью и традиционным производством энергетического оборудования для собственных потребностей и для экспорта. В настоящее время ЧССР не может развивать собственные первичные энергетические ресурсы (принимая во внимание их запасы) в объеме, необходимом для дальнейшего роста национального дохода и для внедрения достижений научно-технической революции в ее экономику. По этой причине ЧССР заинтересована в использовании атомной энергии в энергетических целях. Наши исходные планы были обширными. Развитие атомной энергетики должно было происходить довольно интенсивно на основе ядерных электростанций с тяжеловодными реакторами с газовым охлаждением,сжигающими природный металлический уран. При реализации уникального прототипа постепенно возник ряд технологических проблем, для решения которых потребовалось создать научно-исследовательскую и производственную базу. После сосредоточения усилий наших самых главных машиностроительных заводов первая чехословацкая атомная электростанция готова в настоящее время к эксплуатации. Продление строительства прототипа атомной электростанции и приобретенный опыт в течение его строительства привели к однозначному выводу, что условием для быстрого развития ядерной энергетики в нашей стране при нашем экономическом и промышленном потенциале является более широкая международная кооперация в производстве оборудования для атомных электростанций. В настоящее время можно охарактеризовать роль атомных электростанций в развитии чехословацкой электро-энергетической системы тем, что в 1980 году на ядерных электростанциях будут установлены реакторы мощностью 1,8 ГВт, а в 1985 году их мощность достигнет 5 ГВт. На основе опыта полагаем, что базой для строительства станций будут ядерные электростанции с реакторами советского типа ВВЭР, охлаждаемые водой под давлением и работающие на обогащенном уране. Уже на первых двух электростанциях общей мощностью 1,8 ГВт, строительство которых было начато согласно межправительственному договору в 1970 году, доля наших собственных поставок достигает 77,5% всех капиталовложений. На последующих электростанциях, которые будут строиться в ЧССР, эта доля еще более увеличится. Внимание наших производственных предприятий сосредоточивается на производстве отдельных комплектов первичного и вторичного контуров атомных электростанций, для которых открываются коммерческие возможности не только на внутреннем рынке, но также и на рынке стран-членов Совета Экономической Взаимопомощи. Технологический опыт, приобретенный нашими предприятиями при строительстве уникального прототипа первой чехословацкой атомной электростанции, используется в указанном процессе интеграции. Основой для дальнейшего развития является координированный план научно-исследовательских работ в рамках СЭВа, направленный на строительство реакторов, охлаждаемых водой под давлением, большой единичной мощности. В рамках процесса интеграции на основе тщательного изучения опыта эксплуатации нашей первой атомной электростанции необходимо будет обсудить будущую роль тяжеловодных систем. Общепризнанной долгосрочной перспективой развития атомной энергетики является сооружение реакторов на быстрых нейтронах. В этой области интеграционные тенденции у государства с промышленным потенциалом, подобным нашему потенциалу, становятся достаточно очевидным фактом.

EXPERIENCIA ADQUIRIDA EN LA CONSTRUCCION DE CENTRALES NUCLEARES EN CHECOSLOVAQUIA.

Checoslovaquia es un país industrial considerablemente desarrollado que cuenta con una larga experiencia en la instalación de centrales eléctricas, tanto para las necesidades nacionales como para la exportación. Actualmente, Checoslovaquia no puede desarrollar sus recursos energéticos primarios, teniendo en cuenta sus reservas, a un ritmo necesario para el incremento de la renta nacional y para la implantación de la revolución técnico-científica en su economía. Por esas razones, Checoslovaquia se ha interesado vivamente desde el principio en la utilización de la energía atómica con fines energéticos. Los planes originales eran más bien ambiciosos. El desarrollo de las centrales nucleares checoslovacas hubiera debido ser muy intenso y basarse en reactores de agua pesada refrigerados por gas, que queman uranio metálico natural. Durante el desarrollo y la construcción de este prototipo único se plantearon diversos problemas tecnológicos, cuya resolución exigió el establecimiento de las necesarias bases científicas y de producción. Como consecuencia de los esfuerzos conjuntos de los grupos más importantes productores de maquinaria, se encuentra actualmente dispuesta para entrar en servicio la primera central nuclear checoslovaca. La demora en la construcción de la central prototipo y la experiencia adquirida durante su construcción han conducido a la conclusión unánime de que un desarrollo rápido de la energía nuclear en un país de un potencial económico e industrial como Checoslovaquia solamente se puede conseguir sobre la base de una cooperación internacional muy amplia para la fabricación de los equipos de las centrales nucleares. El propósito que se persigue con la utilización de la energía nuclear al servicio del sistema eléctrico checoslovaco es que en el año 1980 la potencia nuclear instalada aporte 1,8 GW, y en 1985 alcance los 5 GW.

Con referencia a las experiencias mencionadas anteriormente, se considera que estas realizaciones habrán de basarse en las centrales nucleares del tipo soviético VVER, con reactores de agua a presión y uranio enriquecido. Ya en las dos primeras centrales eléctricas, con una potencia total de 1,8 GW, que actualmente se construyen en virtud del acuerdo bilateral concluido el año pasado, la proporción de los suministros nacionales alcanzará un valor del 77,5% de los costos totales de inversión. Se supone que, a medida que se construyan más centrales nucleares en Checoslovaquia, esta proporción aumentará. La industria concentra sus esfuerzos en los equipos seleccionados de los circuitos primario y secundario de las centrales nucleares, para las que se abren posibilidades comerciales no sólo en el mercado nacional sino también de otros países del Consejo de Ayuda Económica Mutua. La experiencia tecnológica adquirida durante la construcción de la primera central nuclear checoslovaca, se está aplicando ahora plenamente en este proceso de integración. La base para su ulterior desarrollo es una colaboración coordinada científica y de investigación, dentro del marco del Consejo de Ayuda Económica Mutua, que conduzca a la construcción de reactores de agua a presión de la mayor potencia posible. Dentro del esquema del proceso de integración será necesario considerar los resultados que se obtengan en el funcionamiento de nuestra primera central nuclear, y evaluar, por consiguiente, las posibilidades de los reactores de agua pesada. Los reactores rápidos, como se reconoce generalmente, constituyen la gran esperanza a largo plazo de la energía nuclear. En este campo, las tendencias a la integración en un Estado del potencial industrial de Checoslovaquia constituyen un hecho de absoluta evidencia.

Для народного хозяйства Чехословацкой Социалистической Республики(ЧССР) характерно, что оно развивалось и продолжает развиваться в условиях борьбы двух противоположностей. С одной стороны, существует высокий уровень развития производительных сил и высокий уровень жизни(при высокой плотности населения). С другой стороны, отсутствует собственная комплексная сырьевая база. В результате этого значительную долю сырья для своего промышленного производства Чехословакия вынуждена импортировать, преимущественно из СССР.

Однако самой крупной и постоянно обостряющейся проблемой в настоящее время является топливно-энергетический баланс. Его структура

ТАБЛИЦА I. СТРУКТУРА ПЕРВИЧНЫХ ЭНЕРГОРЕСУРСОВ ЧССР, %

Энергоресурсы	1950 г	1970 г	1990 г
Бурый уголь	41,3	43,5	27,5
Каменный уголь	55,9	30,3	14,1
Нефть	1,6	20,1	31,1
Газ	–	3,3	6,1
Ядерная энергия	–	–	17,9
Гидроэнергия и импорт электроэнергии	1,2	2,8	2,5

ТАБЛИЦА II. РАСХОД БУРОГО УГЛЯ ИЗ ЕГО ОБЩЕЙ ДОБЫЧИ НА ВЫРАБОТКУ ЭЛЕКТРОЭНЕРГИИ И ТЕПЛА, %

Добыча и расход	1960 г	1970 г	1980 г	1990 г
Общая добыча	100	100	100	100
Расход на выработку электроэнергии и тепла	71,0	77,5	87,0	90,0

на прошлых этапах развивалась под влиянием природных условий в энергоресурсах. Она развивалась, прежде всего, на основе твердого топлива. Конечно, дальнейшее продолжение существенного увеличения добычи угля не соответствовало бы как его запасам, так и возможностям народного хозяйства осуществлять дальнейшие капиталовложения. Поэтому будет необходимо осуществить такие изменения в структуре топливно-энергетического баланса, благодаря которым можно будет обеспечить дальнейшее более эффективное развитие народного хозяйства страны.

Как показано в табл.I, изменению структуры существенным образом способствуют:

а) использование нового энергоресурса, т.е. расщепляющихся материалов,
б) существенное повышение доли жидкого топлива, что будет способствовать не только обеспечению необходимого объема первичных энергоресурсов, но в то же время и повышению эффективности топливно-энергетического хозяйства.

Самые значительные изменения структуры, с точки зрения ресурсов топливно-энергетического баланса, основаны на широком использовании расщепляющихся материалов и на импорте нефти из СССР. Однако, несмотря на эти изменения, главным энергоресурсом остается по 1990 год бурый уголь, использование которого для выработки электроэнергии и тепла, в свою очередь, связано еще и с проблемой загрязнения атмосферы (см. табл.II).

Само собой разумеется, ресурсы бурого угля, при предполагаемом в восьмидесятые годы уровне добычи, окажутся истощенными примерно в течение 60 лет. Ясно, что в связи с этим обстоятельством мы вынуждены были искать подходящие решения, чтобы покрыть постоянно возрастающий дефицит. Решение данной проблемы исключительно за счет импорта энергии или энергоресурсов может слишком обременить баланс внешней торговли. Поэтому, после того как в 1954 году в Советском Союзе была введена в эксплуатацию первая в мире атомная электростанция (и таким образом на практике подтвердилась возможность использовать расщепляющийся материал для выработки электроэнергии), в Чехословакии стали уделять этому вопросу особое внимание. Появилась реальная возможность решить проблему нехватки энергоресурсов в энергетическом балансе путем использования собственных запасов урана. Другие страны также начали уделять значительное внимание вопросу мирного использования атомной энергии для выработки электроэнергии, и во всем мире стали возлагаться большие надежды на этот новый источник генерирования энергии. Оптимизм, который стал преобладать в данной области, повлиял также на рассуждения о перспективах развития ядерной энергетики в ЧССР. И когда мы сегодня, с учетом прошедшего с тех пор времени, даем оценку соображениям, которые в 1955 году прозвучали именно здесь, по случаю Первой Женевской конференции, мы замечаем, что оптимизм тогда в самом деле преобладал.

Еще в 1956 году было подписано в СССР межправительственное соглашение о технической помощи Чехословакии в связи со строительством первой чехословацкой ядерной электростанции А-1. Выбирая подходящий тип реактора, чехословацкая сторона исходила из наличия в ЧССР собственных ресурсов урана. Учитывалась также возможность изготовления твэлов из природного урана в случае осуществления строительства реактора, работающего на природном уране. В результате этих соображений был избран тяжеловодный реактор мощностью 150 МВт(эл), использующий в качестве топлива природный металлический уран, в качестве замедлителя – D_2O и теплоносителя – CO_2. Однако в ходе разработки технического проекта оказалось, что его нельзя будет успешно завершить без экспериментальной проверки целого ряда агрегатов (как, напр. корпусов высокого давления, турбогазодувок, парогенераторов, арматур и т.д.), а также твэлов. В то же время обнаружилось, что с чехословацкой стороны была допущена недооценка технической проблематики А-1. Не хватало как соответствующих научно-исследовательских учреждений, так и необходимых промышленных производственных площадей. Понятно, что все эти обстоятельства, вместе взятые, не могли не отразиться на подготовке А-1.

Каковы основные причины производственных задержек? Они следующие:

1. Необходимо было постепенно создавать научно-исследовательскую и экспериментальную базу для осуществления испытаний некоторых уже упомянутых агрегатов технологического оборудования, а также готовить соответствующих специалистов. Эта база оказалась готовой для начала активной работы по всему комплексу проблем только в 1963–1964 годы.
2. Строительство некоторых специальных производственных предприятий началось лишь в 1964–1965 годах, вследствие чего возможность изготовления технологического оборудования была обеспечена только после 1965 года.
3. Неблагоприятному положению дел в значительной степени способствовал пессимизм (пришедший на смену первоначальному оптимизму), вследствие чего в течение 4 лет строительные работы практически не проводились. Об этом нагляднее всего свидетельствует тот факт, что вплоть до 1964 года было использовано всего лишь 10% общих капиталовложений.

Таковы основные причины, влияние которых надолго отсрочило сооружение А-1. Однако справедливо полагать, что на сооружение А-1 ушло практически 7 лет. Этот период при технической требовательности, предъявляемой к предприятию такого рода, можно вполне сравнивать с периодом строительства подобных сооружений за рубежом, тем более, если учесть имеющиеся кадры и экономический потенциал такой страны, какой является ЧССР. В настоящее время, однако, сооружение А-1 практически окончено и уже начался ее пуск.

Оценивая комплекс результатов, полученных в ходе строительства А-1, следует сказать, что наряду с отрицательным опытом мы получили также целый ряд весьма положительных результатов, которыми мы пользуемся или будем пользоваться не только в дальнейшем развитии ядерной энергетики в ЧССР, но также в развитии некоторых других отраслей промышленности. Мы напомним о некоторых важнейших достижениях в нашей исследовательской работе в данной области, а именно:

1. Найдены и разработаны подходящие виды стали для корпусов реакторов, достигающие все необходимые механические параметры. Одновременно накоплен весьма ценный опыт в отношении циклической усталости и хрупкой прочности у этих специальных видов стали.

2. Освоена сварка частей корпусов толщиной в 150-620 мм, включая их термическую обработку. Таким образом, в нашем распоряжении имеется технология сварки частей и комплексной обработки корпусов непосредственно на строительной площадке.

3. Освоены проверочные дефектоскопические методы и изготовлены автоматические измерительные приборы, при помощи которых мы добились как высокой чувствительности, так и высокой производительности сварочных работ при температурах до 200°С, и т.д.

Многими результатами, полученными в ходе выполнения исследовательских работ и экспериментов, можно будет воспользоваться также при сооружении ядерных электростанций, снабженных реакторами с водой под давлением (советского типа ВВЭР). Не следует упускать из виду и тот факт, что в исследовательской, как и в промышленно-производственной, деятельности воспитан целый ряд специалистов, подготовленных решать сложные задачи ядерной энергетики. Энергетическое машиностроение Чехословакии способно в настоящее время стать квалифицированным партнером по производству определенных частей оборудования ядерных электростанций, которые предстоит сооружать странам-участницам СЭВ.

Общеизвестно, что в ЧССР разрабатывались в виде дальнейших проектов тяжеловодные реакторы типа А-1, а именно для второй (А-2) и третьей (А-3) ядерных электростанций, единичной мощностью 330 МВт(эл) и 500 МВт(эл). Однако в ходе этих работ было обнаружено, что из-за больших сложностей, связанных с разработкой тяжеловодного реактора, возможность разработки и изготовления в Чехословакии преимущественно своими собственными силами промышленного тяжеловодного реактора мощностью 500 МВт(эл) в необходимый срок является нереальной. Поэтому с учетом этого обстоятельства, а также в связи с постоянно возрастающим дефицитом энергетического баланса Чехословацкая комиссия по атомной энергии (ЧСКАЭ) провела глубокий анализ концепции развития в стране ядерной энергетики, основываемой до сего времени на тяжеловодном реакторе, охлаждаемом CO_2 и работающем на природном металлическом уране. Этот анализ привел к заключению, что быстрое развитие ядерной энергетики в такой стране, какой является ЧССР, с таким экономическим и промышленным потенциалом, осуществимо лишь при условии международной кооперации и интеграции в области исследований и, прежде всего, в области производства оборудования ядерных электростанций. Как мы полагаем, к таким же выводам пришли или еще придут и другие страны, экономический потенциал которых соизмерим с потенциалом ЧССР. Не только ядерная энергетика, но и другие с технической точки зрения сложные отрасли служат доказательством интернационального характера науки и техники, так как если учитывать также фактор времени, их можно развивать лишь при наличии соответствующей научно-исследовательской базы.

Эти заключения подтверждаются также результатами модельных программ развития ядерной энергетики, использующей легководные и тяжеловодные реакторы. Результаты дают возможность сделать следующие выводы:

Основное, но в то же время единственное преимущество тяжеловодных реакторов (только при условии, если они с технической точки зрения будут доработаны таким образом, что можно будет добиться высокой степени выгорания) заключается в том, что они расходуют меньше урана и воспроизводят больше плутония.

С другой стороны, тяжеловодные реакторы требуют значительного количества тяжелой воды, что, при современном состоянии ее производства, является главным лимитирующим фактором. То обстоятельство, что на 1000 МВт(эл) уходит примерно 700-800 тонн D_2O, существенным образом ограничивает объем программы ядерной энергетики, основанной на тяжеловодных реакторах.

Имея в виду состояние энергетического баланса ЧССР, в котором дефицит будет постоянно увеличиваться в период 1971-1980 годов, а также учитывая, что этот дефицит невозможно будет действенным образом ликвидировать путем сооружения ядерных электростанций на тяжеловодных реакторах, и далее, принимая во внимание необходимость обеспечить бесперебойное строительство ядерных электростанций после 1980 года, мы пришли к выводу о неизбежности изменения программы, с тем чтобы использовать впредь советские реакторы с водой под давлением типа ВВЭР, которые уже успели себя оправдать на производстве и показали выгодные с экономической точки зрения параметры. Поэтому переломным моментом в развитии ядерной энергетики ЧССР считается заключенное 30 апреля 1970 года межправительственное соглашение между ЧССР и СССР, согласно которому СССР поставит Чехословакии две ядерные электростанции, каждая из двух реакторов типа ВВЭР-440, которые при содействии промышленности ЧССР должны постепенно вступать в эксплуатацию в период 1977-1980 годов, т.е. по одному блоку, начиная с 1977 года, ежегодно. Значение этого соглашения заключается также в том, что ЧССР в области ядерной энергетики приступает, таким образом, к выполнению интегрированной программы стран социалистического содружества, основанной на едином ряде реакторов советского типа ВВЭР. Основным преимуществом такого решения является прежде всего следующее:

1. Обеспечение сооружения необходимых мощностей ядерных электростанций в такие сроки, которых требует развитие энергосистемы в ЧССР.

2. Ядерное машиностроение ЧССР получает реальную, и по срокам благоприятную, возможность производить определенные технологические ком-

поненты оборудования ядерных электростанций не только для ЧССР, но также и для СССР или других стран-участниц СЭВ. Таким образом, можно будет изготовлять более крупные серии, что, в свою очередь, повысит технический, а также и экономический уровень производства. Предшествующая изолированная чехословацкая программа была лишена таких возможностей.

3. Переход к реакторам ВВЭР в то же время делает возможной ориентацию чехословацкой научно-исследовательской и экспериментальной базы на решение избранных проблем по разработке реакторов с водой под давлением (крупных единичных мощностей) и, таким образом, обеспечивает более высокую концентрацию и специализацию этой базы.

Вследствие того что мы в течение нескольких лет стояли на перекрестке решений двух ядерных систем:

– тяжеловодной, которая до сих пор не совсем окончательно разработана и перспективы которой не ясны, и

– легководной, развитие которой предусматривается на период приблизительно до 1990 года,

произошла задержка, весьма неблагоприятная в отношении обеспечения удовлетворительных мощностей в энергетическом балансе. Снова пришлось исследовать возможности более интенсивной эксплуатации отечественных классических ресурсов и, в первую очередь, проверить перспективы увеличения добычи бурого угля. В то же время на случай дальнейшего увеличения добычи бурого угля необходимо было принять во внимание требования защиты окружающей среды и природы. В таких условиях, когда неизбежно требуется сосредоточить электроэнергетические мощности как можно ближе к залежам угля, проблемы загрязнения атмосферы вследствие выбросов SO_2 становятся чрезвычайно серьезными.

Увеличение добычи бурого угля, вообще, и для производства электроэнергии, в частности, ориентировочно показано на рис. 1.

Из приведенного рис. 1 видно, что в ЧССР еще до 1980 года необходимо создать соответствующие условия для быстрых темпов строительства ядерных электростанций в таких масштабах, чтобы они после 1980 года покрывали, в основном, требуемый прирост мощности электростанций в стране.

Одновременно, определяя энергетическую концепцию, нельзя упускать из вида вопросы развития централизованного производства теплоэнергии как для промышленных предприятий, так и для коммунального, бытового потребления. Основным энергоресурсом для выработки тепла, так же как и для производства электроэнергии, в ЧССР в настоящее время является бурый уголь. Поэтому при решении вопросов развития в стране ядерной энергетики значительное внимание уделяется также использованию ядерных теплоэлектроцентралей для выработки теплоэнергии. Целый ряд исследований четко показал, что в условиях ЧССР использование ядерной энергии для выработки тепла является не только актуальным, но и весьма выгодным с экономической точки зрения. На основании этих исследований сделаны следующие выводы:

1. В ЧССР имеется ряд мест, весьма благоприятных для сооружения ядерных теплоэлектроцентралей, в частности, напр., в г. Брно, где работает самая развитая в стране система теплоэлектроцентралей и где такое решение с экономической точки зрения может оказаться выгодным. Поэтому в настоящее время разрабатывается соответствующий проект,

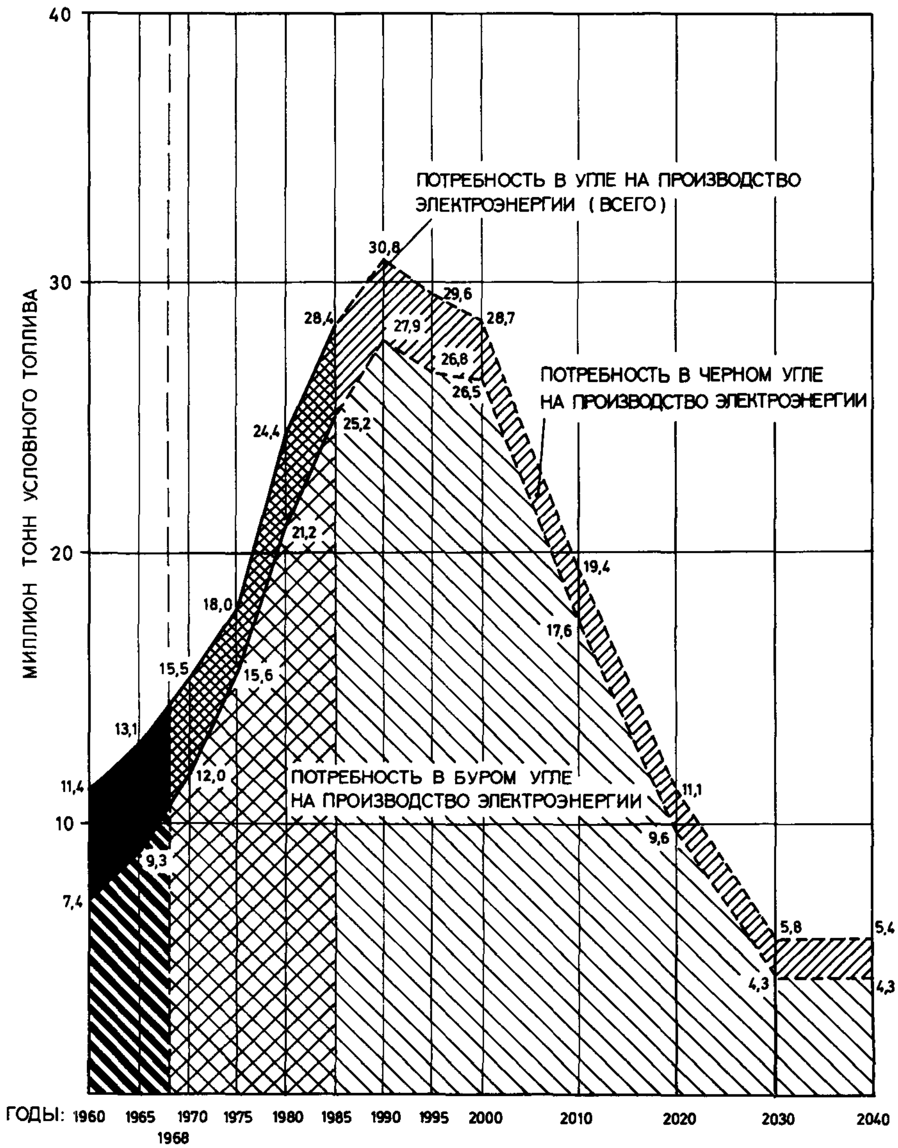

Рис. 1. Ориентировочный прогноз роста потребности в угле для производства электроэнергии в ЧССР до 2040 года.

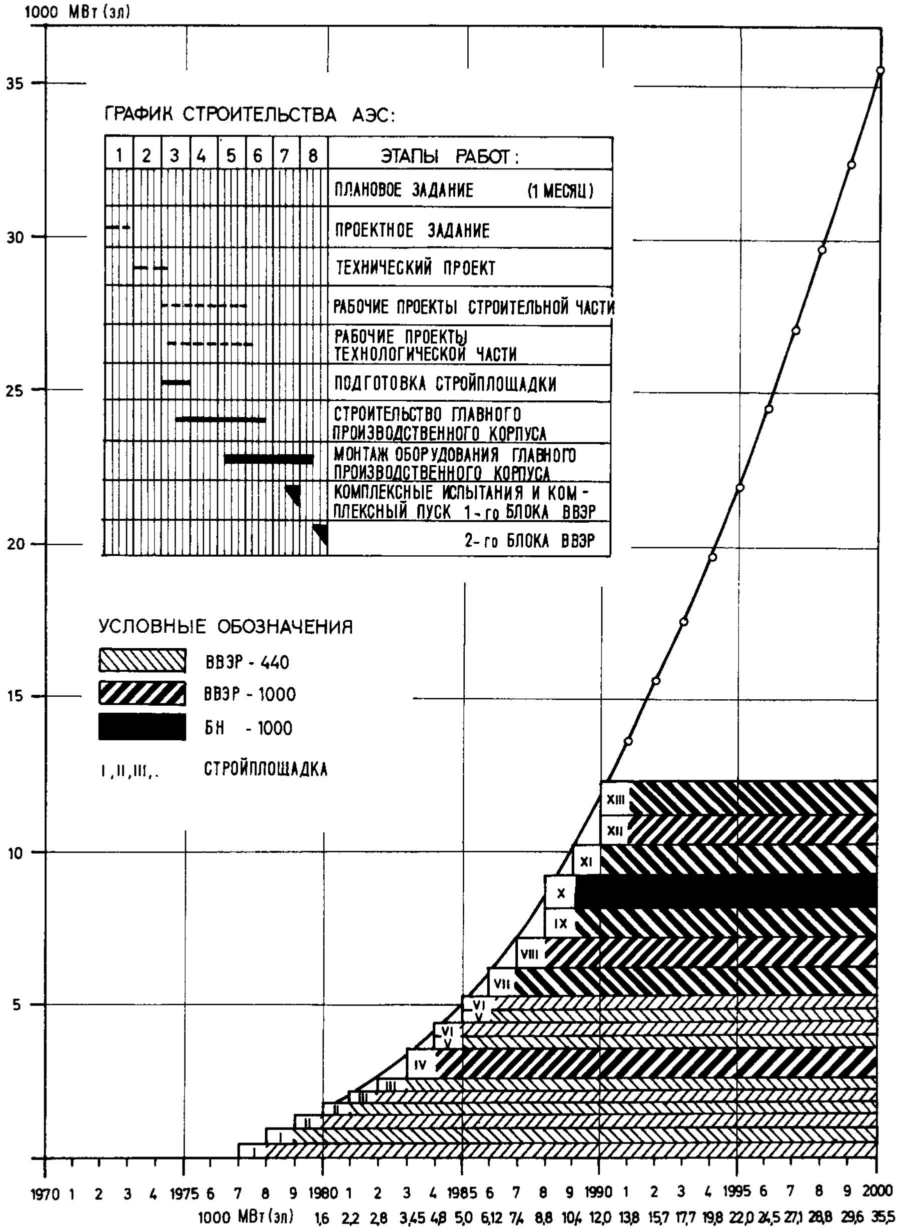

Рис.2. Модель строительства АЭС.

который даст окончательный ответ на вопрос о целесообразности сооружения ядерной теплоэлектроцентрали.

2. Сооружая последующие ядерные электростанции, оснащенные блоками ВВЭР 2×440 МВт(эл), мы можем добиться существенного повышения их эффективности, если на них будут установлены турбины с отбором тепла для технологических целей промышленности и для теплофикации некоторых городов и населенных центров. Поэтому предполагается, что третья и последующие ядерные электростанции будут размещаться в таких районах, где их можно будет использовать для выработки как электроэнергии, так и тепла. Решающий критерий такого решения заключается в обеспечении, соответственно международным стандартам, ядерной безопасности.

При обеспечении развития энергосистемы в ЧССР учитывается следующий рост потребления электроэнергии:

Потребление электроэнергии	1970 г	1980 г	1990 г
10^9 кВт-ч	48,5	92,0	170,0

Чтобы обеспечить такое производство электроэнергии, необходимо установленную мощность в 1990 году увеличить в три раза по сравнению с 1970 годом.

Мощность ядерных электростанций будет увеличиваться следующим образом:

Мощность ядерных электростанций	1980 г	1985 г	1990 г
МВт(эл)	1700	5000	10 000-12 000

На такое развитие рассчитана и разработана модель сооружения ядерных электростанций, показанная на рис. 2.

В этой модели учитывается сооружение до 1985 года ядерных электростанций, оснащенных блоками ВВЭР 2×440 . Предполагается соорудить один блок ВВЭР-1000, который должен обеспечивать строительство после 1985 года. Одновременно предполагается до 1990 года соорудить с помощью Советского Союза еще одну ядерную электростанцию с реактором на быстрых нейтронах. Таковы, вкратце, сегодняшние соображения о развитии ядерной энергетики в ЧССР.

В заключение нам хочется подчеркнуть, что в период 1970-1990 годов энергетика ЧССР будет подвергнута значительным техническим изменениям. Весьма важным моментом является то обстоятельство, что в этот период времени должна осуществиться "нуклеаризация" нашей энергосистемы, в результате осуществления которой доля ядерных электростанций к 1990 году возрастет до 37 - 42%.

Решение о переходе к ядерным электростанциям с советскими реакторами ВВЭР имеет чрезвычайно важное экономическое и прежде всего политическое значение. Оно дает возможность осуществить интеграцию нашей ядерной энергетики с энергетикой Советского Союза и, таким образом, эффективно использовать научно-исследовательскую базу и промышленные производственные мощности ядерного машиностроения.

FORECASTS OF ITALY'S ENERGY REQUIREMENTS UP TO THE YEAR 1990, AND THE ROLE OF NUCLEAR ENERGY

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Abstract–Résumé–Аннотация–Resumen

FORECASTS OF ITALY'S ENERGY REQUIREMENTS UP TO THE YEAR 1990, AND THE ROLE OF NUCLEAR ENERGY.

Part I of the paper analyses the growth of demand related to the individual sources of energy in Italy in the past fifteen years and points out the main problems associated with the energy situation in the country, particularly as concerns reliability and economy of fuel procurement. Based on this analysis and on the anticipated development of Italy's economy, predictions of the energy demand up to 1990 are made and a brief discussion follows on the contribution that each primary source may make to cover the demand in the light of domestic energy resources, the foreseeable trend of the world fuel market, and the anticipated technical and economic evolution of the processes applied for the transformation and utilization of the sources.

Part II of the paper reviews the past history of the Italian electric power system and predicts its future evolution within the framework of the country's energy situation. After a brief description of the main features of the system, the electric energy and power requirements are predicted up to 1990. The potential for developing hydroelectric, geothermal and pumped-storage stations is considered, as well as the role that nuclear energy may be called upon to play to meet the increased requirements. An analysis is made of the various factors that may affect such a role – technical and financial factors, environment protection, dependable sources of supply, etc. – for predicting the development of nuclear stations in Italy over the same period, whence it appears that nuclear energy will increase in importance for covering the demand of electricity.

BESOINS EN ENERGIE PREVUS EN ITALIE JUSQU'EN 1990 ET ROLE DE L'ENERGIE NUCLEAIRE.

La première partie du mémoire analyse l'évolution de la demande constatée en Italie au cours des quinze dernières années en ce qui concerne les différentes sources d'énergie. Les principaux problèmes liés à la situation énergétique du pays sont examinés, en particulier ceux qui concernent la sécurité et l'économie de l'approvisionnement. Sur la base de cette analyse et des perspectives de développement de l'économie les auteurs formulent des prévisions sur la demande d'énergie en Italie jusqu'en 1990 et examinent brièvement la contribution que chaque source primaire pourra fournir pour la satisfaction des besoins, compte tenu des disponibilités énergétiques nationales, des tendances prévisibles du marché mondial et de l'évolution technico-économique probable des procédés de transformation et d'utilisation de chaque source.

La deuxième partie du mémoire est consacrée à l'examen de l'évolution passée et future du réseau électrique italien, dans le cadre de la situation énergétique du pays; après avoir présenté un bref aperçu des caractéristiques principales du réseau, les auteurs formulent des prévisions sur la demande d'énergie jusqu'en 1990. Ils discutent le développement possible des centrales hydro-électriques, géothermiques et à accumulation par pompage, et examinent le rôle que l'énergie nucléaire pourra être appelée à jouer pour satisfaire les besoins nouveaux. Ils analysent les différents facteurs qui pourraient influer sur ce rôle, tels que les facteurs techniques et financiers, la protection du milieu, la sécurité de l'approvisionnement, etc. Sur la base de cette analyse, ils formulent pour la période considérée des prévisions sur le développement des centrales nucléaires en Italie, qui mettent en relief l'importance toujours croissante de l'énergie nucléaire pour la satisfaction des nouveaux besoins énergétiques.

ПРЕДПОЛАГАЕМЫЕ ПОТРЕБНОСТИ ИТАЛИИ В ЭНЕРГИИ НА 1990 год И РОЛЬ ЯДЕРНОЙ ЭНЕРГИИ.

В первой части доклада анализируется увеличение в Италии спроса на различные источники энергии за последние 15 лет и указываются основные проблемы, связанные с энерге-

тическим положением в стране и, в частности, с надежностью и экономикой обеспечения топливом. На основании этого анализа и ожидаемого развития итальянской экономики делаются прогнозы в отношении спроса на энергию по 1990 год и кратко обсуждается тот вклад, который каждый из основных источников может внести в удовлетворение этого спроса с учетом внутренних энергетических ресурсов, предполагаемой тенденции мирового топливного рынка, а также технической и экономической эволюции процессов, применяемых для преобразования и использования этих источников.

Во второй части доклада рассматривается история развития итальянской энергосистемы и предсказывается ее последующая эволюция в рамках энергетического положения страны. После краткого описания основных особенностей этой системы делаются прогнозы в отношении потребностей в энергии и электричестве до 1990 года. Рассматриваются потенциальные возможности строительства гидроэлектрических, геотермальных и гидроаккумулирующих станций, а также роль, которую может сыграть ядерная энергия в удовлетворении возросших потребностей. Дается анализ различных факторов, которые могут повлиять на эту роль ядерной энергии (технические и финансовые факторы, защита от загрязнения окружающей среды, надежность обеспечения топливом и т.д.). На основе этого анализа прогнозируется строительство в Италии ядерных электростанций в указанный период, из чего следует, что ядерная энергия будет приобретать все большее значение в удовлетворении потребностей в энергии.

PREVISION DE LA DEMANDA DE ENERGIA EN ITALIA HASTA 1990 Y PAPEL DE LA ENERGIA NUCLEOELECTRICA.

La parte I de la memoria analiza el crecimiento en Italia de la demanda, referida a las distintas fuentes de energía, en el transcurso de los últimos quince años, y se señalan los principales problemas vinculados con la situación energética del país, sobre todo en lo que concierne a la seguridad y economía en el abastecimiento de combustible. Sobre la base de este análisis y de las perspectivas de desarrollo de la economía, se formulan previsiones sobre la demanda de energía en Italia hasta 1990 y se examina brevemente la posible aportación de cada fuente primaria, habida cuenta de los recursos energéticos nacionales, de la situación previsible del mercado mundial de combustibles y de la evolución técnico-económica probable de los procedimientos de transformación y de utilización de cada fuente.

La parte II de la memoria está dedicada al examen de la evolución pasada y futura de la red eléctrica italiana, dentro del marco de la situación energética del país. Tras una breve descripción de las características principales de la red, se formulan previsiones sobre la demanda de energía y de potencia eléctrica hasta 1990. Se examinan las posibilidades de desarrollo de las centrales hidroeléctricas ordinarias, las geotérmicas, y de las de acumulación por bombeo, así como el papel que podrá representar la energía nucleoeléctrica a fin de subvenir a las nuevas necesidades; se analizan además los diversos factores que podrían influir sobre dicho papel: factores técnicos y financieros, la protección del medio ambiente, la seguridad del abastecimiento, etc. Basándose en este análisis, se formulan previsiones, para el período en cuestión, sobre el desarrollo de las centrales nucleares en Italia, previsiones que ponen de relieve la creciente importancia que ha de adquirir la energía nucleoeléctrica para satisfacer la demanda de electricidad.

PART I

FORECASTS UP TO 1990 [1]

1. PAST TREND OF ENERGY REQUIREMENTS

Between 1953 and 1969 the gross national product at constant prices (1963) grew at an average yearly compound rate of 5.7% and the average income per capita, again referring to constant prices and to the resident population at mid-year, increased from about 360 000 Lire/inhabitant (576 $/inhabitant) in 1953 to about 775 000 Lire/inhabitant (1240 $/inhabitant) in 1969. This rapid growth was accompanied by pronounced modifications in the economic structure as a result of the fast-moving dynamics of the

[1] By F. Marinone.

TABLE I. GROSS CONSUMPTION OF ENERGY IN ITALY IN 1953 AND 1969 BY PRIMARY SOURCES [a]

	1953		1969	
	(10^9 kcal)	(%)	(10^9 kcal)	(%)
Solid fuel	110275	38.0	109929	9.8
Natural gas	18696	6.4	97764	8.8
Petroleum products	85217	29.3	782763	70.2
Primary electricity (hydro, geothermal, nuclear) [b]	76408	26.3	125427	11.2
Total	290596	100.0	1115883	100.0

[a] Inclusive of international bunkerage and the consumption and losses of the energy industry.
[b] The conversion factors adopted here are 1 kWh = 2600 kcal for hydroelectric energy and 1 kWh = 2200 kcal for geothermal and nuclear energy.

industrial and tertiary sectors. The incidence of agriculture on the gross domestic product at factor cost decreased from 20.3 to 12.2% over the period in consideration, whereas the incidence of industry and the tertiary sector increased respectively from 31.2 to 40.4% and from 33.7 to 36.4%.

This economic development determined an exceptional expansion of the energy consumption in a country that lacks sources of energy as well as raw materials in general, a circumstance that in the past was one of the main reasons its industrial development was held back.

As shown in Table I the gross energy consumption in Italy including international bunkerage, rose from 29.1 million t.e.o.[2] in 1953 to 111.6 million t.e.o. in 1969, with a 284% increase equal to an average yearly compound rate of 8.8%.

The over-all availability of energy, taking into account the considerable export of finished products, was even higher in the two years in question, that is, 34.4 and 140.7 million t.e.o., whereas the final consumption (see Table II), net consumption of the energy generating industry and of transformation losses, were, in those two years, 20.6 and 87.5 million t.e.o. All sectors contributed to the increase in consumption, but particularly industry and transport, whose requirements expanded about fivefold.

At the same time, the respective contributions of the primary sources for covering the demand changed radically. There was a marked fallback of solid fuel and primary electricity, the incidence of which decreased respectively from 38.0 to 9.8% and from 26.3 to 11.2%; natural gas rose from 6.4 to 8.8% and the demand for oil grew even more drastically (from 29.3 in 1953 to 70.2% in 1969). The portion covered by national energy sources — essentially natural gas, water and geothermal steam — decreased from 47 to 23% over the same period.

From the foregoing it is evident that the energy sector in Italy is characterized by rapid expansion and strong dependence on foreign primary sources, particularly for oil. In addition, if the national economy, and

[2] t.e.o. = tons of equivalent oil = 10^7 kcal.

TABLE II. FINAL CONSUMPTION OF ENERGY IN ITALY[a] IN SOME YEARS BETWEEN 1953 AND 1969 (10^9 kcal)

Year	Steel industry	Other industries	Transport and bunkerage	Agriculture and fisheries	Domestic and tertiary services	Total
1953	15 945	81 099	45 246	5 759	57 890	205 939
1960	31 018	155 307	100 014	8 249	90 908	385 496
1965	50 167	245 129	178 543	10 881	130 037	614 757
1966	54 936	254 654	197 316	13 210	152 365	672 481
1967	57 986	276 628	202 998	14 669	166 617	718 898
1968	62 818	331 859	216 536	15 361	182 241	808 815
1969	61 819	357 652	229 655	16 598	209 656	875 380
Ratio 1969/1953	387.7	441	507.7	288.2	362.16	425.06

[a] Inclusive of international bunkerage, but net of consumption and losses of the energy industry. Conversion factor for electric energy 1 kWh = 860 kcal.

TABLE III. IMPORTS OF OIL AND COAL, BY COUNTRY OF ORIGIN

Country of origin \ Year	1960	1968	1969	First nine months in 1970
	Crude oil imports (%)			
Middle East	82.7	58.5	57.1	54.0
Africa	2.2	27.0	31.4	35.6
USSR	13.5	11.9	9.1	8.2
Venezuela	1.6	2.6	2.4	2.2
Total	100.0	100.0	100.0	100.0
	Coal imports (%)			
European Community	36.2	31.0	30.0	25.0
Other European countries	14.3	36.0	39.8	40.8
USA	44.8	31.6	28.1	31.0
Other sources	4.7	1.4	2.1	3.2
Total	100.0	100.0	100.0	100.0

chiefly the economy of the manufacturing industry, is to expand, and if Italy's products are to be competitive on the international market, it is essential that quantitatively and qualitatively adequate sources of energy become available on a reliable basis and at the lowest possible cost.

For these reasons, the energy policy in Italy has been directed towards the search for and best utilization of the national sources, while diversifying as much as possible, not only the types of imported fuels from abroad, but also the countries of origin.

The first objective was attained by exploiting practically all the competitive hydroelectric resources in Italy, by utilizing the geothermal forces and the small lignite deposits for the production of electricity, and by launching an intense research for and exploitation of liquid and gaseous hydrocarbons, both on national territory and on the continental shelf.

With regard to the objective of diversifying the origin of imported coal and oil, the situation in these past years is illustrated in Table III.

2. FORECAST OF ENERGY REQUIREMENTS

The past evolution of energy requirements and the prospects of developing Italy's economy justify the belief that the growing trend in energy consumption will continue at a high rate, at least over the current decade. On the other hand, the uncertainty characterizing any forecast obviously assumes greater proportions since the year it refers to is more distant in time. When we try to go beyond a certain time horizon, many other factors may set in to affect the growth and coverage of the demand – economic, technical and political factors, which are much more difficult to evaluate. New technologies and applications may be introduced, abundant reserves of energy may be discovered, and doubtless there will be competitivity of the various sources. In this case, more than a forecast, we speak of working assumptions.

In estimating the growth in energy demand in Italy up to 1990 and in predicting how it will be covered, we have considered it appropriate to take, not a single value for each year, but a range of values within which

TABLE IV. FORECASTS OF GROSS NATIONAL ENERGY CONSUMPTION, CONSUMPTION, INCLUSIVE OF BUNKERAGE

Year	Minimum assumption		Maximum assumption	
	(10^6 t.e.o.)	Average yearly compound increase rate (%)	(10^6 t.e.o.)	Average yearly compound increase rate (%)
1969 (final)	111.6	7.9	111.6	8.7
1975	176.0	6.3	184.5	6.8
1980	239.0	5.0	256.0	6.5
1985	304.5	4.8	351.5	5.3
1990	385.0		456.0	

TABLE V. FORECASTS OF GROSS ENERGY CONSUMPTION IN ITALY IN THE YEARS 1975, 1980, 1985, 1990, BY PRIMARY SOURCES[a]

	Minimum assumption		Maximum assumption		Minimum assumption		Maximum assumption	
	(10^{12} kcal)	(%)	(10^{12} kcal)	(%)	(10^{12} kcal)	(%)	(10^{12} kcal)	(%)
	1975				1980			
Solid fuel	118-138	6.7-7.8	118-138	6.4-7.5	131-171	5.4-7.1	134-174	5.2-6.8
Natural gas	168	9.5	168	9.1	221	9.3	221	8.6
Petroleum products	1333-1313	75.8-74.7	1418-1398	76.9-75.8	1819-1779	76.1-74.4	1969-1929	77.0-75.4
Primary electricity (hydro, geothermal, nuclear)[b]	141	8.0	141	7.6	219	9.2	236	9.2
Total	1760	100.0	1845	100.0	2390	100.0	2560	100.0
	1985				1990			
Solid fuel	137-177	4.5-5.8	146-186	4.2-5.3	136-176	3.5-4.6	154-194	3.4-4.3
Natural gas	246	8.1	246	7.0	246	6.4	246	5.4
Petroleum products	2289-2249	75.2-73.9	2716-2676	77.2-76.1	2660-2620	69.1-68.0	3167-3127	69.4-68.5
Primary electricity (hydro, geothermal, nuclear)[b]	373	12.2	407	11.6	808	21.0	993	21.8
Total	3045	100.0	3515	100.0	3850	100.0	4560	100.0

[a] Inclusive of international bunkerage and the consumption and losses of the energy industry.

[b] The conversion factors adopted here are 1 kWh = 2600 kcal for hydroelectric energy and 1 kWh = 2200 kcal for geothermal and nuclear energy.

the actual figures are expected to fall. So, for the predicted energy demand in the years 1975, 1980, 1985 and 1990, we have indicated upper and lower limits, which respectively constitute the maximum growth assumption and the minimum growth assumption. These two assumptions correspond to two different average yearly rates of increase of the gross national product over the period considered. For the time up to 1980 reference was made to increase rates of 5 and 6%, respectively, which are considered possible in respect of the country's situation, and which presuppose a different utilization of the productive factors and a different increase in productivity. For the following decade, we assumed a slackening of the increase rate with time to take into account both the saturation of demand in some sectors and the gradually reduced availability of manpower.

The values thus determined for the gross national consumption, including bunkerage, are shown in Table IV.

Table V tabulates the predicted coverage of energy requirements, divided by primary sources of energy, based on the following considerations. It should be pointed out, first of all that, mainly for the consuming and manufacturing sectors, where the possible choices are widest, these forecasts are conditioned by many uncertainties resulting chiefly from the availability of the individual sources on the world market, in relation to the respective requirements, and from the competitivity of each source in respect to the others.

(a) The world supply of coal and oil is to be considered sufficient to fulfil the growing demand for a long time to come because the competitive reserves keep in step with the requirements through new discoveries. The difficulties recently experienced because of contingent political and economic circumstances, although very important especially for the provisions that it will be advisable to adopt in order to minimize the consequences of similar situations in the future, appear to affect the cost of energy rather than the reliability of the supply.

(b) Coal consumption is gradually being confined to the steel industry and steam power plant. Since some of the steam power stations in Italy can run on both coal and fuel oil, it is possible to make a choice depending on the future market conditions and on the favourable prospects that may favour coal for use in steam power stations after the recent discoveries in Australia, Africa and Canada.

(c) Because of its peculiar characteristics, natural gas will still be in great demand in some industrial sectors and for domestic applications, even though its per cent incidence on the energy balance is bound to fall. Should the prospecting on national territory and off-shore fail to give the expected results, it will be necessary to continue a sound import policy to ensure the required supplies.

(d) The contribution that nuclear energy may make to the coverage of electricity requirements is discussed in the second part of this paper. On this point we shall merely state here that the share of this new source will become substantial only around the 'eighties; however, even in 1990 the nuclear source should not cover more than one-fifth of the over-all requirements.

(e) Minor developments, in terms of quantity of energy, are to be expected from the exploitation of water resources and geothermal steam.

Therefore, we may expect that over the whole period considered, the coverage of the increased demand will be entrusted mainly to imported oil. This supports the objective of Italy's energy policy aiming at ensuring the supply of this source on a reliable basis and at the lowest possible cost.

PART II

FORECAST OF NUCLEAR ENERGY DEVELOPMENT IN ITALY[3]

1. FORECAST OF THE GROWTH OF POWER REQUIREMENTS IN ITALY UP TO THE YEAR 1990

In 1970 the electricity demand in Italy was nearly 115.6 billion kWh and the winter peak power demand was 19 700 MW; the average consumption per capita was 1975 kWh. In the same year hydroelectric plants contributed to covering the demand by 36.5%, conventional steam power plants by 56.6%, geothermal plants by 2.2% and nuclear plants by 2.7%.

In the past eighteen years, from 1953 to 1970, after the post-war reconstruction stage, the electricity consumption in Italy rose from 31.8 to 115.6 billion kWh and the winter peak power demand rose from 5482 to 19 700 MW. The respective yearly average compound increase rates, assessed on the interpolating tendency curve were 8.1 and 8.5%.

During that period, the structure of the electricity generating media underwent a radical change in Italy because of the gradual depletion of exploitable water resources on one hand and of the rapid progress in the thermoelectric field on the other. Moreover, the gradual expansion and uprating of the country's high voltage network permitted the installation of steam power units of increasing ratings, the largest of which are rated for 600 MW and have been in operation since 1967.

So, while in the 'fifties the hydroelectric production was about 90% of the total, it was only 36.5% in 1970 and is destined to continue a downward trend.

The rate of increase in electricity consumption in Italy was relatively high compared with the average in other industrialized countries, whereas the per capita consumption is still rather low. Therefore, we anticipate that the growth in electricity consumption, just like the over-all energy requirements, will continue to follow the present trend, at least throughout the 'seventies, or may even start to rise slightly faster.

In forecasting the development of electric energy and power requirements in Italy up to 1990, we have indicated a range of values within which the actual future demand is likely to fall, rather than indicate a single value.

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[3] By A.M. Angelini.

TABLE VI. FORECAST OF ELECTRIC ENERGY AND PEAK POWER REQUIREMENTS IN ITALY UP TO 1990

Assumption of development	Minimum		Maximum	
	Energy (kWh x 10^9)	Peak power (MW)	Energy (kWh x 10^9)	Peak power (MW)
1970	116	20 600 [a]	116	20 600
1980	230	41 300 (± 2 400)	280	50 400 (± 3 000)
1985	320	58 200 (± 3 400)	420	75 800 (± 4 400)
1990	450	81 700 (± 4 800)	600	109 500 (± 6 300)
Estimated yearly increase rate:				
1970-1980	7.1	7.2	9.2	9.4
1980-1985	7.0	7.1	8.4	8.5
1985-1990	6.9	7.0	7.4	7.6
1970-1990	7.0	7.1	8.6	8.7

[a] Tendency values.

The results of these forecasts are summarized in Table VI which also tabulates the yearly average compound increase rates resulting from these forecasts. With regard to the winter power peak, Table VI indicates in parentheses the plus or minus deviation from the estimated value that is likely to result from unforeseeable contingencies and weather events.

In view of the time required for the construction of a power station, the electricity requirements estimated for 1976 are already covered by ENEL's plans for new plants — most of which are already under construction. These plans are based on the assumption of maximum development and provide for the commissioning of over 21 000 MW in the seven years between 1970 and 1976. This is an integrated complex of stations, of which approximately 2000 MW will be pumping stations, 1150 MW will be new or totally rebuilt hydroelectric stations, 800-MW nuclear stations, and the remainder conventional steam power stations.

2. PROSPECTS FOR THE DEVELOPMENT OF NUCLEAR STATIONS IN ITALY

We already mentioned that the water resources still to be exploited in Italy are practically nil. The development of geothermal plant depends on the magnitude of the new sources of geothermal steam that will be discovered; our explorations in the past years have given encouraging results, but here, more than elsewhere, it is impossible to make any predictions and therefore we cannot firmly rely on a substantial contribution from this source. As a result, virtually all the new electricity requirements will have to be fulfilled by thermal stations, both conventional and nuclear. An important role may also be played by pumped-storage stations for regulation and spinning reserve [1, 2].

The proportion of thermal plant that may be covered by nuclear plant in Italy is a function of many different factors. First of all, there is the question of reliability of the nuclear units. A sufficiently high degree of reliability is a prerequisite for a large recourse to nuclear energy. In this connection, the operating experience acquired to date with first-generation reactors has not always been positive and it can only partially be extrapolated to the units of the new generation, which differ from their predecessors, not only because they are much larger, but also because of technical and structural innovations [3]. Therefore, we cannot take it for granted that the new units will be characterized by a satisfactory degree of reliability. However, there are many facts that induce us to have confidence; for instance, the enormous industrial and financial effort expended in the nuclear field, the competence and capability of the manufacturers and organizations concerned with nuclear development, the large number of high-rating power stations under construction in many countries. In about five years, thanks to the experience acquired with the units of the new generation, sufficient data and records should be available to substantiate well-founded confidence in the reliability of the so-called proven-type nuclear reactor plants.

Once this confidence on the reliability is attained, the most important factor from the standpoint of a more or less extensive development of nuclear plant is competitivity or, better, the degree of competitivity of nuclear energy.

The limited space available does not allow a review of the many factors — some of a local nature — that affect the kWh generating cost, but it should be pointed out that a few of these factors have changed so much in these past years as to have affected nuclear plant development appreciably. Reference is specifically made to:

(a) the increase in the price of fuel oil; last year this increase was, in Italy, approximately 0.6 mills/10^3 kcal and it considerably strengthened the competitive position of nuclear energy; moreover, an analysis of the world situation appears to indicate that this situation of high prices in the oil industry will persist in the future;

(b) The good prospects of the uranium market in respect of prices, availability, and reliable sources of procurement for the current decade and, very likely, also for the future, particularly in view of the possibilities offered by the advanced reactors;

(c) The high cost of money and the scarcity of capital recently experienced in many countries and particularly in Italy; this situation places an added burden on the cost of electricity generated by nuclear stations, and if it should persist it might constitute a remarkable hindrance to the implementation of vast nuclear plant construction programs;

(d) The ever-increasing importance to be attached to protection of the environment; there is no doubt that from this aspect nuclear stations score points to their advantage; based on experience to date, the release of radioactive substances is many times below the limits specified in regulations that were formulated on a very prudential basis.

In brief, many factors today appear to favour an intensive development of nuclear energy, especially the foreseeable trend of the kWh cost, which is likely to be more favourable to nuclear stations than to conventional thermal stations, also because of the wider margins available for development of the former and because of the youth of nuclear technology.

Conversely, the greatest obstacles that could slacken the pace, or condition the development of nuclear energy, can be identified in a failure of the stations now being built to confirm in the forthcoming years the expectations of satisfactory reliability (and this seems rather improbable), and in a scarcity of capital; concerning the probability of the latter situation in years to come, it is difficult to make predictions.

3. FORECAST OF NUCLEAR PLANT DEVELOPMENT IN ITALY

On the basis of the preceding considerations, practically all the new electric energy requirements will have to be met in Italy with conventional and nuclear power stations. A considerable portion of the regulation and spinning reserve duties will be assigned to pumped-storage stations.

The contribution of each type of plant, as a whole and in conjunction with the plant now in operation or construction, will have to be such as to afford the technical-economic optimum in the coverage of the future load curves. This optimization is to be carried out, of course, in full observance of the limitations posed by service continuity and of the restriction in availability, development rates and modes of operation (minimum continuous loads) of some of the generating means, in addition to regional and environmental circumstances.

The forecast development of the different types of plant is summarized in Table VII.

With regard to nuclear stations in particular, the figure relating to the year 1975 (1450 MW in operation) is the sum of the existing stations (620 MW) and those under construction (40-MW CIRENE prototype and the fourth 800-MW nuclear unit). For the years between 1975 and 1980, the forecasts are based on ENEL's tentative plans for the five-year period 1970-1974, whereby one 800 - 1000-MW nuclear unit will be ordered each year on an average. In 1975 the program came to a standstill because of insufficient capital for new investments; if this situation changes rapidly in the desired direction, we can still hope to implement it totally on schedule. In such a case, in 1980 some 5500 to 6500 MW of nuclear plant would be on base-load duty, and their output would represent about 13-17% of the total electrical output in that year.

The forecasts relating to stations to be commissioned from 1980 onwards — for which a decision will have to be made after 1975 — are based on the following assumptions:

TABLE VII. FORECAST OF THE CAPACITY AVAILABLE IN ITALIAN POWER STATIONS TO COVER THE WINTER PEAK DEMAND[a] IN 1970-1990

Year	Capacity (MW) available to cover winter peak demand [a]						
	Pumped-storage	Hydro (modulation and regulation)	Conventional thermal	Nuclear	Geothermal	Run-of-river	Total
	Case A: Assumption of minimum development of power demand. Nuclear stations competitive at 7000 kWh/kW						
1970	500	6730	15 000	600	320	1450	24 600
1975	2800	7530	27 150	1 450	320	1450	40 700
1980	4400	7530	31 300	5 500	320	1450	50 500
1985	6400	7530	40 300	16 000	320	1450	72 000
1990	8400	7530	40 300	44 000	320	1450	102 000
	Case B: Assumption of minimum development of power demand. Nuclear stations competitive at 5000 kWh/kW						
1970	500	6730	15 000	600	320	1450	24 600
1975	2800	7530	27 150	1 450	320	1450	40 700
1980	4400	7530	42 200	6 500	320	1450	62 400
1985	6400	7530	59 100	20 000	320	1450	94 800
1990	8400	7530	60 300	60 000	320	1450	138 000

[a] This is the capacity available in the stations at winter peak demand on the assumption that no generating machines are out of service for failures or maintenance. For nuclear and steam power stations, this coincides with the maximum capacity.

Normal situation of the financial market, so that there will be no particular limitations on the availability of capital for new investment; and

Operating experience acquired up to 1975 and later with large nuclear stations providing sufficient assurance of their reliability.

Under these assumptions, the determining factor in the development of nuclear plant is essentially represented by economics, in addition, of course, to the limitations posed by service continuity and safety and other technical requirements of the network. However, in forecasting the development of nuclear stations in Italy, it was assumed that in the early 'eighties there would be a gradual shift from an essentially conventional thermal system to a prevailing nuclear system.

To synthesize the anticipated economics of nuclear stations, reference has been made to the hours of utilization per year, at which nuclear stations are competitive with conventional steam power stations. Because of the uncertainties extant on this point, here again two values were assumed, namely 7000 kWh/kW and 5000 kWh/kW.[4]

By combining the first assumption, which implies a slower technical-economic progress of the nuclear plant, with the assumption of minimum growth of electric energy demand indicated in Table VI, we obtain the forecasts for the years 1985 and 1990 for Case A in Table VII.

Likewise, by combining the assumption of nuclear competitivity at a yearly utilization of 5000 kWh/kW with the assumption of maximum growth of electric energy demand, we obtain the forecasts for the years 1985 and 1990 for Case B of Table VII, which are to be considered the forecasts of maximum nuclear plant development in Italy.

Table VII clearly shows what an important role nuclear energy will presumably be given in Italy after 1980; the nuclear installed capacity should be between 16 000 and 20 000 MW in 1985, and between 44 000 and 60 000 MW in 1990.

Of still greater importance might be the contribution of nuclear stations to coverage of the energy demand; in fact, because of the low marginal cost of electricity they produce, the tendency will be to utilize them more and more, compatibly with the technical limitations and with the network requirements. In 1985, approximately 100 billions out of the 320-420 billion kWh of total energy demand might be supplied by nuclear stations; in 1990 nuclear stations might generate 280-390 billions of the total demand of 450-600 billion kWh.

It also appears from Table VII that, in the last five-year period considered (1985-1990), almost all the new thermal plant will be nuclear. This should not be cause for surprise, because this new means of generating electricity, once it is rid of all the technical and economic uncertainties that hold up its development, will tend to assert itself and to cover all the band on the load diagram within which it is competitive, thus displacing upwards the other types of stations.

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[4] It may be interesting to note that if the limit of competitivity were taken to correspond to a yearly utilization of 4000 kWh/kW, the nuclear capacity indicated in Case B of Table VII for the years 1985 and 1990 would increase very slightly.

Of course, this is a transition stage, and once the situation has become stable, the incremental requirements will be met, in rather significant proportions, with the participation of other generating means that are more competitive and more suitable for peak operation or reserve duty.

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RESOURCES OF PRIMARY ENERGY

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Abstract–Résumé–Аннотация–Resumen

RESOURCES OF PRIMARY ENERGY.

The problem of the long-term primary energy supply is extremely complex. It involves three main questions: (1) Whether the required quantity of a certain kind of primary energy be made available at a given time and within a given area; (2) Would the quantity of primary energy meet competitive requirements?; and (3) whether the total supplies for primary energy requirements are guaranteed for centuries on a world-wide basis. The interdependency of these three questions is evident. The annual consumption of energy to be apportioned to a given kind of primary energy, and thus also the annual production of this primary energy, depend on numerous factors which, on their part, are interrelated.

The usable, regenerative sources of the world's energy are about 0.06×10^{18} kcal/yr. Although they could, in principle, meet about a quarter of the world's annual energy requirements by about the year 2000, they can be utilized to a limited extent only in the modern economy.

Fossil fuels amount to about 28×10^{18} kcal, if it is assumed that the atmosphere's oxygen is a derivative of the photosynthesis of the chlorophyll, and that about 1% of the presumed overall reserves of fossil fuels can be gained economically. The usable basic materials for nuclear fission represent energy reserves of around 1.5×10^{21} kcal. At present it is not possible to say anything definite about nuclear fusion except that, judged by human standards, it is inexhaustible.

Taking the present requirements as a basis, fossil fuels would be sufficient for about 460 years, and the basic materials for nuclear fission for even 25 000 years. This consideration, however, leads to false conclusions. It is necessary to consider the world's population growth as well as the increasing per-capita consumption. The result is that the reserves of fossil fuels would, for example, be sufficient up to only towards the end of the 21st century, whereas nuclear fuels would suffice for about 300 years. Thus, on one hand, the world will be dependent upon nuclear fusion in the long term, and, on the other hand, sufficient time remains to develop it.

RESSOURCES EN ENERGIE PRIMAIRE.

Le problème des ressources à longue échéance en énergie primaire est très complexe. Il comporte trois aspects principaux indiqués ci-après: 1) Est-il possible de mettre à la disposition des utilisateurs à un moment donné et dans une région donnée la quantité requise d'une certaine forme d'énergie primaire? 2) Cette quantité permettrait-elle de répondre aux exigences de la concurrence? 3) La totalité des besoins mondiaux en énergie primaire pourra-t-elle être satisfaite pour les siècles à venir? Il est évident que ces trois aspects sont étroitement liés. La consommation annuelle d'énergie sous une forme primaire donnée et, partant, la production annuelle d'énergie primaire dépendent de nombreux facteurs entre lesquels il existe aussi une corrélation.

Les ressources mondiales en énergie qui peuvent être exploitées et régénérées s'élèvent à environ $0,06 \times 10^{18}$ kcal/an. Bien qu'elles suffisent en principe à satisfaire au quart environ des besoins en énergie du monde vers l'an 2000, l'économie moderne ne permet de les utiliser que dans une mesure limitée.

Les combustibles fossiles représentent environ 28×10^{18} kcal, si l'on admet que l'oxygène atmosphérique provient de la photosynthèse de la chlorophylle et qu'il est possible d'exploiter économiquement environ 1% de la totalité des réserves présumées de ces combustibles. Les matières de base utilisables pour la fission nucléaire représentent une réserve d'énergie d'environ $1,5 \times 10^{21}$ kcal. Pour le moment, on ne peut rien dire de précis au sujet de la fusion nucléaire sinon qu'elle constitue, pour autant qu'on puisse en juger, une source d'énergie inépuisable.

D'après les besoins actuels, on peut calculer que les combustibles fossiles suffiraient pendant environ 460 ans, et les matières de base pour la fission nucléaire pendant 25 000 ans. Ces hypothèses risquent toutefois de conduire à des conclusions erronées. En effet, il faut prendre en considération l'accroissement démographique et l augmentation de la consommation par habitant. Compte tenu de ces facteurs, les réserves en combustibles fossiles ne suffiraient que jusqu'à la fin du 21ème

siècle, et les combustibles nucléaires seraient épuisés au bout de 300 ans. Il en résulte d'une part qu'à longue échéance le monde sera tributaire de la fusion nucléaire, et d'autre part, qu'il reste encore suffisamment de temps pour mettre cette forme d'énergie en valeur.

ОСНОВНЫЕ ЭНЕРГЕТИЧЕСКИЕ РЕСУРСЫ.

Проблема длительного снабжения энергией является исключительно сложной. Эта проблема связана с тремя основными вопросами: 1) Может ли быть предоставлено требуемое количество определенного типа энергетического сырья в данное время и в данном конкретном районе? 2) Удовлетворит ли это количество энергетического сырья соответствующие энергетические потребности? 3) Гарантировано ли удовлетворение всех потребностей в электроэнергии в мировом масштабе на предстоящие столетия? Взаимозависимость всех этих трех вопросов очевидна. Ежегодное потребление энергии, связанное с каким-либо конкретным источником энергии, а следовательно, ежегодное производство источников этой энергии зависит от различных факторов, которые, в свою очередь, взаимосвязаны друг с другом.

Годные к использованию регенерируемые источники энергии в мире составляют примерно $0{,}06\times10^{18}$ ккал/год. Запасы ископаемого топлива составляют примерно 28×10^{18} ккал, если исходить из того, что кислород нашей атмосферы является производной процесса фотосинтеза хлорофилла и что добыча около 1% всех предполагаемых ресурсов ископаемого топлива может оказаться экономически целесообразной. Годные к использованию исходные материалы для ядерного синтеза составляют энергетические ресурсы, исчисляемые приблизительно в $1{,}5\times10^{21}$ ккал. Сейчас нельзя сказать чего-либо определенного в отношении ядерного синтеза за исключением того, что, исходя из потребностей человечества, этот источник энергии неистощим.

Взяв за основу нынешние потребности, можно сказать, что ископаемого топлива хватит примерно на 460 лет, исходных же материалов для процессов ядерного деления хватило бы даже на 25 000 лет. Однако такой подсчет ведет к неправильным выводам. Необходимо учитывать рост населения земного шара, а также возрастающее потребление в расчете на душу населения. Таким образом, ресурсов ископаемого топлива будет, например, достаточно лишь до конца двадцать первого столетия, а ядерного топлива хватит примерно на 300 лет. Это означает, что, с одной стороны, мир будет зависеть от ядерного синтеза в течение продолжительного периода времени и, с другой стороны, что имеется достаточно времени для разработки его технологии.

RECURSOS DE ENERGIA PRIMARIA.

El problema del suministro de energía a largo plazo es extremadamente complejo y plantea tres grupos principales de cuestiones: 1) si puede suministrarse la cantidad necesaria de una cierta clase de energía primaria en un momento y en una zona determinados; 2) si se puede conseguir ese suministro en condiciones competitivas; 3) si está asegurada la satisfacción de las necesidades totales de energía primaria durante siglos en escala mundial. Es evidente la interdependencia de esos tres grupos de problemas. El suministro anual de energía que se pueda obtener de un tipo dado de energía primaria, y por consiguiente la producción anual de ese tipo de energía, dependen de numerosos factores que a su vez están correlacionados.

Las fuentes energéticas regenerativas mundiales utilizables alcanzan unas $0{,}06 \times 10^{18}$ kcal/a. Aunque pudieran, en principio, satisfacer aproximadamente una cuarta parte de las necesidades energéticas del mundo hasta aproximadamente el año 2000, no obstante, sólo pueden utilizarse en la economía moderna dentro de unos límites dados.

Los combustibles fósiles suministran unas 28×10^{18} kcal, suponiendo que el oxígeno de nuestra atmósfera es un derivado de la fotosíntesis de la clorofila y que aproximadamente el 1% de las reservas globales de combustibles fósiles pueden obtenerse económicamente. La materia prima para la fisión nuclear representa reservas energéticas de aproximadamente $1{,}5 \times 10^{21}$ kcal. En la actualidad resulta casi imposible establecer cálculos útiles sobre la fusión nuclear, pero una cosa es cierta. desde un punto de vista humano tal fuente de energía es inextinguible.

Tomando las necesidades presentes como base, los combustibles fósiles bastarían para unos 460 años; la materia prima nuclear es suficiente para 25 000 años. Esta consideración, sin embargo, lleva a falsas conclusiones. Es necesario tener en cuenta el crecimiento demográfico mundial y el incremento del consumo per cápita. Resulta así que las reservas de combustibles fósiles serían suficientes sólo hasta finales del siglo XXI, mientras que los combustibles nucleares durarían unos 300 años. Esto significa, por una parte, que a largo plazo el mundo tendrá que depender de la fusión nuclear, y que, por otra parte, queda tiempo suficiente para desarrollarla.

If we define energy as the capability for work we indicate directly the key role that energy plays for the future of mankind. More and more work of a higher quality and a more versatile nature will be needed by mankind, whose working capacity and ability are being increasingly concentrated on mental activities.

The natural resources of energy are referred to as primary energy resources. They are utilized - generally after several conversion processes involving conversion losses - in the form of useful energy or of chemical raw material.

Figure I surveys the different kinds of primary energy and their conversion processes as far as they are today, or will be in the future of practical importance. One should note, as far as the final form of energy is concerned, a trend towards a preference for electricity as the most versatile and valuable form of energy. In the Federal Republic of Germany, by the year 2000, approximately 50% of the overall energy demand may be met by electricity.

The problem of the long-term supply of primary energy is extremely complex. It involves three main questions:

(1) Is it possible to provide at a given time and in a certain geographical area the required amount of work from a definite primary energy?
(2) Does this primary energy meet the requirement of competitive ability?
(3) Can the overall demand for primary energy be met in future centuries?

The interdependence between these three problems is obvious (see Fig. 2). The annual consumption of energy from a given primary energy, and thus the annual output of this primary energy, depend essentially on the following factors, which are also interrelated: Quantities of reserves with a certain time-dependent structure of output costs; price of the primary energy; costs of conversion into the final and/or effective energy form; and price and effect of substituting other primary energies. This will become still more complicated as different energy forms are produced jointly, or together with chemical products.

In the following, simple outlines of the problems as concern the Federal Republic of Germany are given. The first relates to the reserves of primary energy and to their geographic distribution. Since imports for the consumption of primary energy amounted in the Federal Republic of Germany to 44.5% of the total requirements in 1969, and this fraction may rise to 80% by 2000, it is necessary to examine world-wide conditions.

Fundamental mistakes are often made when assessing the reserves of primary energies. Either no distinction is made between the established reserves on the one hand and the probable additional reserves on the other, or the statistics only consider the established reserves. Often the limits of the output costs up to which the reserves are counted are not indicated. By established reserves we understand those known deposits whose primary energy contents have been established to the extent that production by modern methods is possible within determined costs. By the probable additional reserves is meant those deposits of primary energy which lie in extensions of known deposits, or which are not yet explored, but it is known or presumed that they contain the primary energy in question, this presumption being based on extrapolation or preliminary indications. Economic reasons

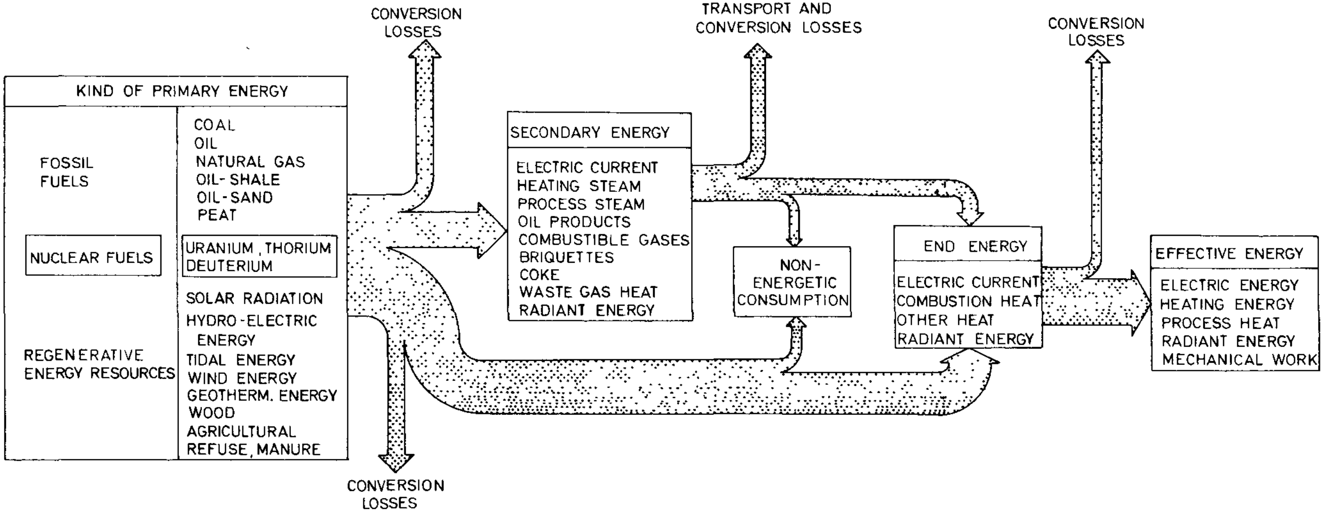

FIG 1. Resources of primary energies and their conversion into effective (secondary) energy.

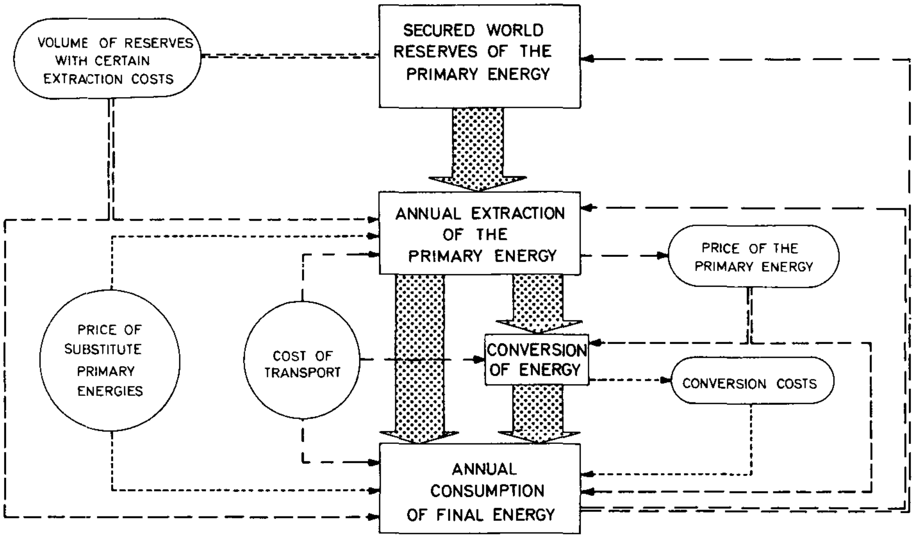

FIG. 2. Interdependence between reserves, extraction and consumption of primary energy.

generally prevent extensive exploration and exploration of deposits, which are ahead of the demand by more than one to two decades.

Figures 3 and 4 survey the world's primary energy reserves as far as they can be derived from available data. They are chiefly based on data compiled for the World Energy Conference 1968, and on later corrections.

In these figures we have used 10^{15} kcal as a uniform unit. The unit Q = 10^{18} Btu, used in the Anglo-Saxon countries for similar studies, corresponds to 250×10^{15} kcal. To give an idea of the amounts of energy of 10^{15} kcal, it would correspond to the present half-yearly consumption of primary energy in the Federal Republic of Germany.

If one starts from the hypothesis that all the world's fossil fuels can be traced back to chlorophyll, and that the oxygen of our atmosphere is a product of the photosynthesis of chlorophyll, the total deposits of fossil fuels would amount to approximately 2.5×10^{21} kcal. Figure 3 shows that the established and the probable additional deposits which, on the basis of present knowledge, could be economically exploited, amount to approximately $9\text{-}22 \times 10^{18}$ kcal. Therefore, approximately 0.5 to 1% of the total presumably existing reserves of fossil fuels have been traced. The factor 100 is, of course, an important uncertainty for any long-term forecast. For example, should it be possible to exploit economically 10% of the total contents of the world's fossil energies the available quantities of energy, compared with the values shown in the Fig. 3, would increase by 10 to 20 times.

These comments clearly show that the price of the primary energy at the place of consumption is of much greater importance than the total energy resources of the world. The latter gives practically no indication as far as the possible contribution of a particular primary energy to meeting energy requirements is concerned. Failing to recognize this fact often leads to misjudgments of the security of supply.

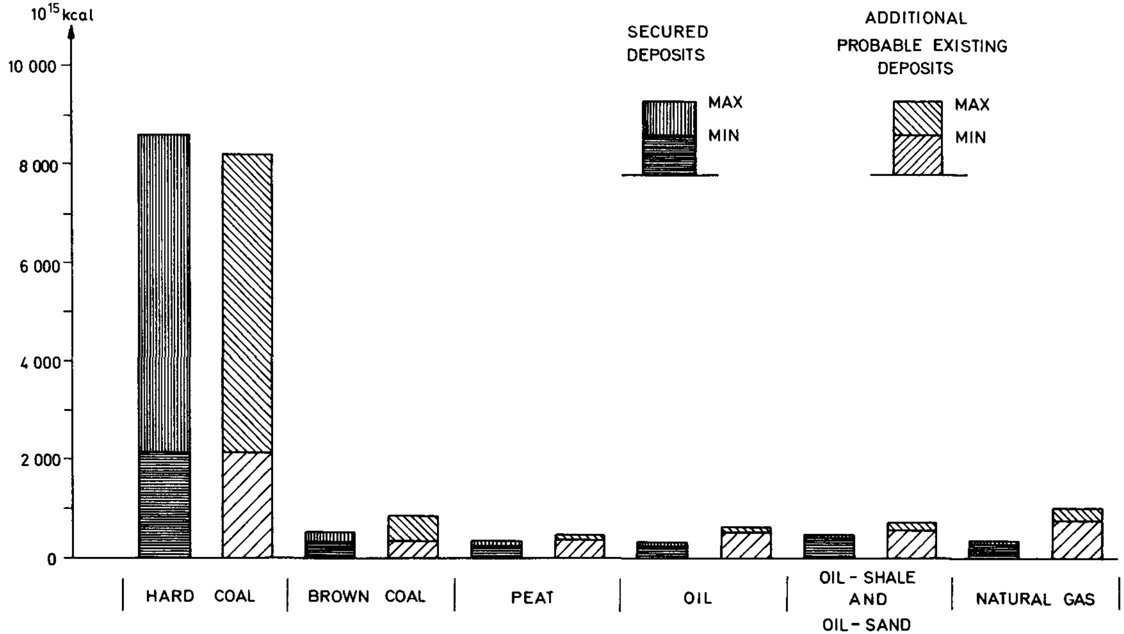

FIG. 3. World reserves of primary energy resources of fossil fuels.

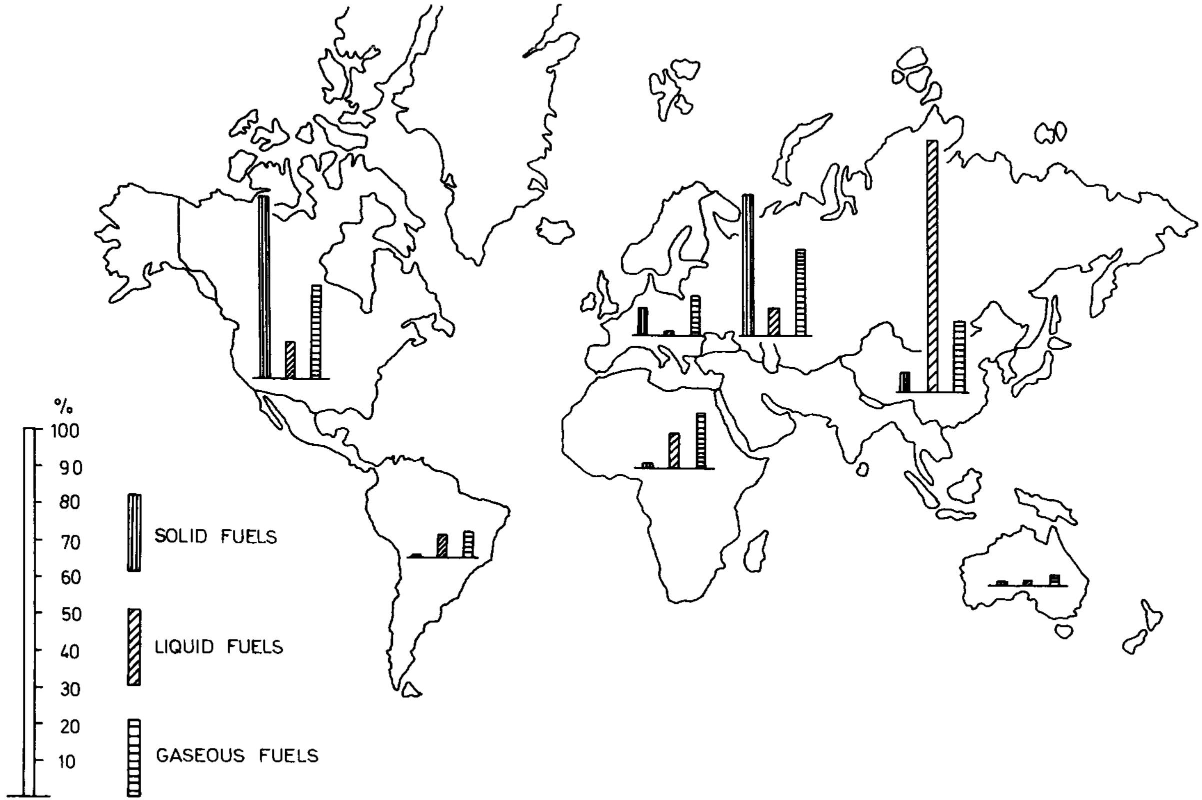

FIG 4. Geographical distribution (in per cent) of the various fossil primary energy sources in the world.

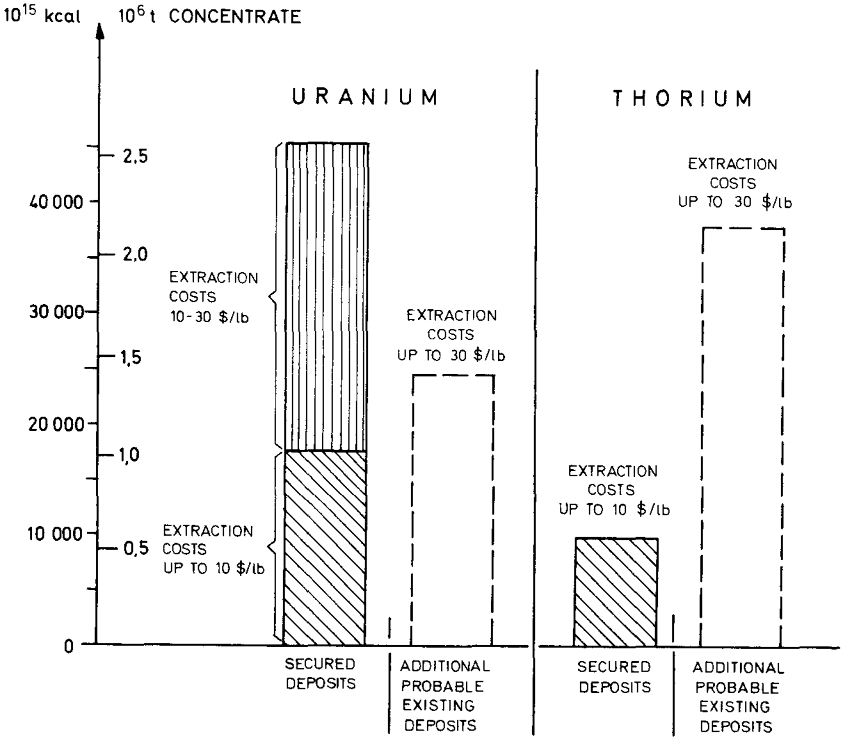

FIG. 5. Primary sources of nuclear energy (China and the USSR excluded).

Figure 4 shows the geographic distribution of the world's fossil fuels energy resources according to what we know at present. We may expect some changes of their distribution, which, however, from the overall point of view, are likely to be only of local and temporary interest.

The world energy potential from fossil fuels can at present be broken down as follows: approximately 70% hard coal, 6% brown coal, 4% peat, 5% oil, 7% oil-shale and oil-sand, and 8% natural gas.

The energy potential of nuclear fissile energy amounts to at least 3.5 times the established and the probable additional deposits of fossil energy resources considering only those deposits which are exploitable at costs not exceeding $30/lb U_3O_8 (see Figs 5 and 6). If higher cost categories and possible uranium extraction from sea-water are included, the reserves of the economically exploitable nuclear primary energies would amount to approximately 70 times the reserves of fossil energies. This statement is based on the assumption that only 1% of the 5000×10^6 t of uranium carbonate contained in sea-water, and only 1/3 ppm of the 10^{14} t of uranium contained in the earth's granites and basalts can be economically extracted (see Fig. 7). As with fossil energies there is also an uncertainty in the forecasts. Nuclear energy resources of much higher prices will prove to be economical because, after the introduction of breeder reactors, the costs of fissile material will have only a minor influence on the production costs of energy. It must be

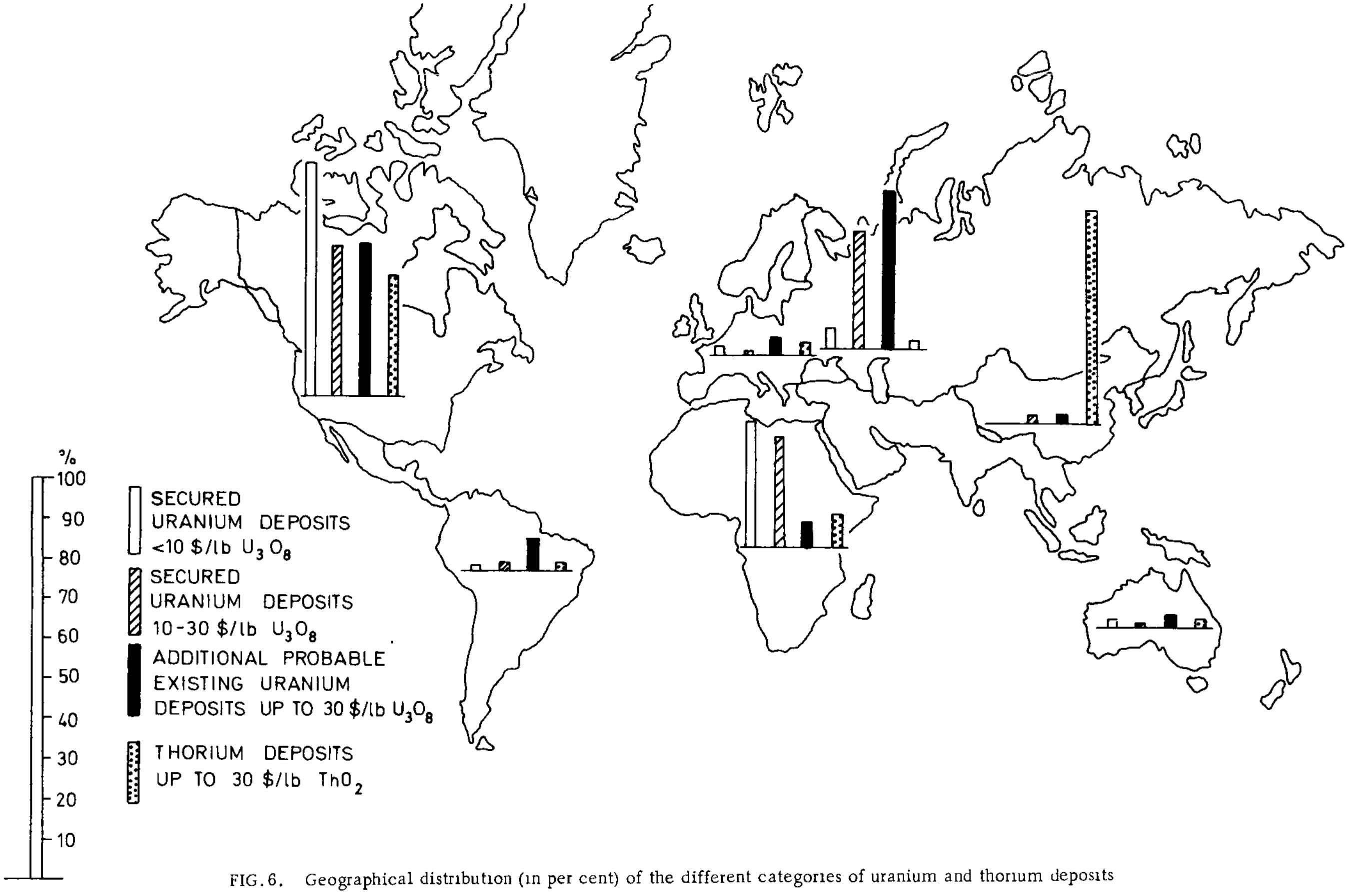

FIG. 6. Geographical distribution (in per cent) of the different categories of uranium and thorium deposits in the world.

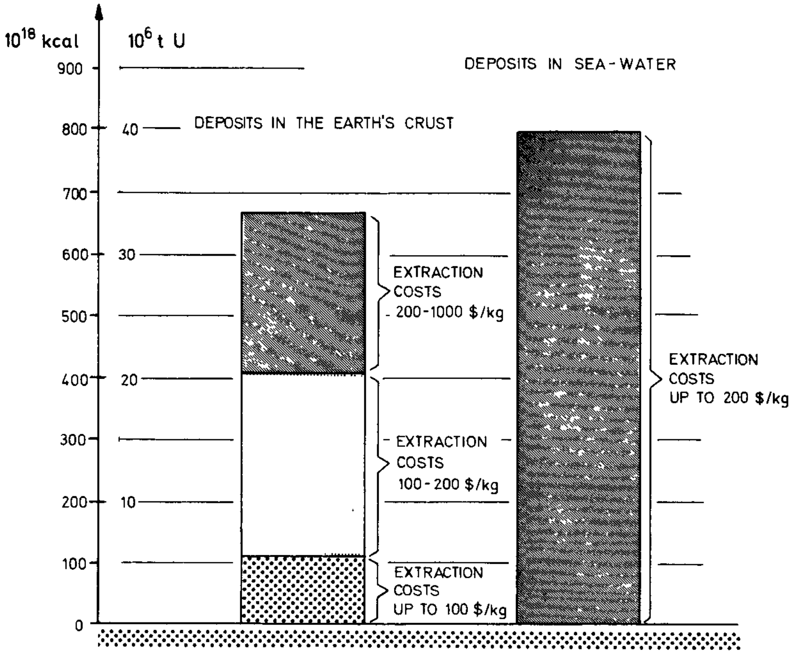

FIG. 7. Probable extractable uranium of high cost categories - 1969.

emphasized that Fig. 5 does not include the nuclear reserves of the People's Republic of China or those of the USSR as no data were available. It is likely that these countries have large deposits at their disposal.

When assessing the deposits it must be borne in mind that further deposits of primary energy will be found and that some may shift from their original price category to lower ones because of technical progress in extraction and treatment. Moreover, deposits of primary energy under the oceans have hardly been explored.

To complete the picture of the energy resources, we must refer to world's regenerative energy resources. In former centuries these constituted the only energy supply basis, but declined in importance in proportion to the increase in the demand for primary energy. As a rough assessment the economically usable quota of the regenerative energy resources are of the order of approximately 60×10^{15} kcal/yr, of which 70% are attributable to wood and agricultural refuse, more than 15% to solar energy, and 10% to hydroelectric power. The latter occupies an exceptional position since it can be converted into valuable electricity with an efficiency of more than 90%.

The regenerative resources of primary energy could cover approximately 1/4 of the world's energy demand by the year 2000. However, it is unlikely that they will be used on that scale, mainly because they are increasingly supplemented, even in developing countries, by the more convenient and economic non-regenerative primary energies.

It is relevant to examine the history of the use of energy. Table I shows that throughout history, until 1870, the regenerative sources of primary energy dominated. Then this leading role was assumed by the non-regenerative fossil fuels. Because of technological progress the scale of the usable forms of energy will be progressively extended. The new energy forms are distinguished in particular by an initially high growth-rate. Thus, we observe a continuous structural change. For instance, since 1910 this change has been characterized by a proportional increase in the quota of oil and natural gas at the expense of coal, whereas energies from wood, peat, and vegetal refuse have decreased considerably in their percentages.

Since 1960, in the era of fossil fuels, the Federal Republic of Germany has undergone a shift towards a greater utilization of liquid and gaseous fuels, an increased use that is due to their economic superiority over solid fuels. They are preferred although their energy potential is only approximately 16% of that of solid fuels.

It was certainly incorrect if, in the past, an imminent depletion of the deposits of liquid and gaseous fuels was repeatedly predicted. However, it is obvious that at a consumption rate of now 3%, and perhaps 5% by the year 2000, these resources are tending to deplete more rapidly than coal, whose consumption rate is at present only approximately 7%. Therefore, it cannot be excluded that one day we shall have to produce liquid and gaseous fuels from solid ones in order to meet the requirements in those areas where they cannot be substituted.

This trend towards an increasing percentage in the use of oil and natural gas will presumably last until the 'eighties, after which the influence of nuclear energy, which will increase even more rapidly, will become more established, and the portion of use of oil and natural gas will decrease. Finally nuclear energy will take the lead by the year 2000.

Whether at a given moment and in a given geographic area the required quantities of a certain primary energy will be available is implicit in the question concerning the security of supply for the particular area. This is particularly important as the geographic distribution of primary energy deposits does not correspond to the distribution of consumption. Therefore, the security of supply of a nation with a passive trade balance can only be guaranteed by a mixture of primary energies of different kinds and geographic origins.

In the Federal Republic of Germany, too, the domestic primary energy production cannot secure the supply of energy in the long run. It cannot even act as a price regulator. By 2000 our demand for primary energy will amount to at least 840×10^6 TCE[1]. The present still relatively high domestic production amounts to about 170×10 TCE. In the long run nuclear fuels will greatly strengthen the security of supply, particularly in the next century, when the reserves of depleted uranium by then accumulated in Germany will constitute the main source of energy.

For the time being we do not need nuclear fusion to cover our energy demand. Its introduction might, however, solve the problem of securing the primary energy supply.

By the way, nuclear energy will, in the long run, render the electric power supplies largely independent of fuel input costs since the costs of

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1 TCE = Tons of coal equivalent

TABLE I. HISTORY OF THE UTILIZATION OF ENERGY

Year	Era	Main energy resources	Energy potential of the different primary energy resources	Cumulated consumption of primary energy
1870	Regenerative energy resources	Muscular power Wood max. portion about 1800	Annual useful regenerative energy resources 0.06×10^{18} kcal/yr of which woold = 0.03×10^{18} kcal/yr	Cumulative up to 1870 2×10^{18} kcal
	Fossil fuels	Coal max. portion about 1910	Utilizable total deposits of fossil fuels $10 - 23 \times 10^{18}$ kcal of which coal equals $6 - 19 \times 10^{18}$ kcal; of which oil equals $1.7 - 2 \times 10^{18}$ kcal (oil-sand and oil-shale incl.); and of which natural gas $1 - 1,2 \times 10^{18}$ kcal	1870 - 1960 1.3×10^{18} kcal
1960		Oil and natural gas max. portion about 1980		1960 - 2000 4.2×10^{18} kcal
2000		Nuclear fission	Utilizable uranium deposits 1.5×10^{21} kcal thorium deposits 1.8×10^{21} kcal	2000 - 2030 12×10^{18} kcal
2030	Nuclear energy	Nuclear fusion	D-D reactions 9×10^{24} kcal lithium reactions (of similar order)	

depleted uranium, or those of heavy water in the case of fusion, will contribute only negligibly to the energy cost.

The figures shown in the two last columns of Table I prove that in the foreseeable future we should fear no shortage of energy. Therefore, the choice of the primary energies will be basically determined by economic considerations and not by the security of supply of different primary energies. This applies even more to the coming decades than to the present. There may be some exceptions in those applications where for technical reasons we cannot change to other energies, for example at present in parts of the transport sectors.

The competitiveness of primary energies is determined by their price, free to the consumer, and by the cost for their conversion into the form of effective energy. Therefore, different prices of primary energies apply to different applications.

The production costs of primary energies consist of the costs of exploration, opening up and developing the deposits, and extraction. To this must be added the costs of converting the primary energy into a transportable form or the product that can be fed into the energy conversion plants. The price free to the consumer is determined not only by the conversion costs but also by transport and some ancillary costs such as taxes and other charges.

Some cost factors are determined by geology, some by technology and some by politics. Besides, the competitive situation exerts a regulative influence. Some energies, such as oil and natural gas, show a high degree of flexibility regarding pricing and thus exert a strong substitution effect over other energies.

Generally the higher its labour costs the more an energy source is threatened by competition. Figure 8 surveys the wage share of the different primary energies free to the consumer. Depending on the location and conditions of the deposits this share may differ very greatly as shown by the example of hard coal. In the light of ever-increasing wages it will, for

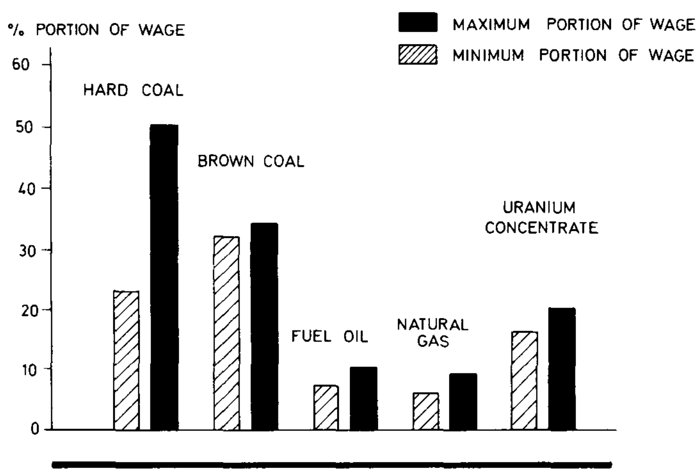
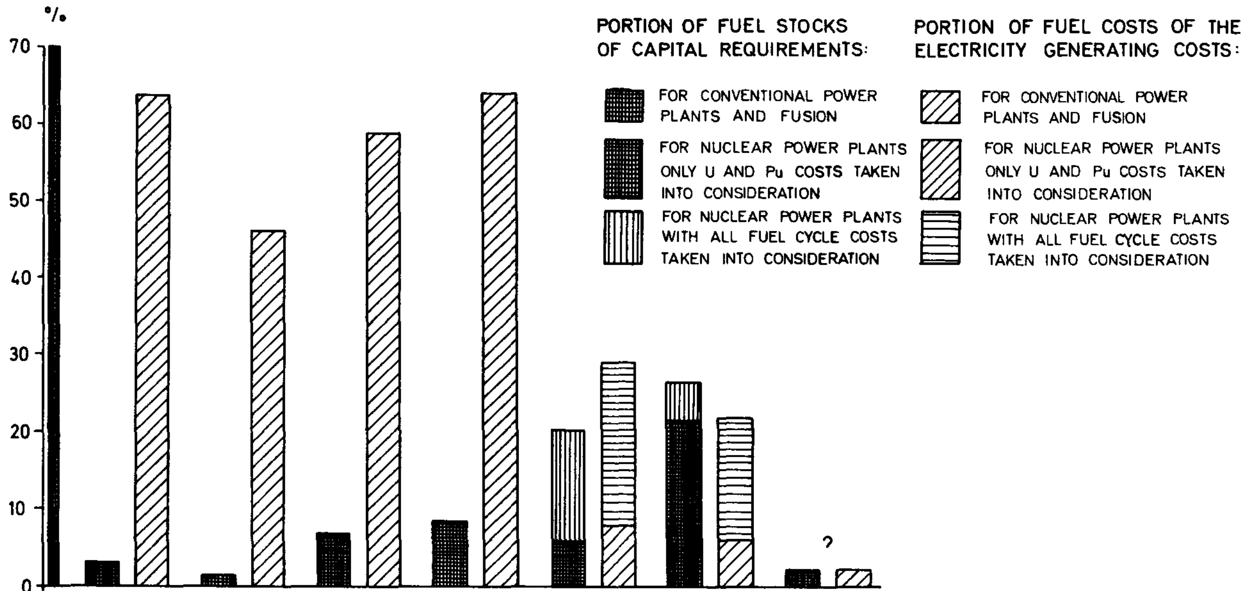


FIG. 8. Percentage of labour costs as a fraction of total costs including transport free to the customer.



POWER PLANT	HARD COAL	BROWN COAL	OIL	NATURAL GAS	NUCL FISS. LIGHT-WATER REACTOR	NUCLEAR FISSION BREEDERS	FUSION
STOCKS FOR MONTHS	1	1	3	3	24	12	12

FIG. 9. Share of fuel costs compared with the total generating costs of a power plant and its electricity generating costs.

the different primary energies, be all the more difficult to counteract price increases by technological progress, the higher the wage share. Also, on account of the long-term development of other cost factors an increase in the prices of classical primary energies may be expected. Nuclear energy has an obvious advantage since the percentage of the uranium concentrate of the end energy costs is extremely low. This is shown very clearly by Fig. 9. It also indicates the share of the fuel stocks in capital requirements, the calculations being based on stocks of one month for the classical energy hard coal and of three months for oil. In spite of the high capital tied up in the initial fuel inventory of the nuclear fission reactors, their energy generating costs are much lower than those of the classical power stations. The higher capital demand for the initial fuel inventory of the fast breeders in attributable to the physics.

In the long run nuclear energy will exert the strongest substitution effect on other energies, especially as it will enter the electricity sector for which, as already mentioned, in the highly industrialized countries by the year 2000 approximately 50% of the primary energy demand will be required. Nuclear energy, therefore, might in future be the most important regulative and stabilizing factor for energy prices. Other energy prices will, as far as they will be sufficiently flexible, adapt themselves to nuclear energy. Oil, for instance, still has considerable margin in view of the taxes and other charges. In the Federal Republic of Germany part of the market for other primary energies will decline rapidly in its absolute values and be even more expressed as a percentage since not only less capacity of energy conversion plants - for instance power plants - will be installed, but also since existing plants will be operated for fewer hours.

For the destiny of mankind the question of meeting energy requirements is extremely important. But this question is only significant if considered on a world-wide scale, and therefore can only be dealt with universally. In relation to the present world energy consumption of 60×10^{15} kcal, the reserves of the fossil fuels (see Fig. 3) would only last for 150 to 370 years; when the energy from nuclear fission is included (see Figs 5 and 7), we obtain a possible utilization period of approximately 25 000 years. These estimates are based on very conservative assumptions concerning the possible energy reserves. Such an approach, however, leads to false conclusions as it considers neither the world population increase nor the ever-increasing per-capita consumption of energy.

While the world population increased very slowly since the pre-Christian era until about 1650, from then onwards a more rapid growth took place that has become a "population explosion" since about 1950. The growth-rate rose to approximately 30% every 10 years, which is about 100 times higher than in the first millenium A.D. The world population is now approximately 3500 million and might rise by 2000 to approximately 6000 million. Even if in future there would be a heavy decline of the world population growth-rate owing to world-wide family planning, it is probably no exaggeration to state that the increase will reach 20 000 million people by the end of the 21st century.

Simultaneously with the growth of world population, however, an increase in the per capita consumption of primary energy will take place in order to secure adequate nutrition and accommodation and to allow people gradually to share in the progress of civilization. During the last 70 years the average utilization factor of the primary energy could be increased from

11.5 to 30%. This dampened the growth of the per-capita consumption of primary energy. A further improvement of the efficiency will, however, be very limited by physical conditions as well as by the possibilities of technical and economic realization. Therefore, almost constant growth-rates of the specific consumption of primary energy are to be expected provisionally. The forecasts concerning the development of the per-capita consumption can, in the long run, be orientated towards those of the United States of America, where the per-capita consumption of energy in 1970 was approximately 73 Gcal/yr.[2] Compared with our development of consumption this indicates a development lead of approximately 17 years, and if compared with the overall world consumption, a lead of more than 50 years. The average world per capita consumption of primary energy is now approximately 17 Gcal/yr.

Let us assume arbitarily for the whole world a saturation point three times higher than the present consumption in the USA, that is approximately 200 Gcal/p/yr.[3]

The Federal Power Commission of the USA expects that by only the end of this century the per-capita consumption of electricity in the USA will rise from the present 6000 kWh/yr to approximately 28 000 kWh/yr, whereas the electricity will possibly cover only 45% of the energy demand. This would mean that by the year 2000 in the USA the specific energy consumption will already amount to approximately 150 Gcal/p/yr. Therefore it seems realistic to assume that in the long run the world consumption will amount to 200 Gcal/p/yr. Such long-term forecasts are of course always problematic. It is, for instance, conceivable that the trend towards consumption may decrease for the benefit of other aims because the way of life of mankind could change radically.

If, however, we assume a continuous development of the present world-wide situation, and that it will be free of catastrophes, the population growth, and even more the increase in the per-capita consumption would, according to what has just been said, lead to annual primary energy demands in the next 100 to 200 years which would set quite different standards for the use of our energy reserves. An annual demand of primary energy of 20 000 million inhabitants $\times$ 200 Gcal/p/yr = 4×10^{18} kcal/yr would mean that reserves of fossil primary energies of around 10^{19} kcal, which might possibly still exist by the year 2100, would meet the requirements of only three more years and that the average reserves for nuclear fission would be sufficient for 300 years even if they could be used to 85%. The conclusions concerning the fossil fuels would not change very much even allowing for an error of a factor of 10 when assessing the reserves.

Such an enormous consumption of energy which is finally converted into heat might even influence the thermal economy of the earth. We must bear in mind that 4×10^{18} kcal/yr correspond to roughly 3% of the thermal energy yielded by the sun to the land masses of the globe. The increase in the CO_2 content in the atmosphere could have a great impact on the climate should there be a large-scale exploitation of fossil fuels. A study of this problem for the future seems to be not only interesting but necessary.

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[2] Gcal = Gigacalorie = 10^6 kcal

[3] Gcal/p/yr = Gigacalories per person per year

The above comments show that the fossil energy resources will not meet the requirements of world energy supplies if considered on a century time scale. Nuclear fission, however, could cover this demand for several centuries. That means that we have ample time to develop economically and technologically the most important resource of energy, namely controlled nuclear fusion. This problem will presumably be solved much earlier than necessary from the viewpoint of energy requirements. Nuclear fission also became feasible earlier than was necessary from the standpoint of the fossil energy reserves.

Now, what can be said about the long-term aspects of energy supplies, from nuclear fusion without indulging too much in speculation? The main problem for the technical realization of controlled nuclear fusion lies in maintaining the required high temperatures of the plasma which reach - even in the case of the most favourable reaction, the deuterium-tritium reaction - around 50×10^6 °K. If we are able to control even higher temperatures, other substances, especially lithium, could be used directly to generate energy.

Whereas the ratio of deuterium to all hydrogen isotopes is 1 to 700 in water, tritium does not exist in nature. It can be produced, for example, by neutron irradiation of lithium-6, with an abundance of 7% in natural lithium.

The concentration of deuterium in the sea-water is roughly 10 000 times higher than that of uranium. This means that the possible production of energy from sea-water, in the case of nuclear fusion, is 10^4 times higher than in the case of nuclear fission. An example may illustrate the potential of energy production by nuclear fusion of the deuterium content of the ocean. If all oceans consisted of oil their combustion would yield only 1/66 of their fusion energy potential. If we succeeded in also using the lithium reaction we could tap an additional resource whose yield would be higher than that of deuterium. This scale could be enlarged at will after achieving still higher reaction temperatures so that nuclear fusion would in fact constitute a practically inexhaustible source of energy for mankind.

In producing uranium or deuterium from sea-water we assumed that in both cases only 1% could be economically extracted. This results in an energy potential of roughly 10^{21} kcal in the case of uranium fission and roughly 10^{25} kcal for nuclear fusion.

Nothing certain can be now said about the cost of the energy generation by fusion reactors since we do not even know how such a reactor will be conceived. It can be assumed that only fusion reactors with a power of several thousand megawatts will be economic. There are signs that their specific construction costs will be about those of fission reactors. The fuel costs from deuterium and tritium, however, might only amount to several hundredths of one pfennig. From this we may conclude that nuclear fusion will not supply us with cost-free electricity, as some may perhaps hope, but that there will only be fixed charges which will encourage extensive utilization of the power offered. It is important to note that, owing to their low variable costs, fusion reactors would depend to a still lesser degree on the fuel costs and their variations than nuclear fission reactors.

In view of the expected relatively low electricity generating costs of future nuclear fission reactors, the fusion reactors will hardly make it possible to obtain important changes in prices. In the future great efforts must be concentrated on reducing transport and distribution costs of energy in order to obtain low overall costs to the consumer.

Though this study is hypothetical on many points, we may make the following conclusions:

(1) The overall world energy resources can, if judged by human standards, be considered as being inexhaustible. This applies even in the light of the exponentially increasing energy consumption.
(2) The problem of energy supplies therefore remains chiefly a problem of costs. Also, in the long run the cost will be the determining factor for the choice and the extent of the utilization of different primary energies.
(3) Fossil energies show, on a long-term basis, a tendency of increasing prices. Anyway they alone could not meet the energy demand of the next century.
(4) Nuclear fission energy, and probably later nuclear fusion, will become the main resources of secure and low-cost energy supplies.
(5) The security of supply must at present be guaranteed by a mixture of different primary energies of various geographical origins. Nuclear energy should almost completely solve this problem.

For the future of a nation the two factors of energy and creative imagination will be much more important than its natural resources.

FORECASTING THE ROLE OF NUCLEAR ENERGY IN SOUTH AFRICA

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Abstract–Résumé–Аннотация–Resumen

FORECASTING THE ROLE OF NUCLEAR ENERGY IN SOUTH AFRICA.

Several features of the South African situation make forecasting the role of nuclear energy more complex than in the highly developed countries of Western Europe. The unique features which contribute to this are (1) the existence of five geographically well-separated load centres averaging over 500 km apart (two inland and three on the coast), (2) only one large low-cost coal reserve, this being at one of the inland centres, and (3) limited inland water resources. A computer model was therefore developed to simulate, under these conditions, the present electrical generation system, and its possible expansion over the next 30 years. The model uses the present-worth method to evaluate alternative modes of system expansion, based on forecasts of regional load growth. Transmission line costing is treated quite generally; for example, intermediate load take-off points on long lines and discontinuous cost functions are considered. Dry-cooled units can be added to the system from a specified date. Plant items are sorted in order of merit, although, if desired, hydro units can be run at specified annual load factors. The introduction of natural and enriched uranium reactors with and without fast breeders has been studied. The results show that it will be economic to aim for a relatively large nuclear installation program commencing in 1980. Based on locally produced plutonium, fast breeders cannot be installed until the last decade of the century. Details are given of the sensitivity of the results to variations in coal price and nuclear fuel cycle costs.

ROLE PREVU DE L'ENERGIE NUCLEAIRE EN AFRIQUE DU SUD.

La situation particulière de l'Afrique du Sud rend la prévision du rôle de l'énergie nucléaire plus complexe que dans les pays hautement développés de l'Europe occidentale. Les particularités uniques qui contribuent à cela sont: 1) l'existence de cinq centres de consommation géographiquement bien séparés, éloignés en moyenne de plus de 500 km (deux à l'intérieur du pays et trois sur la côte); 2) l'existence d'une seule grande réserve de charbon bon marché située dans l'un des centres intérieurs; et 3) des ressources hydrauliques intérieures limitées. Aussi a-t-on mis au point un modèle afin de simuler sur calculateur, dans ces conditions, le système de production électrique actuel et son développement possible dans les 30 années à venir. Le modèle repose sur la méthode utilisée actuellement pour évaluer d'autres modes de développement du système, fondés sur les prévisions de l'augmentation de la consommation régionale. On traite de manière tout à fait générale du coût des lignes électriques; on considère par exemple des points de prélèvement intermédiaires sur des lignes de grande longueur et les fonctions économiques discontinues. A partir d'une date déterminée on pourra ajouter au système des unités à refroidissement du type sec. Les types d'usines sont classés selon leurs qualités intrinsèques; cependant on peut au besoin utiliser des installations hydro-électriques présentant des facteurs de charge annuels déterminés. L'emploi de réacteurs à uranium naturel et enrichi, avec ou sans surgénérateurs rapides, a fait l'objet d'une étude. Les résultats font ressortir l'intérêt économique de la mise en application dès 1980 d'un programme nucléaire relativement important. Dépendant du plutonium produit localement, les surgénérateurs ne pourront être installés avant la dernière décennie du siècle. Des détails sont donnés sur l'influence qu'exercent sur les résultats les variations du prix du charbon et du coût du cycle du combustible nucléaire.

ПРОГНОЗИРОВАНИЕ ИСПОЛЬЗОВАНИЯ АТОМНОЙ ЭНЕРГИИ В ЮЖНО-АФРИКАНСКОЙ РЕСПУБЛИКЕ.

В силу некоторых особенностей обстановки в стране проблема прогнозирования роли атомной энергии в ЮАР является более сложной, чем в высокоразвитых странах Западной Европы. К числу указанных особенностей относятся: 1) наличие пяти самостоятельных в географическом отношении центров нагрузки, удаленных друг от друга на расстояние более 500 км (два в центральной части страны и три на побережье); 2) наличие только одного крупного промышленного месторождения угля, находящегося в одном из центров нагрузки во внутренних районах страны; 3) ограниченность гидроэнергетических ресурсов в центральных районах ЮАР. Поэтому для получения картины современного состояния энергосистемы и ее развития в последующие 30 лет с учетом вышеуказанных особенностей в стране было произведено моделирование на ЭВМ. Полученная модель предусматривает использование современного метода оценки различных направлений развития системы на основе прогнозов роста нагрузки в отдельных районах. Оценка стоимости линий электропередачи рассматривается в общем плане. Например, учитываются промежуточные пункты отбора мощности на линиях передачи большой протяженности и прерывные функции стоимости. В определенное время в энергосистему могут быть включены электрогенераторы с воздушной системой охлаждения. Классификация и выбор станций при моделировании производится в том порядке, который определяется их выгодами, хотя в случае необходимости при определенных годовых коэффициентах нагрузки могут найти применение и гидроэлектростанции. Изучен вопрос сооружения и эксплуатации реакторов на природном и обогащенном уране в условиях наличия и отсутствия в стране реакторов-размножителей на быстрых нейтронах. Исследования показали, что экономически выгодным является строительство крупных ядерных установок начиная с 1980 года. Исходя из условий производства плутония внутри страны до 1990 года не представляется возможным осуществлять сооружение реакторов-размножителей на быстрых нейтронах. В отчете приведены подробные сведения о влиянии изменений стоимости каменного угля и ядерного топливного цикла на результаты прогнозирования развития атомной энергетики.

PREVISIONES ACERCA DEL PAPEL DE LA ENERGIA NUCLEAR EN AFRICA DEL SUR.

La situación de Africa del Sur presenta diversos aspectos que hacen más difícil prever allí el papel de la energía nuclear que en los países muy desarrollados de la Europa occidental. Entre las particularidades que contribuyen a ello hay que considerar 1) la existencia de cinco centros de consumo bien separados geográficamente (dos en el interior y tres en la costa) entre los que hay, como promedio, más de 500 km de distancia; 2) que solamente hay una reserva grande de carbón barato y está en uno de los centros del interior; y 3) que los recursos de agua en el interior del país son limitados. En consecuencia, se ha construido un modelo para simular por medio de un computador, el sistema actual de generación de electricidad en esas condiciones y su expansión posible para los próximos treinta años. El modelo utiliza el método que se emplea actualmente para evaluar las diversas formas en que puede crecer el sistema, basándose en previsiones sobre el crecimiento de la demanda regional de energía. El coste de las líneas de transmisión se trata con toda generalidad; por ejemplo, se consideran puntos intermedios de conexión de carga sobre líneas largas y funciones discontinuas del coste. A partir de una fecha especificada se pueden añadir al sistema unidades refrigeradas en seco. Los distintos tipos de centrales se clasifican en orden de méritos aunque, si se quiere, las unidades hidráulicas se pueden calcular con factores de carga anuales especificados. Se ha estudiado la introducción de reactores de uranio natural y de enriquecido, incluyendo o no los reproductores rápidos. Los resultados demuestran que sería económico proyectar un programa relativamente grande de instalación de centrales nucleares, que comenzase hacia 1980. Si sólo se cuenta con el plutonio producido localmente, no podrán instalarse reproductores rápidos hasta la última década del siglo. Se dan detalles acerca de la sensibilidad del carbón y a los costes del ciclo del combustible nuclear.

1. INTRODUCTION

With inexpensive coal reserves conveniently situated near the larger load centres, there has, in the past, been little incentive to look for alternative methods of power generation in the Republic of South Africa. However, with the continued development which is taking place in the coastal areas of the Cape and Natal, it is becoming essential to compare the economics of the current practice of building long-distance high-voltage transmission lines to serve these areas from the interior, with the possibility of building coastal nuclear power stations. There is even the possibility that at some time in the future it may become necessary to send power inland from coastal nuclear plants if the increasing demand on the water resources finally imposes a limit on the construction of additional inland coal-fired stations.

The first investigation into the possibility of introducing nuclear power into the South African electricity supply system showed that by 1978 it would be cheaper to build a nuclear station in the Western Cape than to increase the capacity of the existing transmission lines [1]. This study was confined to natural uranium fuelled reactors.

A more recent study [2] was made of both natural and enriched uranium reactors to determine their relative economic characteristics and to identify those which would be most suited for installation in South Africa. A short list of five suitable reactor types was accordingly drawn up. The relative economics of these reactors were, however, based on a study of single units operating at assumed load factors, in isolation from other reactors and other forms of power generation. The probable roles which the various types of plant might be called upon to play during their lifetimes were unknown. Apart from the errors which this could introduce in the economic assessment of the various reactor types, the studies were not able to yield any information concerning other factors of vital interest such as the overall rate of consumption of uranium ore and the rate of accumulation of plutonium in the system as a whole, as a function of time. In addition it was not possible to predict the magnitude of the services which might be required in association with the nuclear fuel cycle, thus increasing the difficulty of planning possible local facilities.

Because of several unique features of the South African electricity supply system, it was found necessary to develop a computer model in which the existence of five geographically well-separated load centres could be represented, linked by transmission lines. A short description of the programme is given in this paper, together with preliminary forecasts of the growth of nuclear power predicted with its aid, for various reactor installation strategies. It is recognised that the long-term forecasting of the rate of installation of various types of power plant in any country is fraught with difficulties and uncertainties. To combat this, to some extent, considerable emphasis has been placed on sensitivity analyses in this study.

2. DESCRIPTION OF THE COMPUTER MODEL

The computer model of the South African electricity supply system used in these studies [3] allows the five interconnected load centres to be supplied with power from either coal-burning, hydro-electric or nuclear power plant. Load centres 1 and 5 are inland; 2, 3 and 4 are coastal (Figure 1). The largest low-cost coal reserve is located in region 1, which is also the area having the highest demand for electricity. Initially, if nuclear stations are installed, they may be assumed to be located in the region where the demand exists, if conditions are favourable. Coal-burning plant, however, may be installed either at the load centre, if coal deposits exist nearby (the so-called "pithead" stations), or, if local coal reserves are inadequate, the plant may be installed on a remote coal field, the power being brought in by transmission line. Complete freedom is given in setting up the transmission line capital cost function, and other related problems, such as system stability, are treated in considerable detail. For example, lines shared by more than one load centre and discontinuous cost functions can be specified without difficulty. Hydro-electric power plant is assumed to be installed according to a fixed installation schedule, rather than being subjected to the general economic evaluation described later.

In view of the previous studies which revealed that nuclear plant was not likely to be economical before 1978, this was chosen as the datum year for the present investigation. All items of generating plant that will be in existence at the beginning of 1978 are specified in the input data by size, location and installation date, together with their fixed and variable running costs. The firm power transfer capability of the high voltage transmission lines connecting inland and coastal load centres is also represented.

System expansion beyond 1978 is described by load growth forecasts for each of the regions (Figure 2). This data is presented to the programme in the form of discrete power steps equal to the maximum size of turbo-generator set which the system is able to accommodate. At any given time after 1978, independent forecasts of incremental operating costs for each type of plant (Figure 4) are used to establish a table of merit headed by units having the lowest variable costs, and ending with plant having the highest incremental costs. System operation is simulated by dispatching the various installations against a national load-duration curve.

Calculations are performed at three monthly intervals. If, in any particular period, no plant extension is planned, the programme merely calculates the fixed and variable costs of all the plant in operation at that time. If, however, an addition to the system generating capacity is called for, total system costs are evaluated over 25 years for each of the plant alternatives, and that which gives the lowest system cost is selected for installation. In this way an attempt is made to trace the likely role which each plant type may be called on to perform. For the first iteration a guessed future installation pattern is used as background to the economic assessment. On subsequent iterations the partly optimised results obtained on the previous pass are available. Iteration continues until no further changes are made in the installation pattern or until a specified maximum number of iterations is reached.

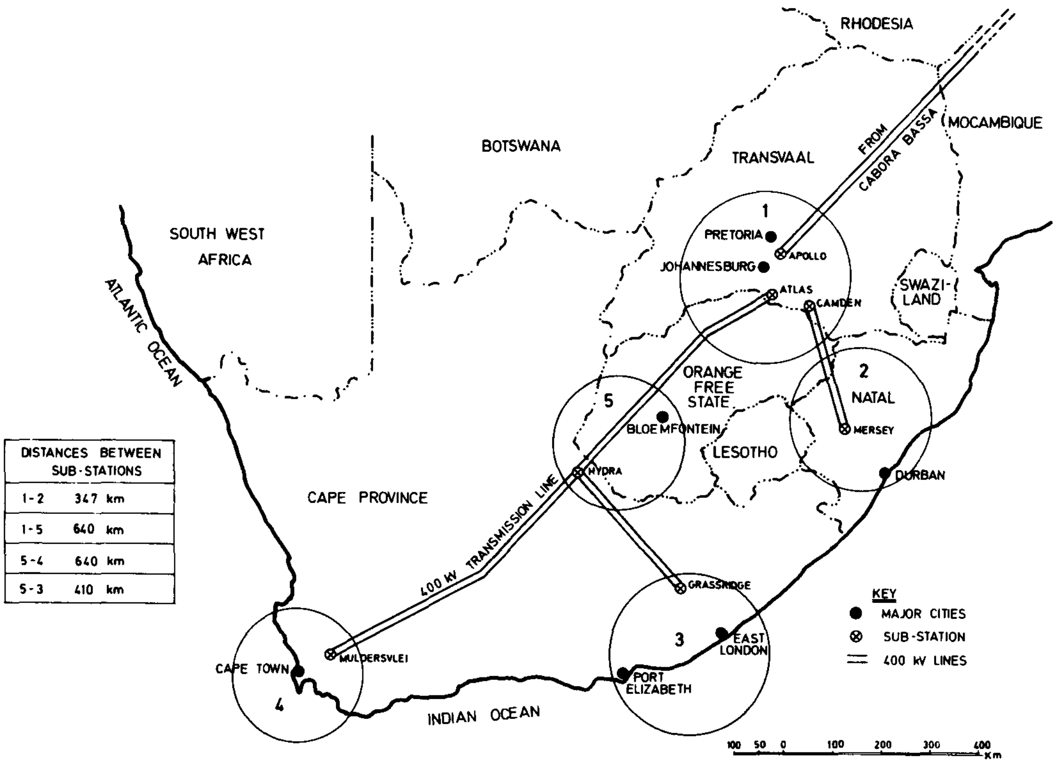

FIG. 1. Simplified map of the South African electricity supply system.

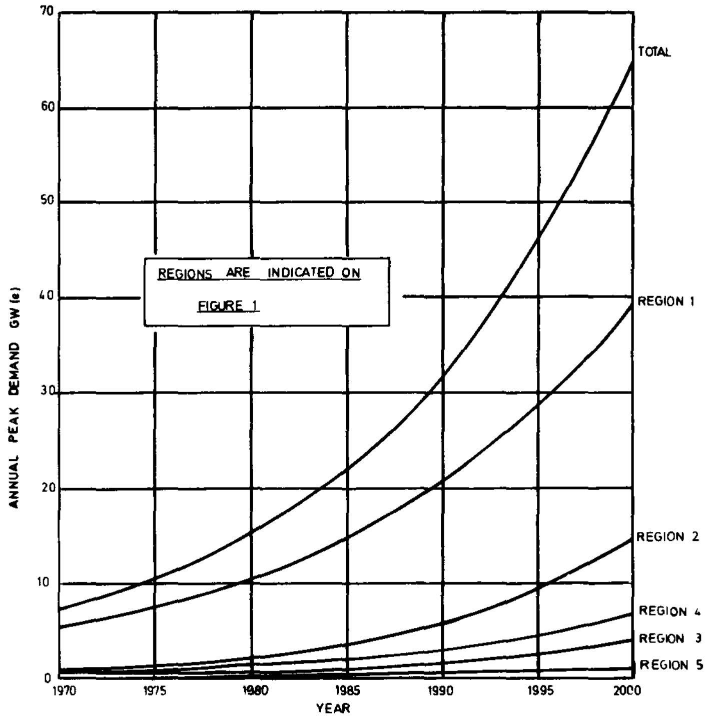

FIG. 2. Estimated regional demands.

Projected plant retirement, specified by a minimum life in the input data, is accepted or deferred to a later date by comparing total system costs with and without the plant under consideration.

3. DATA USED

3.1 General (applicable to nuclear and conventional stations)

(i) Operating lifetime for plant : 35 years minimum.
Financial lifetime : 25 years.

(ii) Dry cooling: Used for all inland power stations from 1980 onwards. Capital cost assumed to be increased by 2%, thermal efficiency reduced by 3.7%.

(iii) Transmission line costs: Approximately R38 000 per kilometer.

(iv) Regional growth curves: Figure 2. These show the net generating capacity, including reserves, required to meet the loads arising in each region, but not necessarily installed in the same region.

(v) Plant capital costs in 1978: Figure 3. Escalation at $4\frac{1}{2}$% p.a.

(vi) Fixed operation and maintenance costs: For a 500 MW(e) unit, the following costs, escalating at 2% p.a., were assumed to apply in 1978:

Coal-fired station	2.06	Rand/kW/a
Light water reactor (LWR)	2.54	
Heavy water reactor (HWR)	3.53	
Fast breeder reactor (FBR)	3.26	

To obtain the fixed cost for plant of other sizes a square root scaling law was applied.

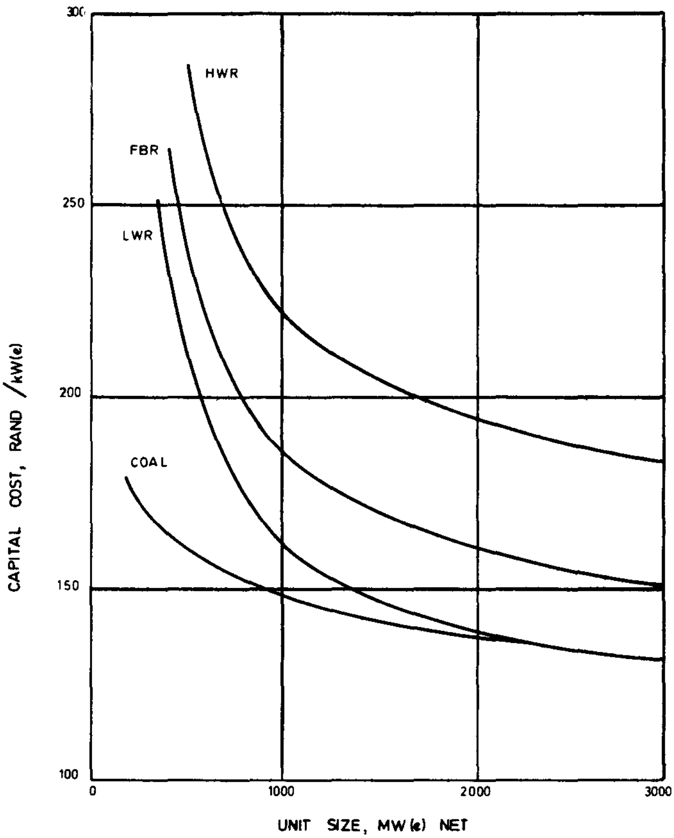

FIG. 3. Variation of capital costs with unit size.

(vii) Discount rate for present worth calculations: 6.5% p.a.

(viii) Capital charge rate: 9.6% p.a. over 25 years, based on an interest rate of 6.5% p.a., a 2.1% p.a. redemption rate and a 1% reserve fund.

(ix) Size of largest units installed at a given time during the study period:

1978 - 1981	500	MW(e) net
1981 - 1987	800	
1987 - 1992	1150	
1992 - 1995	1500	
1995 - 2003	2000	

3.2 Coal burning plant

(i) Thermal efficiency of 500 MW(e) unit: 0.348

(ii) Incremental fuel cost: 0.0709 c/kWh, escalating at $2\frac{1}{2}$% p.a., 3% and 4%.

3.3 Converter reactors 500 MW(e)	LWR	HWR
Thermal efficiency	0.335	0.294
Average burn-up (MWd(th)/tonne)	27 700	8 800
Initial enrichment (%)	2.23	Natural uranium
Feed enrichment (%)	2.62	Natural uranium
Discharge enrichment (%)	0.766	0.19
Discharge plutonium (%)	0.54	0.30
Specific inventory (tonne/MW(th))	0.0438	0.0433

Incremental fuel costs [4, 5] : See Figure 4.

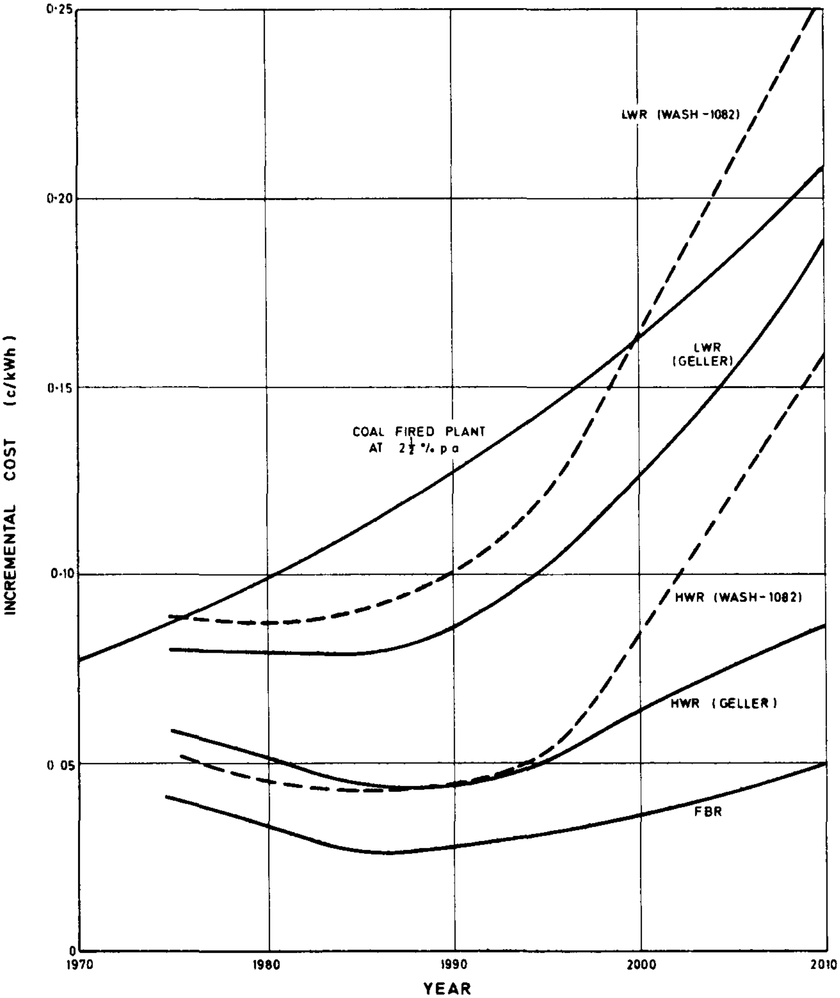

FIG. 4. Incremental fuel costs.

3.4 Fast breeder reactors

Data for a 1000 MW(e) fast breeder reactor for installation in the late 1980s:

Thermal efficiency	0.43
Average burn-up (core)	41 000 MWd(th)/tonne
Plutonium content of replacement fuel elements	19.4%
Breeding ratio	1.47
Specific inventory of core	0.0046 tonne/MW(th)
Fuel cycle costs: See Figure 4.	

Note: All costs given in South African currency, 100 cents = one Rand = $1.39 (U.S.)

4. RESULTS AND DISCUSSION

The results of the study and their sensitivity to certain parameters are summarised in Figures 5, 6 and 7, but discussion will be confined in the first instance to the results obtained with the reference data which are taken as $2\frac{1}{2}\%$ per annum coal cost escalation rate and the predictions of nuclear fuel cycle costs based on the work of Geller [4].

4.1 Growth of nuclear capacity

The installation of converter reactors has been controlled purely by economic considerations, whereas fast breeders have been added to the system as quickly as plutonium stocks permit. On this basis the calculations indicate that in considering the addition of light water reactors plus fast breeders to the system the installed nuclear capacity by the end of the century could approach 35 GW(e) in a total installed capacity of 84 GW(e). Owing to the higher capital costs which were derived for the natural uranium reactor used in this study, the installation of HWRs plus FBRs leads to only 23 GW(e) of nuclear capacity by the end of the century. However, owing to the greater rate of plutonium production achieved with the HWRs, breeders can be introduced earlier (1993) despite the fact that the total installed nuclear capacity is lower prior to their introduction. By the year 2000 with the LWR installed the breeder capacity is only 8 GW whereas, if the HWR is chosen, it is almost 13 GW.

The results of the calculations show that the first and second installations are on the coast at a point furthest from the coalfields - Cape Town. They further indicate that quite a large nuclear programme will be required to meet the load growth forecast in the coastal areas of Natal, the Eastern Cape and the Western Cape over the next 30 years. The first load increment in the Western Cape, encountered after the study datum, occurs in 1980, calling for an installed capacity of 500 MW(e). This is in agreement with earlier "short-term" studies [1]. The second installation is also predicted to be on the same site.

With the data used no nuclear installations appear to be viable at the inland load centre until the introduction of the fast breeder in the mid 1990s, though coastal load increments are not always met by the installation of a nuclear power station, as seen in the next section.

4.2 Growth of transmission line network

It is only in the case of installing the more expensive natural uranium reactors that it appears necessary to increase the firm capacity of the transmission lines from the inland coalfields to the coast, and then only to Natal where the input of power by transmission could reach 9000 MW by 1992. No expansion of the existing (1978) network serving the Eastern and Western Cape (Regions 3 and 4 respectively) appears necessary for any of the reactor installation strategies.

These statements require qualification in that, firstly, inland water limitations may make it necessary to transmit power from the coast to region 1 and, secondly, adequate deficiency cover in the form of several units capable of very rapid response must, of course, be provided for the largest unit installed in any given area. The transmission line network will have an important role to play in meeting this requirement by enabling one region to draw on the pooled spare capacity of other regions.

4.3 Demand for raw materials

Over the period from 1978 - 2000 approximately 2 000 million tonnes of coal would be required to support the power programme if no nuclear stations are installed. The total saleable South African coal reserves from present mining areas have been estimated at 10 500 million tonnes [6], so there should be no coal supply problems over the next 30 years or so. Figure 6 indicates that the installation of enriched uranium reactors could almost halve the cumulative coal required up to the end of the century, but, if natural uranium reactors are installed, an intermediate quantity of coal will be required, about 1 600 million tonnes.

The study has shown that the installation of the mixture of fast and thermal reactors, governed by purely economic considerations, gives rise to a projected cumulative U_3O_8 requirement of up to 90 000 tonnes for all reactor types by the end of the century. Omitting

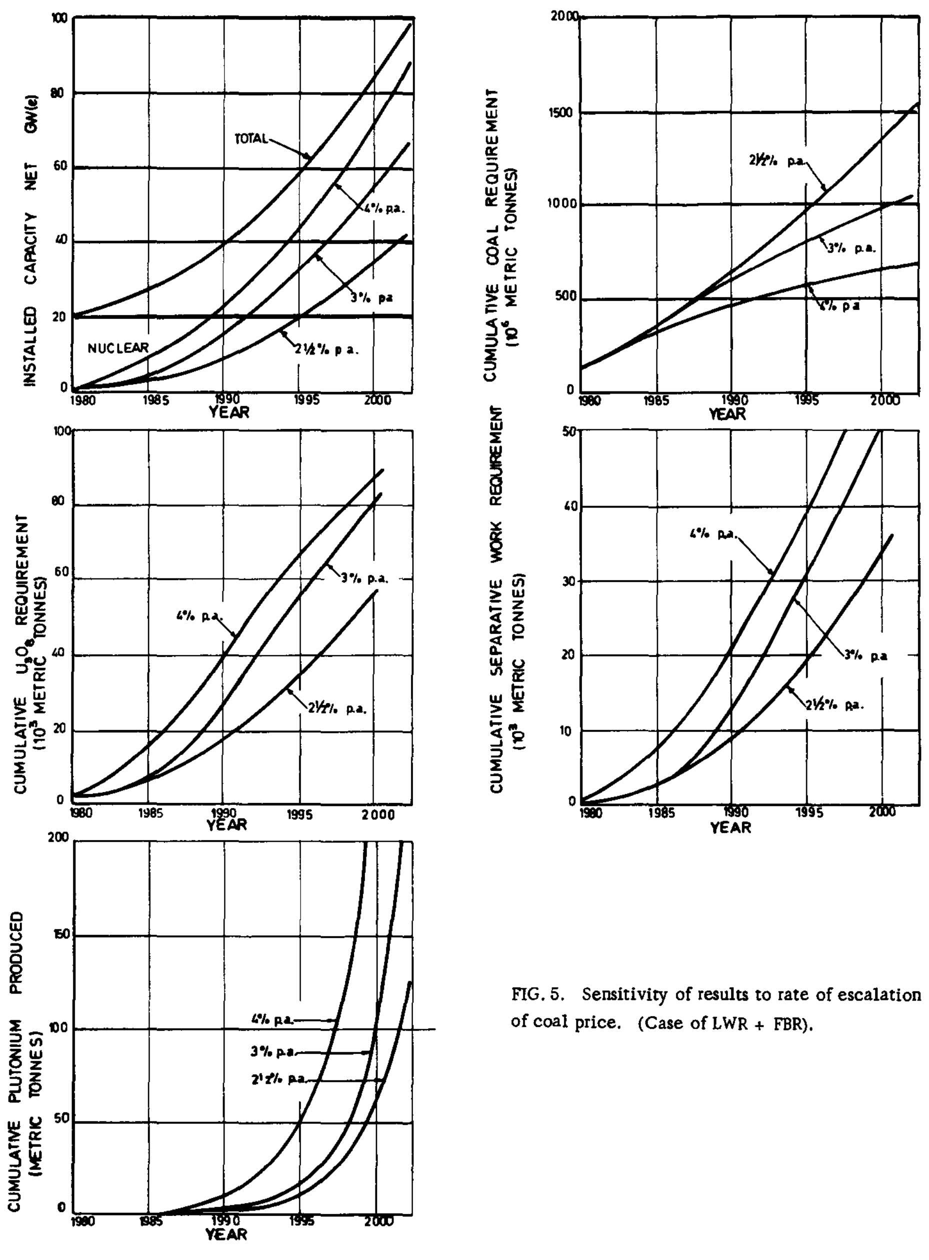

FIG. 5. Sensitivity of results to rate of escalation of coal price. (Case of LWR + FBR).

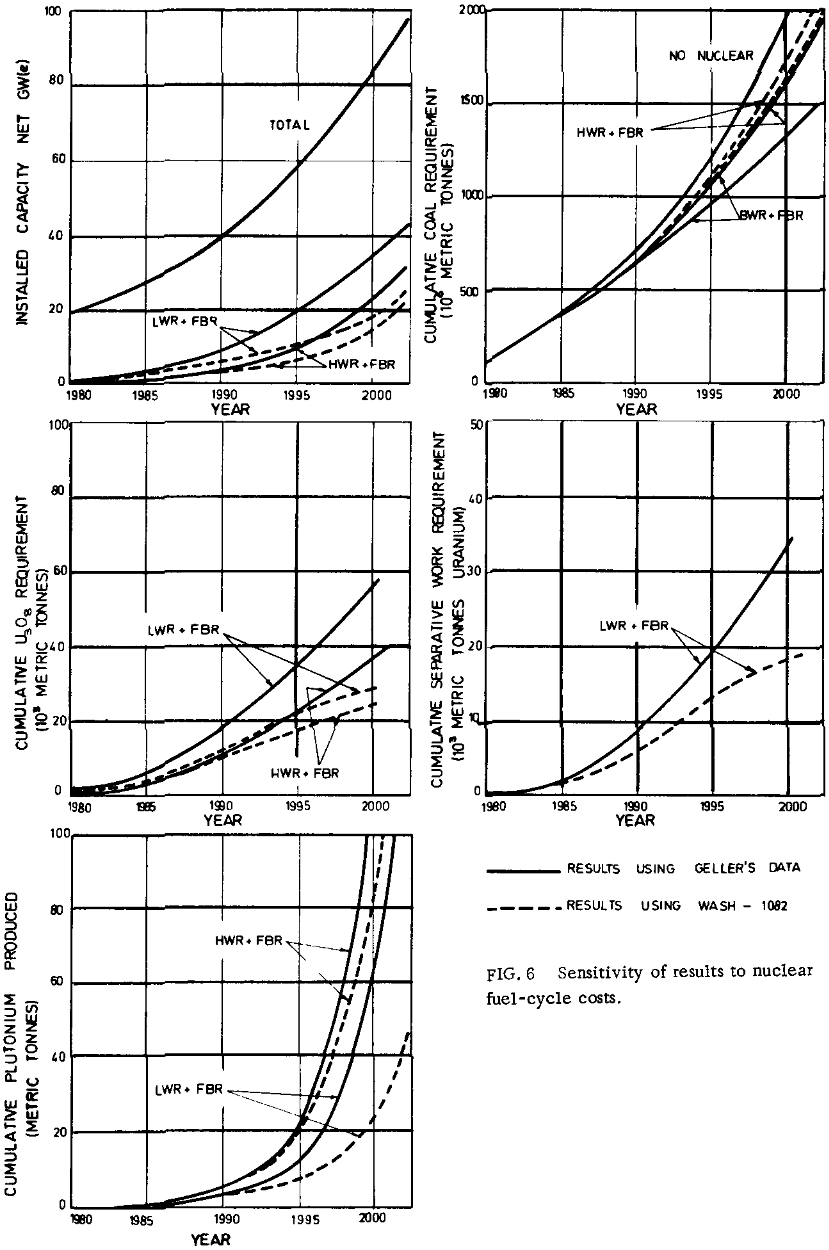

FIG. 6 Sensitivity of results to nuclear fuel-cycle costs.

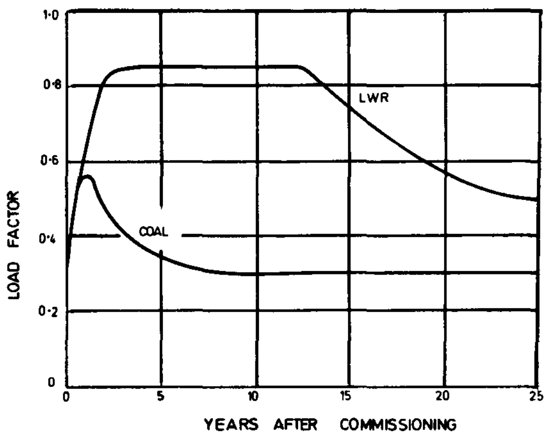

FIG. 7. Predicted load factors for 500-MW(e) LWR and coal stations commissioned in 1980.

the fast breeders from the study does not significantly affect this figure since it has been assumed that breeders will only be introduced when sufficient plutonium has been produced from the thermal reactor installations. With the data used in this study the breeders do not appear until the mid 1990s. The South African reserves in the price range below $10/lb have been estimated at 200 000 tonnes [7].

4.4 Demand for fuel cycle services

A cumulative separative work requirement of up to 55 000 tonne units could be required by the year 2000 to support the proposed installation programme of LWRs and fast breeders. The annual requirement towards the end of the century would be about 2 000 tonne units and this would remain fairly constant for some time afterwards owing to the introduction of the breeder.

The annual demands for fuel element fabrication and reprocessing services are shown in Figure 8. Fabrication requirements are virtually the same for both types of thermal reactor although a smaller total capacity of heavy water reactors would be installed.

4.5 Predicted load factors

As mentioned in the introduction to this paper, a study of this nature should enable a more realistic assessment than hitherto to be made of the expected load factor variation during the life of alternative station types commissioned in any given year. Predicted load factors for 500 MW(e) units commissioned in 1980 are shown in Figure 7. The nuclear unit would be installed at the coast, and the coal-fired station would be a dry-cooled unit installed inland in Region 1. Order-of-merit operation of the coal-fired unit is found to restrict its annual average load factor very severely. In its best year the unit would hardly exceed a load factor of 60%, and within 10 years it would fall to 30% and would then drop even lower were it not tied, in this example, to a minimum load factor by assumed coal supply contract limitations. The same behaviour for the coal station alternative is exhibited for all the reactor installation programmes studied. An LWR installed at the coastal site would be able to maintain an average annual load factor of 85% for the first 13 years of its life, but then it is quickly displaced in the merit order table by larger more efficient units.

4.6 Sensitivity studies

4.6.1 Rate of escalation of coal price

In order to study the effect of coal price on the results, it was decided to run the case of LWRs plus fast breeders for two higher values of the price escalation rate, viz. 3% and

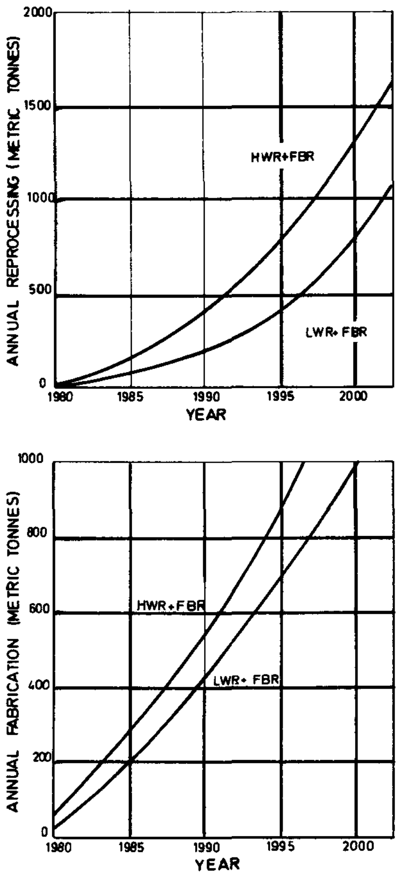

FIG. 8. Annual demand for fuel-element fabrication and reprocessing.

4% per annum. The results are shown in Figure 5 and indicate, as would be expected, a faster growth of the installed nuclear capacity. On a percentage basis this is more pronounced over the early years of the study where the effect of an increase in coal price escalation from the nominal case of 2½% p.a. to 4% p.a. is to almost treble the nuclear capacity required by 1990. The additional units are all installed inland and the first appears in 1988 in the case of a 3% escalation rate, but as early as 1981 if the price of coal rises at 4% per annum. In view of the sensitivity of the results to coal price it is clearly necessary to make a closer study of coal price trends. This is emphasised by the fact that the results of the calculations show a greater change from 2½% to 3% than from 3% to 4%. The cumulative coal requirement, for example, drops by 370 million tonnes for the first ½% increase in escalation rate but by only a similar amount for the next whole percent. Cost escalation rates of 2½% and 4% are considered to bracket likely future coal costs.

The requirements of the nuclear fuel cycle are affected by higher coal prices chiefly during the middle years of the study, for example, the cumulative U_3O_8 demand increases from 17 to 40 thousand tonnes by 1990 for a 1½% increase in coal price escalation rate. But by the year 2000 the cumulative demands in the two cases are 55 and 87 thousand tonnes. A similar increase is observed in the demand for enrichment services, and about four times as much plutonium is produced by the year 2000 using the higher coal prices. This, of course, leads to an earlier introduction of breeders.

4.6.2 Rate of escalation of nuclear fuel costs

In order to study the effect of higher estimates of nuclear fuel cycle costs, the equilibrium LWR and HWR incremental costs were calculated using data from WASH-1082 [5] and the 1971 separative work costs in place of Geller's data [4] (Nominal case). The calculations were carried out using the lowest coal price escalation rate ($2\frac{1}{2}$%).

The data from WASH-1082 give rise to higher equilibrium LWR costs than those calculated from Geller's data, with the differences increasing in later years (Figure 5). This has the effect of reducing the forecast LWR + FBR nuclear capacity by the year 2000 from 34 to 17 GW(e). For an HWR the equilibrium fuel cycle costs before 1990 calculated from the alternative data are slightly lower than those obtained using Geller's data. After 1990, however, the reverse holds with the differences increasing rapidly with time. The effect of this is to leave the predictions of nuclear capacity up to 1990 virtually unchanged, but to bring about a big reduction in nuclear installations over the following 10 years. By the end of the century the expected nuclear capacity of HWRs + FBRs would be reduced from 23 to 15 GW(e) under these conditions.

4.6.3 Higher interest rates

The interest rate on borrowed capital which was used for this study was taken as 6.5%. This was thought to be a little low, and the two basic cases were re-run for 8.5% and 10.5% interest rates. The total installed nuclear capacity for the LWR + FBR case was not reduced at all in either case but, as might be expected, the more capital-intensive natural uranium system suffered slightly, the total installed capacity by the year 2000 dropping from 23 GW(e) to just over 20 GW(e) for an interest rate of 10.5%. The calculated installed capacities therefore appear to be relatively insensitive to interest rate.

5. CONCLUSIONS

Under conditions of favourable nuclear fuel cycle costs an installed nuclear capacity of about 34 GW(e) in a total of 84 GW(e) could be expected in South Africa by the end of the century if only LWRs and FBRs are considered. However, higher nuclear fuel cycle costs, which affect mainly the growth in capacity in the last decade, could reduce this by half. Because of higher predicted overall costs, a programme of natural uranium reactors and fast breeders would give rise to nuclear capacities of 23 and 15 GW(e), respectively, under the high and low fuel cost conditions.

The influence of higher rates of escalation in coal costs, on the other hand, is felt mostly over the early years of the nuclear programme. A modest increase in the rate, say from $2\frac{1}{2}$% to 3%, almost doubles the nuclear capacity to be expected by 1990. However, the next 1% increase in rate has a very much smaller effect.

The sensitivity studies show that a more accurate forecast of nuclear capacity is strongly dependent on a close study of the trends in fuel costs, both nuclear and conventional. However, with the data used in this study, it appears likely that the installed nuclear capacity in the Republic of South Africa by the year 2000 could be between 20 and 40 GW(e).

ACKNOWLEDGEMENT

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DEFINICION DE UN PROGRAMA DE REACTORES DE POTENCIA PARA MEXICO

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Abstract–Résumé–Аннотация–Resumen

DEFINITION OF A POWER REACTOR PROGRAM FOR MEXICO

A power reactor program for Mexico must have as a goal the solution of the national energy problems so that the country will eventually have an adequate energy supply so that the country's present self-sufficiency in energy resources can be maintained if possible. Because of the lack of development of the heavy electrical equipment industry, and in particular the total absence of investment in power reactors, Mexico is free to choose any reactor type and could in fact change type and supplier according to the market conditions at the moment of decision. This policy, which would be analogous to that followed by private electric utilities, is not likely to be appropiate for Mexico's nationalized energy sector. To define a program for technology assimilation and development, it is first necessary to consider the evolution of various reactors in the world and the prospects for their utilization in Mexico. Therefore, probabilities were assigned to the use of different reactor types in Mexico, including fusion reactors, at several dates up to the year 2000. It was thus possible to assess a group of factors so as to assign the relative weights to development plans within a comprehensive policy, taking into consideration as much as possible the economic aspects of associated costs and benefits.

ETABLISSEMENT D'UN PROGRAMME DE REACTEURS DE PUISSANCE POUR LE MEXIQUE.

Un programme de réacteurs de puissance pour le Mexique doit viser à résoudre les problèmes énergétiques nationaux de façon que le pays dispose à long terme de ressources énergétiques suffisantes en continuant, si possible, à suffire à ses besoins. Etant donné l'état peu développé de l'industrie des équipements électro-mécaniques lourds et, en particulier, l'absence totale d'investissements dans les réacteurs de puissance, le Mexique est libre de choisir n'importe quelle filière de réacteurs et, en principe, il pourrait changer de filière et de fournisseur selon les conditions du marché au moment où la décision sera prise. Cette politique, qui serait analogue à celle suivie par les compagnies d'électricité privées, ne convient guère à un pays et particulièrement au secteur énergétique nationalisé mexicain. Pour mettre au point un programme de développement et d'intégration de la technologie, il faut au préalable étudier les tendances possibles de l'évolution des réacteurs dans le monde et les perspectives de leur utilisation au Mexique. Dans ce but, on a déterminé la probabilité d'utilisation de différentes filières de réacteurs au Mexique, y compris les réacteurs à fusion, pour différentes dates jusqu'à l'an 2000. On a ainsi pu élaborer un ensemble de prévisions permettant d'assigner un ordre d'importance relative aux plans de développement dans le cadre d'une politique globale, en tenant compte dans la mesure du possible des facteurs économiques liés aux coûts et aux bénéfices.

ОПРЕДЕЛЕНИЕ ПРОГРАММЫ ЭНЕРГЕТИЧЕСКИХ РЕАКТОРОВ ДЛЯ МЕКСИКИ.

Программа энергетических реакторов для Мексики должна быть направлена на решение национальных проблем по производству электроэнергии с тем, чтобы страна имела достаточное снабжение энергией, сохраняя, если возможно, самообеспеченность в энергоресурсах. Вследствие слабого развития производства тяжелого энергетического оборудования и, в частности, полного отсутствия капиталовложений в ядерные реакторы, Мексика свободно может выбирать любой тип реактора, изменить в принципе его тип, а также поставщика соответственно рыночным условиям в момент принятия решения. Такая политика, которая была бы аналогичной деятельности частных электрических предприятий, вероятно, не будет соответствовать национализированному энергетическому сектору Мексики. Для того чтобы определить программу технологической ассимиляции и развития, необходимо, в первую очередь, рассмотреть эволюцию различных типов реакторов в мире и перспективы их использования в Мексике. С этой целью были определены возможности использования различных типов реакторов в Мексике, включая термоядерные реакторы за несколько периодов по 2000 год. Таким образом, стало возможным установить группу факторов. для того чтобы определить относительную важность планов развития в рамках общей политики, принимая во внимание, насколько это возможно, экономические аспекты связанных с ними расходов и прибылей.

DEFINICION DE UN PROGRAMA DE REACTORES DE POTENCIA PARA MEXICO.

Un programa de reactores de potencia para México debe tender a la solución de los problemas energéticos nacionales de modo que el país cuente, a largo plazo, con un suministro adecuado de energía, preferentemente conservando la situación actual de autosuficiencia. Debido al estado poco desarrollado de la industria de equipos electromecánicos pesados y en particular a la ausencia total de inversiones en reactores de potencia, México se encuentra en libertad de escoger cualquier línea de reactores y en principio sería posible cambiar de tipo y de proveedor según las condiciones del mercado en el momento de tomar una decisión. Esta política, que sería análoga a la seguida por compañías de suministro eléctrico privadas, es poco probable que convenga a un país y concretamente al sector energético nacionalizado de México. Para poder definir un programa de desarrollo y de asimilación de tecnología, es necesario antes considerar las posibles trayectorias de evolución de los reactores en el mundo y las perspectivas de su utilización en México. Con este objeto, se asignaron probabilidades al uso de diferentes tipos de reactores, incluyendo los de fusión, en México, en varias fechas hasta el año 2000. Se pudo así construir un conjunto de «futuros» que permite asignar pesos relativos a planes de desarrollo dentro de una política global, tomando en cuenta en la medida de lo posible los factores económicos de costos y beneficios asociados.

1. INTRODUCCION

Puede postularse, muy generalmente, que un programa de reactores de potencia para México debe contribuir a la solución de los problemas energéticos nacionales, con el objetivo de que el país cuente, a mediano y largo plazo, con un suministro adecuado de energía, preferentemente conservando la situación actual de autosuficiencia.

En México el sector energético se encuentra totalmente nacionalizado, lo que permite en principio una coordinación de las políticas de los organismos descentralizados que lo integran y, concretamente, de Petróleos Mexicanos, Comisión Federal de Electricidad y Comisión Nacional de Energía Nuclear. Por otra parte, el poco desarrollo de la industria de equipos electromecánicos pesados y la ausencia de inversiones en plantas nucleoeléctricas, dejan bastante libertad para definir una política en materia de reactores de potencia.

Hasta la fecha, la situación energética del país se ha caracterizado por el dominio casi total de los hidrocarburos que han satisfecho más del 90 por ciento de la demanda de energía, en condiciones que pueden juzgarse favorables. Sin embargo, el aumento registrado en los últimos años en los costos de exploración y explotación del petróleo en México, indica la conveniencia de incluir las centrales nucleares en los planes de expansión del sistema eléctrico centro-sur interconectado [1] y existe el proyecto de construir una primera unidad nuclear de aproximadamente 600 MW en el lugar llamado Laguna Verde, sobre el Golfo de México, a unos 280 km al este de la ciudad de México [2].

2. POLITICAS POSIBLES

Con estas condiciones iniciales y de contorno, se pueden examinar las opciones que se presentan. La más simple, sería decidir la instalación de cada central nuclear tomando en cuenta únicamente el costo contable de la energía producida, de modo similar a como procedería una compañía privada de suministro eléctrico en un país desarrollado. Esto conduciría, muy probablemente, a cambiar de tipo y fabricante de reactor con frecuencia, dependiendo de las condiciones que prevalecieran en el mercado internacional en el momento de tomar cada decisión. En estas circunstancias, sería difícil, por no decir imposible, planear una participación creciente de la industria nacional en la construcción de las centrales nucleares y en particular llegar a realizar en el país, en condiciones económicas, el máximo posible de los procesos integrantes de los ciclos de combustibles.

Otra posibilidad sería tratar de desarrollar totalmente la tecnología de reactores de potencia, con la idea de poder alcanzar, en este campo, una capacidad y una autonomía de las que carecemos en otros sectores industriales más tradicionales. Con toda seguridad, esta alternativa sería extremadamente costosa y contribuiría a agravar, en lugar de resolver, muchos de los problemas de desarrollo a los que México, como otros países, se enfrenta.

Una política intermedia entre los dos extremos indicados parecería mucho más sensata para un país como México. Las centrales nucleares que se construyan tendrán que ser adiciones confiables y económicas a las redes eléctricas del país. Aunque inicialmente la mayor parte del equipo se compre en el extranjero, se fomentará la participación creciente de la industria nacional, mediante estímulos y ayudas que pueden incluir la estandarización de equipos en la medida de lo posible y la adopción de mecanismos para facilitar la transferencia de tecnología y la implantación de mejores sistemas de control de calidad. En la rama de los combustibles nucleares, se procurará la realización en México de una parte cada vez mayor del ciclo total, de acuerdo con las economías de escala que sean alcanzables, evaluando los costos con un criterio nacional, necesariamente más amplio que el de una empresa eléctrica, gubernamental o privada.

La adopción de una política como la señalada demanda del estado y en especial de la Comisión Nacional de Energía Nuclear, la fijación de orientaciones y objetivos en investigaciones científicas y tecnológicas que faciliten la asimilación y dominio de tecnologías probadas, o la familiarización con las tecnologías en desarrollo en otras partes del mundo, de modo que se prepare la participación oportuna de la industria nacional en los proyectos futuros de reactores de potencia.

El problema que se presenta es uno de asignación de recursos, basándose en proyecciones forzosamente subjetivas sobre la orientación de los conocimientos y el estado del mundo. Por más que se procure introducir flexibilidad en los programas de investigación y desarrollo, es necesario visualizar el futuro, o los "futuros" posibles, asignándoles pesos adecuados para tomar en cuenta su probabilidad subjetiva de ocurrencia. Por otra parte, las extrapolaciones de la potencia nuclear instalada conducen rápidamente a cifras de consideración [3] que necesitan ser afectadas de una tasa de descuento para conservar la perspectiva correcta en el tiempo.

CUADRO I

POTENCIA NUCLEAR Y POTENCIA ELECTRICA TOTAL

Año	ESTADO X1				ESTADO X2				PROMEDIO			
	Adición Nuclear GW	Potencia Nuclear GW	Potencia Total GW	Relación %	Adición Nuclear GW	Potencia Nuclear GW	Potencia Total GW	Relación %	Adición Nuclear GW	Potencia Nuclear GW	Potencia Total GW	Relación %
1972	0,6	0	7,0	0	0,6	0	7,2	0	0,60	0	7,06	0
1979	1,2	0,6	11 ,2	5,4	1,8	0,6	14,4	4,2	1,38	0,60	12,16	4,9
1986	2,4	1,8	17,9	10,1	5,4	2,4	28,8	8,3	3,30	1,98	21,17	9,3
1993	4,8	4,2	28,6	14,7	16,2	7,8	57,6	13,5	8,22	5,28	37,30	14,2
2000	9,6	9,0	45,8	19,7	48,6	24,0	115,2	20,8	21,30	13,50	66,62	20,2
2007	--	18,6	73,3	25,4	--	72,6	230,4	31,5	--	34,80	120,43	28,9

3. ALTERNATIVAS DE DESARROLLO

Un método posible para tomar en cuenta, sin demasiada complejidad, los factores anteriores, consiste en asignar dos estados posibles al "mundo", caracterizado fundamentalmente por la abundancia de uranio y otros dos estados a "México", caracterizado por la rapidez de su desarrollo.

Definamos:

U1: Estado del mundo caracterizado por la existencia durante varias décadas de uranio barato. En estas condiciones, los reactores de cría y de fusión tienen un desarrollo lento y los reactores convertidores son pronto abandonados por falta de incentivos económicos. En cambio, se desarrollan y se vuelven más accesibles los métodos de enriquecimiento del uranio. Probabilidad asignada a ese estado: 0,7.

U2: Estado del mundo caracterizado por el advenimiento, a partir de 1980, del uranio caro. Se impulsa considerablemente el desarrollo del reactor de cría enfriado por sodio, de otros tipos de reactores de cría y de la fusión termonuclear controlada. Los reactores convertidores tienen un lugar importante si se atrasan los reactores de cría. El enriquecimiento del uranio no se extiende a muchos países. Probabilidad de este estado: 0,3.

X1: Estado de México caracterizado por una tasa de desarrollo similar a la actual. La potencia eléctrica instalada se duplica cada 10 años, o se multiplica por 1,6 cada 7 años. Cada 7 años se decide la instalación del doble de la potencia nuclear decidida en la fecha anterior, comenzando con la decisión en 1972 de instalar 600 MW. Se es indiferente ante los tipos de reactores, guiándose fundamentalmente en la selección por el costo contable de la energía producida. El factor de descuento es de 0,5 cada 7 años, o sea una tasa anual de 10,4 por ciento, lo que correspondería aproximadamente a una tasa de preferencia en el tiempo de 6 por ciento y a una tasa por aceleración de riesgo que en nuestro caso puede interpretarse como una tasa por innovación tecnológica, de 4 por ciento. Probabilidad de este estado: 0,7.

X2: Estado de México caracterizado por una tasa de desarrollo apreciablemente superior a la actual. La potencia eléctrica instalada se duplica cada 7 años. Cada 7 años se decide instalar el triple de la potencia nuclear decidida en la fecha anterior, comenzando con la decisión en 1972 de instalar 600 MW. Se da preferencia a los tipos de reactores cuyas tecnologías pueden implantarse más fácilmente en México. El factor de descuento es de 0,4 cada 7 años, o sea una tasa anual de 14 por ciento, lo que correspondería aproximadamente a una tasa de preferencia en el tiempo de 8 por ciento y a una tasa por innovación tecnológica de 6 por ciento. La probabilidad de este estado se estima en 0,3.

El cuadro I muestra el crecimiento de la potencia nuclear y de la potencia eléctrica total, instaladas en redes de servicio público, para los estados X1 y X2 y para el promedio que puede definirse a partir de las probabilidades asignadas.

CUADRO II

PROBABILIDADES DE TRANSICION

FECHA	TRANSICION	PROBABILIDADES Futuro A	Futuro B	Futuro C	Futuro D
1972	L	0,9	0,8	0,8	0,8
1979	L/H	0,2	0,4	0,4	0,5
	H/L	0,5	0,4	0,4	0,3
1986	L,L/H	0,1	0,4	0,4	0,4
	L,L/M	0	0,1	0,2	0,3
	H,H/H	0,5	0,6	0,8	0,7
1993	L,L,L/L	0,7	0,5	0,2	0,1
	L,L,H/M	0,2	0,2	0,3	0,3
	L,L,H/O	0	0	0,1	0,1
	H,H,H/H	0,5	0,6	0,6	0,6
2000	L,L,L,L/L	0,3	0,2	0,1	0,1
	L,L,H,M/M	0,8	0,8	0,5	0,6
	L,L,H,M/F	0,1	0,1	0,2	0,2
	H,H,H,H/H	0,3	0,3	0,4	0,4
	H,H,H,H/O	0,1	0,1	0,2	0,2

CUADRO III

POTENCIA NUCLEAR DECIDIDA EN EL FUTURO A

(en GW)

FECHA	L	H	M	O	F	TOTAL
1972	0,54	0,06	--	--	--	0,60
1979	0,92	0,28	0,00	--	--	1,20
1986	1,93	0,42	0,05	--	--	2,40
1993	3,01	0,81	0,98	0,00	0,00	4,80
2000	2,05	0,52	5,19	0,92	0,92	9,60
TOTAL	8,45	2,09	6,22	0,92	0,92	18,60

Siendo prácticamente independientes los estados de México y del mundo, se pueden definir entonces cuatro "futuros" para el desarrollo de los reactores de potencia en México:

A: Futuro determinado por U1 y X1. Probabilidad : 0,49.
B: Futuro determinado por U1 y X2. Probabilidad : 0,21.
C: Futuro determinado por U2 y X1 . Probabilidad : 0,21.
D: Futuro determinado por U2 y X2. Probabilidad : 0,09.

En la imposibilidad de considerar en detalle todos los tipos de reactores posibles, nos limitaremos en esta exploración a aquéllos cuya utilización en México se considera más plausible, esto es: reactores de agua ligera que se representarán con la letra L, reactores de agua pesada (H), reactores de cría enfriados por metal líquido (M), otros reactores de cría en general (O) y reactores de fusión (F).

A partir de 1972, en cada fecha de decisión se asignaron probabilidades condicionales que no son otra cosa sino las probabilidades de transición a cada tipo de reactor, dada una línea de desarrollo pasado y de acuerdo con el futuro que se esté considerando. Entre el grán numero de probabilidades condicionales que hubo que asignar, el cuadro II recoge unas cuantas que sirven de ilustración al procedimiento descrito.

Los cuadros III a VII muestran los resultados obtenidos para la potencia cuya instalación se decide, por tipo de reactor, para cada uno de los futuros y el futuro promedio.

CUADRO IV

POTENCIA NUCLEAR DECIDIDA EN EL FUTURO B

(en GW)

FECHA	L	H	M	O	F	TOTAL
1972	0,48	0,12	--	--	--	0,60
1979	1,01	0,79	0,00	--	--	1,80
1986	2,40	2,46	0,54	--	--	5,40
1993	5,75	6,35	4,10	0,00	0,00	16,20
2000	4,08	4,66	30,37	4,57	4,92	48,60
TOTAL	13,72	14,38	35,01	4,57	4,92	72,60

Aun en el caso del futuro promedio, las cifras que resultan no reflejan adecuadamente la importancia relativa de los diferentes tipos de reactores, debido a los diferentes tiempos en que se toman las decisiones y a las diferentes tasas de descuento que, según el tipo de desarrollo, deben adoptarse. El cuadro VIII muestra los valores presentes de las potencias cuya instalación se decide entre 1972 y 2000, utilizando los factores de descuento mencionados anteriormente y adoptando como 1 000 el valor presente de 600 MW decididos en 1972.

CUADRO V

POTENCIA NUCLEAR DECIDIDA EN EL FUTURO C

(en GW)

FECHA	L	H	M	O	F	TOTAL
1972	0,48	0,12	--	--	--	0,60
1979	0,65	0,55	0,00	--	--	1,20
1986	0,71	1,32	0,37	--	--	2,40
1993	0,42	1,97	1,68	0,24	0,49	4,80
2000	0,09	2,25	3,54	1,59	2,13	9,60
TOTAL	2,35	6,21	5,59	1,83	2,62	18,60

CUADRO VI

POTENCIA NUCLEAR DECIDIDA EN EL FUTURO D

(en GW)

FECHA	L	H	M	O	F	TOTAL
1972	0,48	0,12	--	--	--	0,60
1979	0,68	0,94	0,18	--	--	1,80
1986	0,89	2,78	1,73	--	--	5,40
1993	0,28	6,55	7,14	0,58	1,65	16,20
2000	0,05	9,23	21,53	6,95	10,84	48,60
TOTAL	2,38	19,62	30,58	7,53	12,49	72,60

CUADRO VII

POTENCIA NUCLEAR DECIDIDA EN EL FUTURO PROMEDIO

(en GW)

FECHA	L	H	M	O	F	TOTAL
1972	0,51	0,09	--	--	--	0,60
1979	0,86	0,50	0,02	--	--	1,38
1986	1,68	1,25	0,37	--	--	3,30
1993	2,80	2,73	2,34	0,10	0,25	8,22
2000	1,88	2,54	11,60	2,37	2,91	21,30
TOTAL	7,73	7,11	14,33	2,47	3,16	34,80

CUADRO VIII

VALOR PRESENTE RELATIVO DE LAS POTENCIAS DECIDIDAS

TIPO DE REACTOR	FUTURO A	FUTURO B	FUTURO C	FUTURO D	PROMEDIO
L	3,313	2,899	1,732	1,523	2,733
H	0,727	2,261	1,857	2,659	1,460
M	0,769	1,877	0,872	2,262	1,158
O	0,095	0,195	0,215	0,359	0,165
F	0,096	0,210	0,324	0,639	0,217
TOTAL	5,000	7,442	5,000	7,442	5,733

En definitiva, puede verse que la importancia actual relativa de los diferentes tipos de reactores en los futuros propuestos puede representarse aproximadamente por los números 0,48, 0,25, 0,20, 0,03 y 0,04 para los reactores de agua ligera, de agua pesada, de cría enfriados por metal líquido, de cría de otros tipos y de fusión, respectivamente.

Debe hacerse notar que estos pesos relativos se refieren a decisiones de instalación y por tanto dan una idea de la importancia de las inversiones, no así de los gastos de operación y muy principalmente de los gastos de combustible, que necesitarían un cálculo separado de los valores presentes de la energía generada en cada año.

4. CONCLUSIONES

La definición de un programa de reactores de potencia requiere la elección de una política en materia de desarrollo de reactores de potencia. Evitando los dos extremos de no hacer nada, o de querer hacerlo todo, queda una banda muy amplia de posibilidades que no puede precisarse más que por una evaluación, necesariamente subjetiva, del porvenir.

El tipo de análisis presentado permite una exploración sistemática del futuro, en principio con todo el detalle que uno desee. El hecho de que los resultados encontrados reflejen bastante bien el cuadro intuitivo que uno posee, no debe considerarse como un defecto sino, al contrario, como una indicación de que este tipo de método que hace explícitas las hipótesis de partida puede utilizarse en la formulación de planes de desarrollo.

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DISCUSSION ON AGENDA ITEM 1.2

Projected role of nuclear energy in meeting future energy needs

DISCUSSION ON THE FOLLOWING GROUP OF PAPERS:

P/467 UK Presented by Sir John Hill

P/569 France Presented by X. Michon

There was no discussion on these papers.

DISCUSSION ON THE FOLLOWING GROUP OF PAPERS:

P/347 Yugoslavia Presented by J. Salom-Šuica

P/712 USSR Presented by A.M. Petros'yants

L. TWUM-DANSO: Perhaps Mr. Petros'yants (Paper P/712) could say what percentage of the Soviet Union's electricity production is nuclear.

A.M. PETROS'YANTS: The proportion of nuclear power is still relatively small. The total capacity of all the power stations in the USSR at present amounts to 170 million kW and the nuclear capacity is about 2.5 million kW. The point is that the USSR is well provided with energy resources. Nuclear power will be playing an important part by the end of the present century.

DISCUSSION ON THE FOLLOWING GROUP OF PAPERS:

P/298 Japan Presented by W. Hiraizumi

P/802 Brazil Presented by J.A. Marquès de Souza

W. LEPECKI: I should like to ask Mr. Hiraizumi what is the role of the heavy-water reactor in the Japanese program, and what is the status of the heavy-water prototype?

T. YAMADA: Perhaps I can answer this question. Light-water reactors are preferred in Japan and this situation will probably continue in the foreseeable future. However, from the standpoint of efficient utilization of nuclear fuels, light-water reactors are not very satisfactory, and we opted for heavy-water reactors with a view to achieving a balance between economy and efficient fuel utilization. The prototype we are now constructing is a 160-MW heavy-water moderated, light-water-cooled reactor (FUGEN), and we are expecting it to go into operation in 1974-75.

The Japanese heavy-water reactors are not unlike the Candu-BLWR and the SGHWR, but they also have significant differences as we intend to use plutonium fuel.

In the late 'seventies we expect that many heavy-water reactors will be operating in the Japanese electricity network, along with light-water reactors.

I would refer you to Paper P/232 for further details.

N. AYBERS: If I understand Mr. Marquès de Souza (Paper P/802) correctly, the Brazilians are hoping to develop a local fuel-cycle industry covering all phases of the fuel-cycle. Does this mean they will also take care of all phases of the enriched-uranium fuel cycle?

J.A. MARQUÈS DE SOUZA: As regards the different phases of the fuel cycle in the Brazilian program the situation is as follows:

Prospecting and drilling: actively developed;
Mining and yellow-cake production: commercial contract under way for installations;
Uranium purification and UO_2-pellet production: pilot plants in operation (designed and built in our own country);
Fuel-element fabrication and reprocessing: laboratory studies (see Paper P/197);
Uranium enrichment: technico-economical and feasibility studies.

DISCUSSION ON THE FOLLOWING GROUP OF PAPERS:

P/778	*Korea*	*Presented by Y.K. Yoon*
P/541	*CSSR*	*Presented by J. Neumann*
P/818	*Italy*	*Presented by A.M. Angelini*
P/359	*FRG*	
P/660	*South Africa*	
P/788	*Mexico*	

A.M. WEINBERG: I should like to comment briefly on paper P/359 by Mr. Mandel. Mr. Mandel's estimate of the energy content of the sea – assuming the D-D reaction can eventually be mastered – is 9×10^{24} kcal, i.e. about 5000 times the energy content of the extractable uranium and thorium contained in the rocks of the earth. These figures are not in line with similar estimates of our own, which show the two sources to be much more nearly equal. Of course, if fusion always had to depend on the D-T reaction with lithium as raw material, the balance would be different; the energy in uranium and thorium together is greater than that in lithium.

H. MANDEL: These long-term predictions constitute no more than a general assessment of possibilities which would appear to exist in principle; enormous research programs extending over long periods of time will be necessary, as we all know, before any of these possibilities can be realized in practice. For the moment our estimates can well be made in orders of magnitude. Hence I estimated the fusion energy potential of the deuterium in the seas on the basis of the average energy recovery from the two D-D reactions. The result was a total potential of 9×10^{26} kcal. But no doubt only part of the deuterium content of the seas will be economically extractable. I took that part to be 1% and so arrived at the figure quoted in my paper – 9×10^{24} kcal – for the economically extractable energy potential of the deuterium contained in the seas.

From Mr. Weinberg's comment it is not clear of course whether the estimates to which he refers yielded different results on the basis of the same initial assumptions. What he does say is that the estimates have led to roughly equal values for the energy content of the seas and the energy content of the extractable uranium and thorium contained in the rocks of the earth. I have not examined this last relationship; rather, I confined myself, for purposes of comparison, to the fission energy potential of the economically extractable uranium contained in the seas – assuming, as before in the case of deuterium, that only 1% could be extracted economically.

Mr. Weinberg's comparison with the energy content of the uranium and thorium that can be extracted from the earth's crust might well suggest misleading conclusions, because the extractable fraction of uranium and thorium in rock is not a quantity that can be assessed easily. If we assume that the extractable fractions are the same in every case, Mr. Weinberg's conclusion regarding the approximate equality of the energy potentials attributable to uranium and thorium fission and to deuterium fusion would be confirmed by my initial figures too. But in fact the fraction of uranium and thorium that can be extracted economically from the earth's crust is probably smaller by orders of magnitude than the fraction of deuterium that can be extracted economically from the seas, particularly if factors such as accessibility of deposits are taken into account. Given the inherent difficulty of such a comparison, I followed the practice normally used in assessing conventional energy sources and derived my figures for economically extractable uranium and thorium from published data which have been substantiated by geological investigations.

AGENDA ITEM 5.4

Organization of national atomic energy commissions
and their relationship with other bodies and institutions

Organisation des commissions nationales de l'énergie atomique
et leurs relations avec d'autres organes et institutions

Организация национальных комиссий по атомной энергии
и их связь с другими органами и учреждениями

Organización de las comisiones nacionales de energía atómica
y sus relaciones con otros órganos e instituciones

Chairman

G. H. de CARVALHO, Brazil

Vice-Chairman

T. SHIBATA, Japan

Scientific Secretaries

H. T. DAW, IAEA
Y. NISHIWAKI, IAEA

CANADA
A/CONF 49/P/166

GOVERNMENT, UTILITIES, INDUSTRY AND UNIVERSITIES: PARTNERS FOR NUCLEAR DEVELOPMENT IN CANADA AND ABROAD

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Abstract–Résumé–Аннотация–Resumen

GOVERNMENT, UTILITIES, INDUSTRY AND UNIVERSITIES: PARTNERS FOR NUCLEAR DEVELOPMENT IN CANADA AND ABROAD.

In Canada, eleven power reactors installed or planned at four sites will provide 5520 MW(e) for an investment of $1800 million. Uranium production during the decade 1958 - 1967 totalled 79 700 ton U_3O_8 worth $1621 million. For nuclear research, development and control, the Federal Government employs about 6000 people and spends about $80 million/yr, which includes the cost of operating three major research reactors (> 30 MW each). Aggregate commercial isotope production has reached 14 mCi, and Canada has about 3000 licensed users. Three power and two research reactors of Canadian design are or will be installed in developing countries overseas. Legislation in 1946 made atomic energy a federal responsibility and established an Atomic Energy Control Board. The Board's regulations, which deal primarily with health, safety and security, are administered with the cooperation of appropriate departments of the federal and provincial governments. Large-scale nuclear research began in 1941 and continued under the National Research Council until 1952 when the Federal Government created a public corporation, Atomic Energy of Canada Limited, to take over both research and the exploitation of atomic energy. Another public corporation, Eldorado Nuclear Limited, conducts research and development on the processing of uranium and operates Canada's only uranium refinery, but prospecting and mining are undertaken largely by private companies. The publicly owned electrical utilities of Ontario and Quebec operate nuclear power stations and participate with governments in their financing. Private industry undertakes extensive development and manufacturing, mainly under contract to Atomic Energy of Canada Limited and the utilities, and industry has formed its own Canadian Nuclear Association. Canadian universities undertake nuclear research, and receive significant government support; one has operated a research reactor since 1959. Canada's nuclear program is entirely directed to peaceful applications, and Canada has ratified the Treaty on Non-Proliferation of Nuclear Weapons. The government has eleven bilateral treaties for nuclear cooperation; inter-agency agreements facilitate such cooperation with four additional countries. Appropriate loans support reactor construction in developing countries, and training has been arranged.

LE GOUVERNEMENT, LES ENTREPRISES D'ELECTRICITE, L'INDUSTRIE ET LES UNIVERSITES PARTICIPENT DE CONCERT AU DEVELOPPEMENT NUCLEAIRE AU CANADA ET A L'ETRANGER.

Au Canada, onze réacteurs de puissance installés ou commandés fourniront, sur quatre sites, 5520 MW(e); l'investissement total sera de 1,8 milliards de dollars. La production d'uranium, au cours de la décennie 1958 - 1967, a atteint 79 700 tonnes d'U_3O_8 valant au total 1,621 milliards de dollars. Pour la recherche, le développement et le contrôle nucléaires, le Gouvernement fédéral emploie près de 6000 personnes et dépense approximativement 80 millions de dollars par an, somme comprenant les frais d'exploitation de trois grands réacteurs de recherche (ayant, chacun, une puissance supérieure à 30 MW). La production totale de radio-éléments commerciaux a atteint jusqu'à présent 14 mCi et il y a au Canada environ 3000 utilisateurs qualifiés. Trois réacteurs de puissance et deux réacteurs de recherche de conception canadienne sont ou seront installés outre-mer, dans des pays en voie de développement. La Loi de 1946 a confié au Gouvernement fédéral la responsabilité de l'énergie nucléaire et elle a établi la Commission de contrôle de l'énergie atomique. Les règlements de cette Commission, qui concernent principalement la santé, la sécurité et la sûreté, sont

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appliqués avec la coopération des ministères appropriés du Gouvernement fédéral et des gouvernements provinciaux. La recherche nucléaire canadienne à grande échelle a débuté en 1941. Par la suite, et jusqu'en 1952, elle a été poursuivie sous l'égide du Conseil national de la recherche. Ensuite, le Gouvernement fédéral a créé une entreprise d'Etat, l'Energie atomique du Canada, pour poursuivre la recherche atomique et son exploitation. Une autre entreprise d'Etat, Eldorado nucléaire, effectue des travaux de recherche et de développement concernant le traitement de l'uranium et elle exploite la seule raffinerie d'uranium du Canada, tandis que la prospection et l'extraction minières sont effectuées en grande partie par des sociétés privées. Les entreprises d'électricité de l'Ontario et du Québec exploitent des centrales nucléaires et participent, avec les gouvernements, à leur financement. Des entreprises industrielles privées procèdent à d'importants travaux de développement et de fabrication, dans la plupart des cas sous contrats passés avec l'Energie atomique du Canada ou avec les entreprises d'électricité. Les entreprises industrielles ont formé l'Association canadienne pour l'énergie nucléaire. Les universités canadiennes effectuent des recherches nucléaires et reçoivent, pour ce faire, une aide substantielle du Gouvernement. L'une de ces universités exploite un réacteur de recherche depuis 1959. Le programme nucléaire canadien est entièrement consacré à des applications pacifiques et le Canada a ratifié le Traité de non-prolifération des armes nucléaires. Le Gouvernement a adhéré à onze traités bilatéraux de coopération nucléaire. Des accords conclus entre agences facilitent cette coopération avec quatre autres pays. Des prêts appropriés permettent la construction de réacteurs dans les pays en voie de développement et le personnel étranger peut être formé au Canada.

ПРАВИТЕЛЬСТВО, ПРЕДПРИЯТИЯ, ПРОМЫШЛЕННОСТЬ И УНИВЕРСИТЕТЫ: ПАРТНЕРЫ ПО РАЗВИТИЮ ЯДЕРНОЙ ЭНЕРГИИ В КАНАДЕ И ЗА ГРАНИЦЕЙ.

В Канаде в четырех местах установлены или запланированы одиннадцать энергетических реакторов общей мощностью 5520 МВт (эл) при капитальных вложениях в 1800 млн.долларов. Производство урана за десятилетний период с 1958 по 1967 год составило 79 700 т закиси-окиси урана общей стоимостью 1621 млн.долларов. Для проведения ядерных исследований, разработок и контроля федеральное правительство содержит штат около 6000 человек и ежегодно ассигнует 80 млн.долларов, куда входит стоимость эксплуатации трех основных исследовательских реакторов (мощностью более 30 МВт каждый). Общее коммерческое производство изотопов достигло 14 мКи, и в настоящее время в Канаде около 3000 потребителей имеют лицензии на их использование. Три энергетических и два исследовательских реактора канадской конструкции установлены или будут установлены в развивающихся странах. В соответствии с законодательством 1946 года на федеральное правительство возложена ответственность за атомную энергию и учреждено Управление по контролю за атомной энергией. Выполнение инструкций Управления, касающихся в основном вопросов здравоохранения, техники безопасности и обеспечения секретности, контролируется совместно с соответствующими департаментами федерального и провинциальных правительств. Проведение ядерных исследований в широких масштабах началось в 1941 году и продолжалось под руководством Национального исследовательского Совета до 1952 года, когда федеральным правительством было создано государственное объединение "Атомик энерджи оф Канада" для проведения исследовательских работ и использования атомной энергии. Другое государственное объединение "Эльдорадо ньюклеар" проводит исследования и разработки по переработке урана и управляет канадскими предприятиями только по обогащению урана, тогда как разведка и добыча урана осуществляется в основном частными компаниями. Государственные электрические предприятия Онтарио и Квебека эксплуатируют атомные электростанции и совместно с правительствами принимают участие в их финансировании. Частная промышленность осуществляет обширные разработки и производство, в основном по контракту с объединением "Атомик энерджи оф Канада" и предприятиями, а промышленность создала свою собственную Ядерную Ассоциацию Канады. Канадские университеты проводят ядерные исследования и получают значительную помощь со стороны правительства; в одном из университетов исследовательский реактор эксплуатируется с 1959 года. Программа ядерных исследований Канады всецело направлена на мирное применение. Канада ратифицировала Договор о нераспространении ядерного оружия. Правительство имеет одиннадцать двусторонних соглашений о сотрудничестве в области атомной энергии; межведомственные соглашения способствуют такому сотрудничеству еще с четырьмя странами. Развивающимся странам предоставляются соответствующие займы для строительства реакторов; производится подготовка местных кадров.

GOBIERNO, EMPRESAS ELECTRICAS, INDUSTRIA Y UNIVERSIDADES PARTICIPAN EN EL DESARROLLO NUCLEAR EN EL CANADA Y FUERA DE EL.

El Canadá ha invertido 1800 millones de dólares en once reactores de potencia que proporcionarán 5520 MW(e) y que se han instalado o proyectado en cuatro emplazamientos. La producción de uranio durante el decenio 1958 - 1967 alcanzó 79 700 toneladas de U_3O_8 por valor de 1621 millones de dólares. El Gobierno emplea a unas 6000 personas para la investigación, desarrollo y control nucleares y gasta al año unos

80 millones de dólares incluyendo los costes de funcionamiento de tres reactores de investigación principales (cada uno de ellos de más de 30 MW). La producción comercial de isótopos ha alcanzado 14 mCi en total y el Canadá tiene unos 3000 usuarios autorizados. Tres reactores de potencia y dos de investigación diseñados en el Canadá han sido o serán instalados en países extranjeros en vías de desarrollo. La Ley de 1946 hizo responsable al Gobierno Federal de la Energía Atómica y creó una Junta de Control (Atomic Energy Control Board). Los reglamentos de esta Junta, que tratan principalmente de la salud, de la seguridad y de los seguros, se aplican con la cooperación de los departamentos apropiados de los gobiernos federal y provinciales. La investigación nuclear en gran escala comenzó en 1941 y continuó a cargo del National Research Council hasta 1952 en que el gobierno federal creó una empresa pública, la Atomic Energy of Canada Limited, para que se hiciera cargo, tanto de la investigación como de la explotación de la energía atómica. Otra empresa pública, Eldorado Nuclear Limited, se ocupa de la investigación y del desarrollo de la elaboración del uranio y explota la única refinería de uranio canadiense. Sin embargo la prospección y la minería corren a cargo de las compañías privadas en su mayor parte. Las empresas eléctricas nacionalizadas de Ontario y Quebec explotan las centrales nucleoeléctricas y participan con el gobierno en su financiación. La industria privada se ocupa en gran parte del desarrollo y de la fabricación, sobre todo en forma de contratos con la Atomic Energy of Canada Limited y las empresas eléctricas, y ha formado su propia asociación: Canadian Nuclear Association. Las Universidades canadienses se ocupan de la investigación nuclear y reciben un apoyo notable del gobierno. Una de ellas lleva operando un reactor de investigación desde 1959. El programa nuclear canadiense está enteramente dedicado a las aplicaciones pacíficas y el Canadá ha ratificado el Tratado de no Proliferación de Armas Nucleares. El gobierno ha firmado once tratados bilaterales para la cooperación nuclear. Hay otros cuatro países más con los cuales la cooperación se canaliza a través de acuerdos entre organismos. Préstamos apropiados ayudan a la construcción de reactores en países en vías de desarrollo, concertándose también programas de adiestramiento.

The organization of atomic energy in Canada reflects the priorities of scientific and economic policy as well as the accidents of history. Canada gained an early start because of its involvement in the military program of the Second World War [1,2], but immediately after that War, the priorities changed to those of research and of peaceful applications. Legislation was passed to define responsibilities, and an institutional framework was established [3].

During the last twenty-five years, the achievements of research and development have defined the routes to economic applications. The basic law has been consolidated, and the institutions have developed — but more in size than number. For Canada, the nuclear activities of these twenty-five years have involved trade and investment that may be counted in billions of dollars. The locations of the major centres are identified in Fig. 1.

The basic philosophy has been to make use of existing institutions wherever possible. New institutions have been created only when the volume of work or special needs required them. Thus, although the main regulatory body, the Atomic Energy Control Board (AECB), was founded in 1946, it was not until 1960 that its staff reached ten persons. The application and enforcement of the Board's regulations has largely been carried out through the agencies of appropriate existing bodies. For example, the Department of National Health and Welfare and corresponding provincial bodies undertake the monitoring and inspection necessary to ensure the protection of persons from radiation hazards. Similarly,

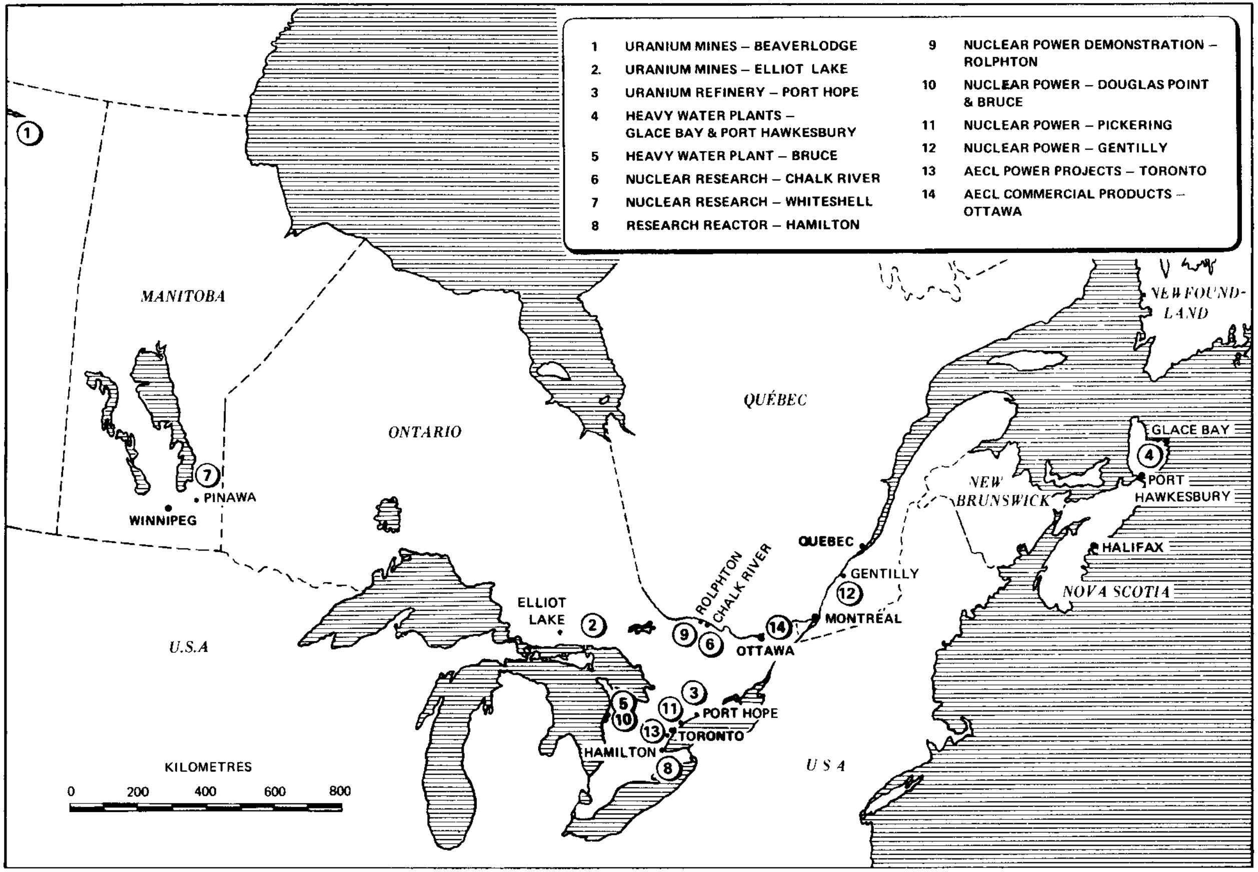

FIG 1 Principal nuclear installations in Canada.

the government's main arm for research and development, the National Research Council, carried operational responsibility for nuclear research until 1952, when this work had reached an extent and maturity that necessitated the formation of a separate institution.

LEGISLATION [4,5]

Canada is a confederation of ten provinces. The Constitution, which dates from 1867, assigns particular responsibilities to the federal parliament and to the provincial legislatures, and all responsibilities not so assigned are responsibilities of the federal parliament. But the Constitution also empowers the federal parliament to take under its own jurisdiction "Such Works" as it declares to be "for the general Advantage of Canada"; and, in 1946, the federal parliament made such a declaration to cover all activities related to atomic energy. Having done so, the federal parliament acquired exclusive jurisdiction, and the provincial legislatures have refrained accordingly.

The principal statute is the Atomic Energy Control Act, which was first made law in 1946 and has subsequently been amended [6]. The Act is a short document establishing and defining the powers of the AECB [7], a body with five members whose President is also its full-time executive officer. The Act empowers the Board to make regulations [8] covering the development of all aspects of atomic energy, to disseminate and control information, and to offer scholarships and grants to promote research and the training of personnel. The Act authorizes a Minister designated by the government to carry out research and the exploitation of atomic energy and gives him substantial powers for this purpose, including the power to acquire or establish companies that are wholly owned in the name of Her Majesty and that are supported by monies voted by parliament.

The only other piece of legislation specifically concerned with atomic energy is the recent Nuclear Liability Act [9,10]. This places all responsibility for nuclear damage on the operator of a nuclear installation. It requires the operator to obtain insurance in the amount of $75 million (part of which may be re-insured by the government). It also provides for the establishment of a Nuclear Damage Claims Commission to deal with claims for compensation when the government deems that a special tribunal is necessary. The Act recognizes that Canada may enter international arrangements in respect of nuclear liability, but Canada is not at present a party to any such arrangement.

In statements to the federal parliament [11], the government has also indicated its intentions to introduce legislation or regulations that would set limits on foreign ownership in companies engaged in uranium mining.

REGULATION AND CONTROL

Health and Safety

Standards for the radiation protection of atomic-energy workers and of the general population are given legal effect in the Regulations [8] of the AECB. These standards closely parallel the recommendations of the International Commission for Radiological Protection.

Control of Nuclear Materials

By issuing licences, the AECB regulates all dealings in prescribed materials, such as uranium, thorium, plutonium and heavy water. A person finding a mineral deposit containing more than 0.05% by weight of uranium or thorium is required to inform the Geological Survey of Canada. Thereafter an AECB licence is required to explore or to mine a uranium property. Mining licences are given only to companies that have been incorporated under Canadian federal or provincial law.

The uranium licences require detailed reporting on the exploration and on production. Sales within Canada may be made only to appropriately licensed bodies and exports are strictly controlled. A policy first announced in 1958 and extended in 1965 and 1969 [12] requires safeguards agreements for exports if these exceed 2 500 pounds (1 134 kg) to any one country; the amounts are limited to those required for a five-year stockpile in the safeguarded installation. With the coming into force of the Treaty on the Non-Proliferation of Nuclear Weapons (NPT), Canada will take into account the NPT safeguards agreements that countries may have concluded with the International Atomic Energy Agency (IAEA).

Until October 1968, only the federal government or its agencies could own plutonium, enriched uranium or uranium-233. Private ownership is now possible with the appropriate licences, but these are granted only after a thorough investigation of an applicant's facilities, equipment and procedures. The personnel must have had adequate training and, when the amounts exceed 100 g, the application is considered by a Criticality Panel. As for other operations involving radioactive materials and radiation, the AECB seeks the advice of the Department of National Health and Welfare and of the appropriate provincial health department on radiation safety before granting a licence.

Export licences are processed with the co-operation of the Department of Industry, Trade and Commerce; import licences are processed with the co-operation of the Department of National Revenue (Customs).

Radioisotopes

Licences are required for all dealings in radioisotopes involving more than a defined minimum level of activity. A licence is issued only when the AECB and its health advisors are satisfied that the applicant is qualified and equipped to use the material with safety. Medical applications of radioisotopes are reviewed by an Advisory Committee on the Clinical Uses of Radioisotopes of the Department of National Health and Welfare and must conform with the Food and Drug Regulations.

Periodic checks are made to ensure that licencees comply with the regulations and standards. The inspectors have been appointed from among the staff of the Department of National Health and Welfare and from appropriate departments of provincial governments.

TABLE I. CANADIAN NUCLEAR REACTORS

Research and Test Reactors [13]

Name (Date)	Location	Power	Type and Purpose
ZEEP (1945)	Chalk River, Ontario	<100W	Tank for D_2O-moderated lattice experiments
NRX[a] (1947)	Chalk River, Ontario	30-40MW	D_2O-moderated, H_2O-cooled for research, engineering tests and isotope production
NRU (1957)	Chalk River, Ontario	100-125MW	D_2O-moderated, D_2O-cooled for research, engineering tests and isotope production
PTR (1957)	Chalk River, Ontario	10kW	Highly enriched pool reactor for swing measurements of reactivity
Toronto University (1958)	Toronto, Ontario	–	Sub-critical university reactor for research and teaching, D_2O-moderated
McMaster University (1959)	Hamilton, Ontario	2MW	Highly enriched pool reactor for university and industrial research and isotope production
ZED-2 (1960)	Chalk River, Ontario	150W	Tank for D_2O-moderated lattice experiments
WR-1 (1965)	Pinawa, Manitoba	60MW	D_2O-moderated, organic-cooled for research and engineering tests
SLOWPOKE (1970)	Chalk River, Ontario[b]	5kW	Highly enriched self-regulating pool reactor for neutron activation

Power Reactors (including those committed for construction)[c,d]

Station and Location	Start-up	Power MW(e)	Coolant
NPD, Rolphton, Ontario	1962	22.5	Boiling D_2O
Douglas Point, Ontario	1967	208	Pressurized D_2O
Gentilly, Québec	1971	250	Boiling H_2O
Pickering, Ontario	1971→	4x508	Pressurized D_2O
Bruce, Ontario	1975→	4x752	Pressurized D_2O

[a] The NRX design is used in the CIRUS reactor at Trombay, India, and in a reactor under construction in Taiwan.

[b] SLOWPOKE has been moved to the University of Toronto and went into operation there on June 28, 1971.

[c] All reactors are moderated with heavy water and fuelled with natural-uranium oxide in zirconium-alloy pressure tubes.

[d] Canadian reactor designs are also employed for the KANUPP 125-MW(e) nuclear power plant in Pakistan and the RAPP 2x200-MW(e) stations in Rajasthan State, India.

At present, Canada has about 3 000 licensed users of isotopes. Starting from 1 January 1970 the validity of all licences is limited to two years, after which they must be renewed.

Reactors

A list of Canadian reactors is given in Table I. A technical account of the criteria for judging reactor safety in Canada is given in another paper [14] presented at this Conference. All proposals are subject to formal and detailed reviews in at least three steps — for approving the site, for construction and then for operation.

Before licences are issued, the AECB refers the application to its Reactor Safety Advisory Committee (RSAC). The members are appointed because of their expert knowledge and, in some cases, also as representatives of appropriate government departments. For any particular application, the membership is augmented by appropriate officers of the provincial governments involved and by the Medical Officer of Health of the local city or county administration. The RSAC is assisted by AECB staff members who also act as inspectors to ensure compliance with the conditions of licences that are issued; the AECB maintains staff members resident at certain sites.

The AECB also maintains a control over the qualifications and experience of the key personnel operating the reactors that it has licensed. Shift supervisors and control-room operators are examined by the AECB's Reactor Operators Examination Committee.

Reactors operated by the federal government have been exempted from the need for AECB licences. These are all research reactors and are within the establishments of the government-owned company, Atomic Energy of Canada Limited (AECL). AECL has its own Nuclear Safety Advisory Committee which includes a member of the staff of AECB.

Accelerators

Over many years the appropriate federal and provincial departments have developed procedures to ensure that X-ray machines and other radiation-emitting devices [15] are operated safely. However, in recent years there has been an upsurge in the construction and use of particle accelerators, not only for research, but also for medicine and industry. Altogether there are now about 50 particle accelerators in Canada, and many of these machines are capable of producing very intense fields of radiation and substantial quantities of radioactive materials. The AECB has, therefore, progressively developed a system of licensing and surveillance and has an Accelerator Safety Advisory Committee whose composition and functions parallel those of its Reactor Safety Advisory Committee. A formal licensing procedure has been mandatory since March 1970.

Other Nuclear Plants

Using its broad general powers under the Act and Regulations, the AECB may intervene where appropriate to review the safety of any plant that processes prescribed materials and to subject it to a formal licensing procedure. Committees are established with the appropriate expertise and representation. Such bodies have studied the safety of a plant for the production of uranium hexafluoride and several plants for the production of heavy water.

Transportation of Nuclear Materials

The various authorities that regulate transportation by rail, sea and air obtain technical advice from the AECB on packaging and shipping procedures for radioactive material. The AECB itself regulates the transport of radioactive materials by road pending the designation of an authority to regulate all aspects of the transport of dangerous commodities by road. The AECB's Shipping Containers Order applies to all forms of transport.

The regulations applied in Canada are based on those proposed by the IAEA in 1967, and Canada is taking an active part in the work of revising its draft regulations. In accordance with the IAEA recommendation, large shipments of radioactive material are subject to "certificates of compliance", which are prepared by AECB and endorsed by the appropriate authority for rail, sea or air transport.

RESEARCH AND DEVELOPMENT

Government research and development in atomic energy is largely the responsibility of AECL. This is a company set up pursuant to the Atomic Energy Control Act. It reports to parliament through the Minister of Energy, Mines and Resources [16].

The company is headed by a Board of Directors whose eleven members are appointed by the Minster and who bring to the Board experience in the universities, the electrical utilities and industry. A simplified organization chart is shown in Fig. 2. The current budget for research and development is about $70 million.

When the company was formed in 1952, it took over the Division of Atomic Energy of the National Research Council (NRC). With the NRC Division, came the staff, laboratories and equipment that had been built up over the preceding seven years at Chalk River, Ontario. Now known as the Chalk River Nuclear Laboratories, this establishment represents Canada's principal investment in nuclear research and development. In recent years, the staff has remained fairly constant at about 2 400 of which about 400 have been professional research workers with appropriate training in physics, chemistry, biology, engineering or related disciplines.

It is interesting to note that at no time has the government concentrated all its nuclear research effort in one establishment. Geological research has been left with the Geological Survey of Canada and the equivalent provincial departments. Research on extraction and processing of uranium has been mainly the responsibility of the Mines Branch (now part of the Department of Energy, Mines and Resources) and to some extent, of Eldorado Nuclear Limited, another public corporation. For many years the Chalk River establishment did not employ its own metallurgists; instead the Mines Branch conducted metallurgical research in

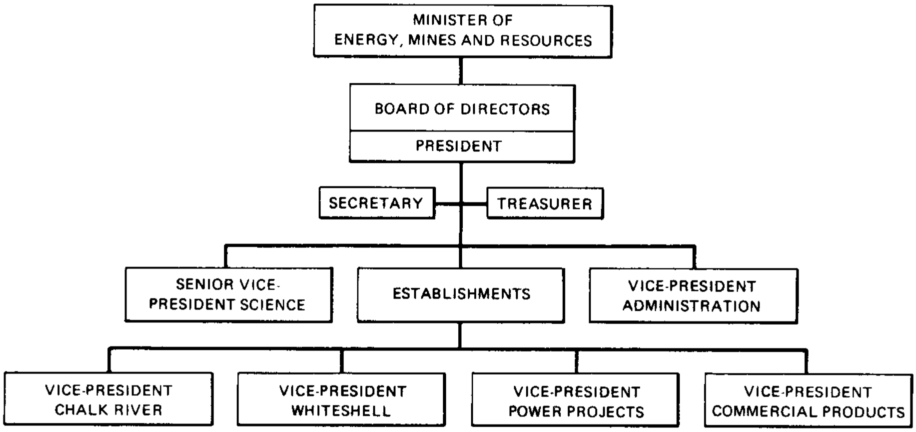

FIG. 2. Atomic Energy of Canada Limited: Simplified organization chart.

support of the nuclear program both at Ottawa and in special facilities at Chalk River. Similarly, NRC retains responsibilities for the standardization of radioactive sources, and it shares with Chalk River the responsibilities for fundamental research in radiation biology [17]. The Department of National Health and Welfare has conducted studies related to the radiation protection of workers and the general population. The Department of Agriculture has been concerned with radioactive contamination of food by fall-out and methods for its reduction.

Thus, it can be seen that no rigid boundaries have been drawn between the research responsibilities of the different federal agencies. Work is done where the talent and equipment exist, and duplication has been avoided through appropriate consultations — most of them informal.

The boundaries between basic and applied research are always difficult to delineate. Nevertheless, it is true to say that the Chalk River program has always had a substantial component of true basic research — nuclear and solid-state physics, nuclear and radiation chemistry, materials science and radiation biology. The existence of this strong component of basic research is believed to have had an important influence in maintaining high scientific standards through all phases of the establishment's work. Personnel with many years of experience in basic research have moved over into applied research and have brought with them advanced concepts in experimental methodology. When serious immediate problems arose in applied research, basic research workers could be called in to join temporary task forces that were highly successful in finding the needed solutions.

But, while the basic research programs have been broad, the applied research programs have tended to be highly concentrated. In the early 1950's Canada decided to follow a single route to economic nuclear power — the heavy-water-moderated reactor. For a country with Canada's limited resources in applied research, dissipation of effort in several directions might have been disastrous and, in any case, would have not permitted the progress that was made.

The applied research programs at Chalk River in support of nuclear power have particularly involved reactor physics, fuel development, moderator and coolant chemistry, corrosion and radiation effects on reactor materials, electronics and simulation, and computer studies of costs.

The investments in equipment — particularly the reactors, the reactor loops, the accelerators, the facilities for work on highly radioactive materials, such as irradiated fuel, high-speed computers and the engineering equipment — have been supported by a strong infra-structure of technical services and tradesmen. Because of its remoteness from centres of industrial activity, Chalk River needed to develop its own cadres of draughtsmen, maintenance crews, construction workers, transportation services, storekeepers, electricians, carpenters, etc. With a flexible in-house capability, effort is directed where it is most immediately needed and, where necessary, can be maintained for all the hours of the day and all the days of the year.

Towards the end of the 1950's, Chalk River had grown so that the number of its employees was approaching 2 500. At this point the management of AECL took note of the experience of other large research and development establishments and recognized that continued growth might lead to a need for much more complex administrative structure. AECL had had a very small head office in Ottawa and, at Chalk River, administration had been kept as a relatively small component of the total staff. Much depended on the patterns of close informal communication that build up in a society that is somewhat isolated and that is dedicated to common objectives. If further growth made it impossible to rely on this informal co-ordination, a much more complex structure might become necessary.

The decision was taken to limit further expansion at Chalk River and to set up a new research centre at Pinawa in the province of Manitoba. Known as the Whiteshell Nuclear Research Establishment, this is now completing its first decade. Many of the original staff came by transfer from Chalk River; they brought with them the traditions and experience of the older establishment and were able to maintain close links with their colleagues still located there. Whiteshell embarked on a program of basic research centred on the properties of materials and a program of applied research centred on the use of organic coolants for improving the steam-cycle efficiency of heavy-water-moderated power reactors. Because of the extent of the program of basic nuclear physics at Chalk River, Whiteshell has excluded this from its range of activities. Whiteshell's staff now totals about 800 with about 150 professional research workers.

Other establishments of AECL — its Commercial Products group in Ottawa and its Power Projects group near Toronto — carry out applied research and development in fields directly associated with their main objectives.

Canadian universities have had a long tradition of participation in nuclear research. It was at McGill University in Montreal that Ernest Rutherford carried out much of his early research on radioactivity. In the postwar years many universities have acquired accelerators for research and one, McMaster University in Hamilton, Ontario, has a 2 - MW pool reactor.

As part of the financial support that universities receive from federal and provincial governments, there is a continuing program of grants in support of university research related to atomic energy. Advisory committees review the work underway and make appropriate recommendations to NRC and AECB, the principal granting bodies. A separate major item is the construction of the Tri-University Meson Facility (TRIUMF), a 500-MeV spiral-ridge cyclotron [18]; the capital grants for this facility total almost $30 million.

AECL maintains close contacts with appropriate departments of Canadian universities, partly through contracts under which the universities carry out research or development to meet AECL objectives. Both Chalk River and Whiteshell provide facilities for Ph.D. candidates. At Chalk River an Experiments Advisory Committee reconciles the needs of university and AECL scientists for time on Chalk River equipment. Whiteshell has a special arrangement with the University of Manitoba under which some of its staff hold honorary faculty appointments.

Industrial research on atomic energy has mainly developed through co-operative programs with AECL. At present, AECL is spending about $4 million per year on development contracts with industry. One major emphasis has been in the field of materials development, particularly for reactor fuels. Another is in design and development of new instruments [19], and a noteworthy example is the development of large lithium-drifted germanium detectors for precise measurement of gamma photons [20].

PRODUCTION OF NUCLEAR MATERIALS

Co-operation between government and industry [21] is illustrated by the growth of production capabilities for uranium, thorium, heavy water and zirconium.

The history and current status of Canada's uranium and thorium industry [22] are more fully outlined in another paper at this Conference [23]. Most of the uranium ore production capacity is in the hands of private companies, and these have benefitted from the efforts of the Geological Survey of Canada, of the geological agencies of provincial governments and of university departments of geology. Important support has also come from the Mines Branch of the Department of Energy, Mines and Resources in the development of chemical methods of processing ores. A company — originally expropriated during the Second World War and now a Crown company known as Eldorado Nuclear Limited — operates the uranium refinery at Port Hope, Ontario. Feed for this refinery comes from Eldorado's own mining operations and from the various private companies that are still operating their mines and mills.

The vast expansion of the industry — particularly in the private sector — responded to the opportunities provided by government contracts with the United States and the United Kingdom: production in the decade 1958—1967 totalled 79 700 tonnes U_3O_8 worth $1 621 million. But despite some stretching out of these contracts, demand for uranium has been low in recent years. The government has provided some mitigation by buying for stockpiles, but in general the industry has had to conserve its resources and await the development of a stronger market. To provide for power reactors under construction, Ontario Hydro[1] has made some long-term purchases, and forecasts for the remainder of this century indicate that the uranium industry will once again become a key component of Canada's national economy.

At present Canada is not enriching uranium, although Eldorado does have a plant that produces UF_6 for enrichment elsewhere; it can also handle enriched UF_6 in its processes for preparing feed to nuclear fuel fabricators. The question of an enrichment plant for Canada is under periodic review by the governments and industries that would need to be involved.

The Canadian General Electric Company Limited (CGE) and the Canadian Westinghouse Company Limited operate highly developed plants for the production of finished nuclear fuel. They have both co-operated closely with AECL, Ontario Hydro and Eldorado in research, development and irradiation testing to perfect the processes that now permit fuelling of Canadian power reactors at costs well below 1 m$/kWh [24]. Their planning is facilitated by contracts from AECL and the power-reactor operators which give reliable indication of the production needed in the ensuing five years. Orders from other countries for finished fuel have not been large in comparison with domestic needs, but the capacity exists to handle larger orders.

Canadian power-reactor fuel is clad in zirconium alloys, and zirconium is used extensively in the reactor structures. Eldorado completed a plant in 1969 to extract zirconium, separate hafnium and produce 300 tonne/year zirconium-metal billets. The market has not yet been great enough to establish a Canadian industry producing zirconium tubes, although industrial development of such processes has been carried out under AECL contracts.

Canada has a developing capacity for the production of heavy water [25]. Construction of the first two large plants was made possible by the favourable conditions offered by the government of Nova Scotia as part of its effort to attract new industry, and by the prices guaranteed by AECL for purchases over the first years of operation. The third plant is being built by private industry directly for AECL; it will use steam from the Douglas Point nuclear power station — and eventually from the Bruce nuclear power station — as a source of process heat. Because of the delays

[1] The Hydro-Electric Power Commission of Ontario, the public utility providing electricity to the entire province

in bringing the first two plants into production,AECL has been purchasing heavy water on the world market to provide the amounts needed for Canadian Deuterium Uranium (CANDU) power reactors in this country and abroad.

NUCLEAR POWER

It was in the early 1950's that AECL first recognized that its research work was pointing the way to a method of producing electricity that could compete in cost with the other sources of new power likely to be available in certain parts of Canada. In particular the province of Ontario was near to completing the harnessing of all its water-power resources within reasonable distances of the load centres, and it was beginning to build thermal stations fired with imported coal. Nuclear power offered the possibility of stabilizing the cost of electricity and of avoiding substantial expenditures of foreign exchange.

A study team was put together in 1954 to review AECL's work and to make appropriate recommendations. The team involved individuals from utilities and industry, as well as staff from AECL itself. It recommended the construction of a demonstration reactor, cooled and moderated with heavy water and fuelled with natural uranium. The design and construction of this reactor became a joint project involving AECL, Ontario Hydro and CGE. CGE had offered to invest some of its own money in the design work and was selected as the industrial partner following competitive bids.

A team was set up at the Peterborough plant of CGE, and many of the staff were recruited from the experienced engineering personnel at Chalk River. Ontario Hydro used mainly its own personnel, but, where necessary, arranged for their training during attachments to Chalk River. Many Canadian industries became involved through sub-contracts for design and supply of components. AECL owns the nuclear portion of the Nuclear Power Demonstration (NPD) station, and Ontario Hydro owns the remainder of the plant. The entire station is operated by Ontario Hydro, which bills AECL for the costs of operating the nuclear systems, but purchases the steam produced at prices linked to the cost of coal in southern Ontario. Ontario Hydro feeds the electricity from NPD into its provincial network.

It was a continuation of the original study group (with somewhat different membership) that drew up the conceptual design of the 208-MW(e) Douglas Point station. This time, however, the detailed design and construction became the joint responsibility of AECL and Ontario Hydro. AECL established its Power Projects group near to Toronto to handle the work and again drew heavily on the engineering personnel at Chalk River to find the necessary staff. Ontario Hydro attached its own engineers to Power Projects where they worked as regular members of the AECL teams.

For Douglas Point, the financing was somewhat different from what it had been for NPD. The federal government, through AECL, was the main source of the initial capital and it owns the entire station. The agreement provides that Ontario Hydro purchase the power at the prices at which it buys electricity from interconnected utilities. As with NPD, Ontario Hydro operates the station and feeds the power into its provincial network; provision is made for the eventual purchase of the station by Ontario Hydro.

A major shift in the decision-making and financial responsibilities came with the commencement of work for the 4 x 508-MW(e) Pickering station. With the increasing maturity of the design, the utility — Ontario Hydro — took over the major role. The first two reactors of the Pickering station were financed through interest-bearing loans provided jointly by three partners: the federal government, the government of Ontario, and Ontario Hydro. A formula was agreed for the progressive repayment of their investments out of revenue from the station. The services of AECL Power Projects were purchased for the design of the nuclear portion of the station.

For the third and fourth reactors at Pickering and for the 4 x 752-MW(e) Bruce station, the shift in financial responsibility goes all the way; Ontario Hydro raises the capital without any participation by the federal government. Again, however, AECL Power Projects is providing design service on a repayment basis.

The 250-MW(e) Gentilly station represented a different design concept; although the moderator is still heavy water, the medium for heat transport is boiling light water instead of the pressurized heavy water employed in the Douglas Point, Pickering and Bruce stations. Because of the novelty involved, the arrangements with the utility, la Commission hydro-électrique de Québec, follow closely the pattern established for Douglas Point, i.e., AECL finances and owns the station, but Hydro-Québec participated in the design, contracted for its construction, operates the station and will ultimately buy it.

AECL Power Projects has grown to a staff of nearly 1 000 including about 250 professional engineers. As well as the design offices, it has its own development laboratory and can draw on the research and development teams at Chalk River and Whiteshell for assistance in the resolution of particular problems.

Fuller accounts of operating experience [26] and cost improvement work [27] are given in other papers at this Conference. Meanwhile Chalk River and Whiteshell carry on studies of more advanced systems [28,29], and have given continuing attention to the metallurgy of reactor materials [30] and to matters such as environmental protection [31].

The CGE team at Peterborough, which was originally formed to design NPD, followed this with other nuclear-reactor work, notably the design of the WR-1 test reactor for Whiteshell and the design and construction of the KANUPP power plant for Pakistan. However, when further orders did not materialize, CGE elected to concentrate the work of this team on fuel-handling machines and systems. Other Canadian companies have continued to develop their capacities to respond to the expanding needs of the nuclear power program, and one group of companies in the Montreal area has formed a consortium, Canatom Limited, to offer nuclear consulting services in Canada and abroad.

ISOTOPES AND RADIATION

Canada was one of the first countries to enter the world market with cobalt-60. An early start was possible because of the production capacity of the NRX reactor, and with the success of the first irradiators and beam therapy equipment, provision was made for increasing production capacity in NRU and in the power reactors. In recent years annual sales of isotopes and related equipment have amounted to about $10 million, most of them going to export.

The Commercial Products group of AECL receives irradiated materials from the reactors and puts them into the forms needed for sale. Depending on the isotope, this may involve chemical as well as mechanical handling. Equipment is produced for mounting the radiation sources, and often this equipment represents a greater proportion of the total value than the isotope material itself. This is especially true of the automated irradiation equipment for cancer therapy and the large complex systems designed for industrial sterilization.

Commercial Products provides design and consulting services to potential isotope users and helps in the development of processes. Much of the research and development is of a co-operative nature involving other appropriate institutions. Thus development of the food and agricultural applications [32] has been carried out with federal and provincial departments of agriculture, with universities and with some of the larger food-processing industries; Commercial Products has taken the initiative in seeking approvals for particular applications from the federal Food and Drug Directorate. Industrial applications [33] have been developed in association with particular companies. But although Commercial Products has obtained the advice of the medical profession in the design of its therapy equipment, research on the medical applications of isotopes and radiation has largely been left to the universities and hospitals [34]. Unlike some other countries, the federal government has not mounted any large program in the medical applications of atomic energy; it has maintained a small effort related to its responsibilities for the protection of atomic-energy workers.

INFORMATION AND EDUCATION

The results of AECL's research and development work are published in the appropriate scientific and technical journals, both national and international. More detailed information is offered in a series of technical reports which are both sold to the public and exchanged with other institutions around the world [35].

AECL's technical information service, based at Chalk River, maintains a national collection of atomic-energy literature and makes its services available throughout the country [36]; it also provides the focus for Canada's participation in the International Nuclear Information System (INIS).

A Canadian Nuclear Association was established in 1960 and is primarily an association of corporate bodies — although provision is also made for individuals to join. At present it has about 170 corporate members including about 30 from other countries; the Canadian corporate members are mostly industries active in the nuclear field, especially mining and engineering, but they also include agencies of federal and provincial governments, utilities, university departments, banks and investment houses. The Association has eleven active committees studying particular aspects of nuclear development and making recommendations to the membership. It holds one major general conference each year at which Canadian nuclear progress is reviewed and often holds smaller shorter meetings on particular subjects. It publishes a monthly newsletter, *Nuclear Canada*. A trade magazine, *Canadian Nuclear Technology*, was issued from 1961 to 1967 by a large publisher of such magazines, but it was not a commercial success. Many Canadian nuclear scientists and engineers are members of the American Nuclear Society and participate in its professional activities.

AECL also sponsors conferences from time to time on appropriate subjects and offers the use of its facilities for atomic-energy meetings organized by international and professional groups. The series of AECL symposia on atomic power [37] have provided an important medium for alerting senior officials of government, utilities and industry to the progressive development of our nuclear power capability and its prospects for the future.

Nuclear education in Canada was the subject of a recent review article [38]. In contrast to some other countries, Canada has relied more on on-the-job training than on the development of formal courses. Particularly noteworthy, however, is the Nuclear Training Centre established by Ontario Hydro at the NPD reactor at Rolphton, Ontario [39]. The centre has a staff of about 15 training officers and is equipped with laboratories for studies in health physics, electrical and mechanical work, hydraulics, heat transfer and computer simulation. Courses extend up to five years in duration and are directed to the needs of those who will manage and operate nuclear power stations. La Commission hydro-électrique de Québec has also inaugurated training programs at which technical instruction is available in French.

Many universities (particularly those that have accelerators) provide for postgraduate research and training in nuclear science. For nuclear engineering, formal courses are in operation at Toronto University, where there is a sub-critical reactor; McMaster University, which has a 2-MW pool reactor; Royal Military College in Kingston, Ontario; and l'Ecole Polytechnique in Montreal.

INTERNATIONAL CO-OPERATION AND DEVELOPMENT

Although Canada participates actively in formal international arrangements for co-operation in atomic energy, we believe that the informal communication that exists within the "invisible colleges" of workers in particular subject areas provides the most effective mechanism for promoting co-operation and good will. By participation at international scientific meetings, by visits and correspondence, and by receiving post-doctoral fellows in our laboratories, the network of personal relationships is developed.

Canada is a member of IAEA, an associate member of the European Nuclear Energy Agency (ENEA) and has ratified NPT. It has signed inter-governmental bilateral agreements for co-operation in the peaceful uses of atomic energy with Australia [40], Euratom [41], the Federal Republic of Germany [42], India [43,44], Japan [45], Pakistan [46,47], Spain [48], Sweden [49], Switzerland [50,51], the United Kingdom [52] and the United States [52—57]. Formal agreements also have been signed between AECL and agencies with similar responsibilities in four additional countries — France, Italy, Romania and the Soviet Union.

It is government policy to support the work of the IAEA, and the safeguards responsibilities arising from two bilateral agreements have been transferred to the IAEA [58,59].

Canada also supports the IAEA in its efforts to bring nuclear technology to bear on the problems of development. It makes its experts available for IAEA programs, and receives trainees, sponsored by the IAEA, from developing countries. Under the Colombo Plan, Canada helped to provide India with the CIRUS reactor which follows the NRX design [60]. Later, agreements between Canada and India made provision for the building of RAPP, the nuclear power station in Rajasthan state, with export credits guaranteed by the government of Canada. RAPP follows the Douglas Point design and the agreements made provision for training of Indian operators by AECL and Ontario Hydro. The KANUPP nuclear power station near Karachi in Pakistan also follows basic CANDU principles, but with some design variations worked out by Canadian General Electric, the principal Canadian supplier. Again the government of Canada guaranteed the necessary loans, and Pakistani trainees have been received by AECL and Ontario Hydro.

Various other bilateral and multilateral arrangements have been worked out for the supply of Canadian nuclear equipment, particularly ^{60}Co gamma irradiators, to developing countries.

The most recent overseas reactor project involved the commercial sale of a research reactor of NRX type to Taiwan. Engineering responsibility is entrusted to the Canatom consortium, and AECL has provided training for the Taiwanese staff that will operate the reactor.

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[56] *Amendment to agreement for co-operation concerning civil uses of atomic energy between the Government of Canada and the Government of the United States of America* (signed 25 May 1962), Canada Treaty Series 1962, No. 10; United Nations Treaty Series 453 362.

[57] *Exchange of Notes between the Government of Canada and the Government of the United States of America concerning the application of safeguards to the transfer of small quantities of uranium from Canada to the United States of America*, registered with the United Nations on 3 Feb 1970 as Treaty No. 10265.

[58] *Agreement between the International Atomic Energy Agency, the Government of Canada and the Government of Japan for the application of Agency safeguards in respect of the bilateral agreement between those governments for co-operation in the peaceful uses of atomic energy* (signed 20 Jun 1966), Canada Treaty Series 1966, No. 12; United Nations Treaty Series 572 263.

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PLANNING AND CONTROL INVOLVED IN THE GOVERNMENTAL PROMOTION OF NUCLEAR ENERGY PROGRAMS

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Abstract–Résumé–Аннотация–Resumen

PLANNING AND CONTROL INVOLVED IN THE GOVERNMENTAL PROMOTION OF NUCLEAR ENERGY PROGRAMS.

In the Federal Republic of Germany, governmental promotion of nuclear energy is primarily devoted to advanced sectors of nuclear technology; industry-oriented development is carried out by private industry. The development of nuclear technology is carried on in governmental nuclear research establishments and by industrial companies. The emphasis in governmental activities is placed mainly on tasks of planning and control. Planning objectives are determined on the basis of the prevailing situations. Alternative measures and programs for achieving these objectives have to be developed. Assessments of requirements, systems analysis, expert opinions and forecasts are tools used in evaluating the scientific, technical, economic and social benefits of nuclear energy programs. Once established, programs have to pass through a process of political decision. Specific planning problems are (1) the consideration of constraints such as limited financial and manpower resources, the temporary character of promotion measures, and the influence of social and economic structures, (2) the method of medium-term financial planning and its influence on planning programs – previous decisions, particularly those relating to investment, have made the financial margin for program planning small, (3) cooperation between advisers and government agents, (4) effective assignment of tasks to the large research and development centres according to the principle of division of efforts, best possible organization of work in the centres, (5) harmonization of national and international planning. The control of promotion measures is primarily an efficiency survey. Control is exercised during the implementation of a program ("continuous control") as well as after completion of individual program sections ("assessment of results"). Efficiency surveys are gaining importance as a means of rendering account to the public. They serve to make promotion measures and decisions more transparent. Specific problems in controlling efficiency arise in control methods, quantification of results, and adequate organization of research and development work. Current practices of efficiency control, which may be employed at several levels, include the appointment of experts and project control by project committees. In the years to come, government's promotion of nuclear technology will probably diminish, and responsibilities are expected to shift from government to industry. This will have consequences for future practices concerning the planning and control of national nuclear energy programs.

LA PROMOTION DES PROGRAMMES NUCLEAIRES PAR LE GOUVERNEMENT: PLANIFICATION ET CONTROLE.

En République fédérale d'Allemagne ce sont avant tout les domaines avancés de la technique nucléaire qui bénéficient de l'aide du Gouvernement; le développement à orientation industrielle est pris en charge par l'industrie privée. Le développement de la technique nucléaire se fait dans les établissements publics de recherche nucléaire et dans l'industrie. Le Gouvernement consacre surtout ses activités à des tâches de planification et de contrôle. La planification est basée sur des objectifs fixés en fonction des conditions de départ. Ceci suppose la mise au point de mesures et de programmes de remplacement. L'évaluation des programmes nucléaires du point de vue scientifique, technique, économique et social se fait à l'aide d'enquêtes sur les besoins, d'analyses de système, d'expertises et de pronostics. Le programme fixé doit être soumis à une procédure de décision politique. Les problèmes particuliers posés par la planification sont les suivants: 1) la prise en considération de conditions marginales telles que la limitation des moyens financiers et de la main-d'œuvre disponible, le caractère temporaire des mesures d'encouragement, et l'influence des structures sociales et économiques; 2) le procédé de programmation financière à moyen terme et son influence sur la conception des programmes; des décisions prises dans le passé, notamment en matière d'investissements, ont eu pour conséquence une marge de liberté réduite, sur le plan financier, pour la conception des programmes; 3) la coopération entre conseillers et Gouvernement; 4) l'utilisation dynamique, basée sur le principe de la division du travail, des grands centres de recherche et de développement; l'organisation optimale des travaux

dans les centres; 5) l'harmonisation des programmations nationales et internationales. Le contrôle des mesures d'encouragement est avant tout un contrôle de l'efficacité. Ce contrôle s'effectue d'une part lors de l'exécution des programmes (≪contrôle permanent≫) et d'autre part à la fin des différentes phases du programme (≪contrôle des résultats≫). L'importance du contrôle de l'efficacité ne cesse de croître: il constitue un moyen d'informer le public et de rendre plus compréhensibles les mesures d'encouragement et les décisions. Les problèmes particuliers que pose le contrôle de l'efficacité touchent aux méthodes de contrôle, à la quantification des résultats, à l'organisation adéquate des travaux de recherche et de développement. Les méthodes courantes de contrôle de l'efficacité, qui peuvent être appliquées à plusieurs niveaux, comprennent également la convocation de comités d'experts et le contrôle des projets par des comités de projet. Pour les années à venir, on peut prévoir une diminution de l'aide gouvernementale à la technique nucléaire et un déplacement des responsabilités de Gouvernement à l'industrie, ce qui aura des conséquences sur les méthodes futures de conception et de contrôle des programmes nucléaires nationaux.

СОДЕЙСТВИЕ ПРАВИТЕЛЬСТВА В ОСУЩЕСТВЛЕНИИ ЯДЕРНЫХ ПРОГРАММ: ПЛАНИРОВАНИЕ И КОНТРОЛЬ.

В Федеративной Республике Германии правительственная помощь в области ядерной энергии оказывается прежде всего развитым секторам ядерной технологии, разработки с ориентацией на промышленность ведутся частными фирмами. Разработка ядерной технологии осуществляется в правительственных центрах ядерных исследований и промышленными компаниями. Основное внимание при этом правительство уделяет планированию и контролю. Цели планирования определяются на основе сложившейся ситуации. Разрабатываются альтернативные мероприятия и программы для достижения этих целей. Оценка потребностей, анализ систем, мнения экспертов и прогнозы являются теми средствами, которые используются при оценке научных, технических, экономических и социальных выгод в результате осуществления ядерных программ. Разработанные программы становятся предметом политического решения. Конкретные проблемы планирования: 1) Учет факторов, ограничивающих финансовые и людские ресурсы, временный характер мер по содействию, а также влияние социальных и экономических структур, 2) Метод промежуточного финансового планирования и его влияние на планирование программ – ранее принятые решения, в частности те, которые касаются инвестирования, сделали незначительными финансовые возможности программирования; 3) Сотрудничество между консультативными и правительственными учреждениями, 4) Эффективная постановка задач перед крупными исследовательскими центрами в соответствии с принципом разделения усилий; максимально эффективная организация работ в центрах; 5) Координация национального и международного планирования. Проверка эффективности является основной формой контроля за осуществлением мер по содействию. Контроль осуществляется в ходе выполнения программы ("постоянный контроль"), а также после завершения отдельных ее разделов ("оценка результатов"). Проверка эффективности приобретает большое значение как средство учета общественного мнения. Она делает более понятными меры и решения по оказанию содействия. Конкретные проблемы при проверке эффективности возникают в методах контроля, результатах количественного определения, соответствующей организации исследовательских и конструкторских работ. Существующая практика проверки эффективности, которая может быть использована на различных уровнях, включает назначение экспертов и контроль за осуществлением проекта со стороны комиссий по проектам. В последующие годы содействие правительства развитию ядерной технологии, вероятно, сократится, и соответствующие обязанности, как ожидается, перейдут от правительства к промышленности. Это отразится на будущей практике планирования и контроля за осуществлением национальных ядерных программ.

LA PLANIFICACION Y EL CONTROL EN LA AYUDA OFICIAL A LOS PROGRAMAS NUCLEARES.

En la República Federal de Alemania se benefician en primer lugar de la ayuda oficial a la industria nuclear los sectores más avanzados de la técnica, mientras que la industria privada se ocupa de desarrollar aquellos que se encuentran en fase casi industrial. El desarrollo de la técnica nuclear se efectúa en los centros oficiales de investigación nuclear y en la industria. La acción de gobierno se dirige primordialmente hacia la planificación y el control. Los objetivos se fijan según la situación que prevalezca. Esto supone la elaboración de alternativas de acción y de programas. Para evaluar la utilidad científica, técnica, económica y social se realizan encuestas sobre las necesidades y análisis de los sistemas, se oyen las opiniones de los expertos y se consideran los pronósticos. El programa fijado hay que someterlo a un procedimiento de decisión política. Los problemas particulares de la planificación son los siguientes: 1) Hay que tomar en consideración algunas condiciones marginales como, por ejemplo, la limitación de los medios financieros y del potencial humano, la limitación temporal de los planes de promoción y, por último, la influencia de las estructuras sociales y

económicas; 2) El procedimiento para la programación financiera a medio plazo y la influencia de ésta sobre la concepción de los programas; algunas decisiones tomadas en lo pasado, especialmente en materia de inversiones, han tenido como consecuencia reducir el margen de maniobra financiera para la concepción de los programas; 3) La colaboración entre los asesores y el gobierno; 4) La utilización dinámica, basada sobre los principios de la división del trabajo, de los grandes centros de investigación y de desarrollo; la organización óptima de los trabajos realizados en los centros; 5) La armonización de los planes nacionales e internacionales. El control de las medidas de promoción es sobre todo un control de la eficacia. Este control se efectúa, de un lado, mientras se ejecutan los programas (control permanente), y de otro lado, al final de cada una de las diferentes fases del programa (control de los resultados). La importancia del control de la eficacia cobra cada día más importancia como medio de información a la opinión pública, pues permite que queden más claras tanto las ayudas que se prestan como las decisiones que se toman. Se plantean problemas particulares de control de la eficacia en los métodos de control, en la cuantificación de los resultados, y en la organización adecuada de la labor de investigación y desarrollo. El control de la eficacia que puede efectuarse a diferentes niveles de este control comprenden la designación de expertos y el control de los proyectos por los comités correspondientes. En los próximos años se espera que disminuya la ayuda oficial para las técnicas nucleares y que el gobierno ceda esas responsabilidades a la industria. Esto traerá consecuencias en cuanto a los métodos futuros de concebir y controlar los programas nucleares nacionales.

1. THE PROMOTION OF NUCLEAR ENERGY BY THE GOVERNMENT OF THE FEDERAL REPUBLIC OF GERMANY

1.1. The selection, formulation and promotion of large-scale technological research and development programs are objectives of modern science policy. Such programs are a nation's or a society's answer to challenges with which it is confronted internally or externally.

The U.S. "Manhattan" Project was the answer to a military, the Apollo Project to a peaceful challenge from outside. Nuclear energy programs are the answer to a peaceful challenge inside a nation: the challenge to ensure, in the long run, the supply of energy during a prolonged phase of an extraordinary expansion of power consumption.

In the field of peaceful research and technological development, governments are increasingly faced with new responsibilities. Control of environmental pollution, transport technology, urban planning and development, aeronautical engineering, marine research and peace research are some examples. The promotion of nuclear research and development for peaceful purposes is thus but one measure — though of major importance — among numerous initiatives taken by governments for the advancement of research and technological development.

1.2. Experience has shown that the promotion of all newly arising tasks would exceed the available national resources. It is therefore the responsibility of national research policy to formulate an overall concept of governmental research and development programs and to establish priorities in these programs. The isolated promotion of various technological programs by different government agencies without an overall view and co-ordination necessarily leads to reduced efficiency and otherwise avoidable expenditure.

Government promotion policy will be oriented towards "advanced missions", i.e. missions which are urgently awaiting solution in the decades to come. As soon as an innovation process has begun, governments will entrust industry or the responsible public institutions with the further development of the techniques concerned.

1.3. Government promotion of nuclear engineering in the Federal Republic of Germany is thus aimed at the development of advanced reactor systems and their fuel cycles, the improvement of safety and protection measures, as well as at the securing of fuel supplies for the future.

Active partners in this promotion include industrial enterprises, for instance companies of the electrical engineering, machine-building and metal industries on the manufacturing side, utilities as operators and large government-supported scientific centres as additional "generators" of scientific and technological know-how. Under the Federal Government system of the Federal Republic of Germany, the State comprises both the Federal Government and the German Bundestag as well as the governments of the Länder and their parliaments. Finally, the scientific community, which consists of the Universities and the non-university research institutes, and in particular the Max Planck Society, is another partner in the promotion process. These institutions carry out first and foremost basic research; they give competent advice and express scientific criticism. There are close subject-based, personal and often institutionalized contacts and links between the large scientific centres and other research institutes. Last but not least, mention should be made of the international organizations, the international nuclear research centres and the industrial companies of other countries as partners in this compound system. They, too, contribute essentially to the development of nuclear engineering in the Federal Republic.

Cooperation between these partners is governed by the principle of free market economy. Under this principle, the more economical solution is given the chance of success, no matter whether this solution was found at home or abroad.

1.4. What is the Government's task in this interaction? The task is not so much to give individual directions or take measures, but rather to plan ahead, to control and evaluate research and development work, as well as to co-ordinate all activities and take into consideration political and financial boundary conditions. In these activities, the Government has to understand itself as a partner who is always prepared to reconsider continuously the weight and kind of the influence it exerts.

On the one hand, the Government plays the part of the stimulator and initiator, particularly in the planning of research and development. On the other hand, it sometimes has to adopt the role of the one who delays a project, or says no to it, in particular in connection with control and evaluation. Responsible research policy will thus have to put up with criticism and attacks and will not always meet with approval.

The Government has to render account of its promotion measures to Parliament and to the general public. All partners concerned must face public criticism and must inform the public about programs and projects in such a way that it can make up its own mind and criticize, if need be. The public must have access to all major decisions and the arguments on which they are based.

2. PLANNING BASIS AND THE PROCESS OF POLITICAL DECISION-MAKING

2.1. Planning is based on the formulated objectives of promotion measures. Here, the Government will confine itself to establishing "broad" objectives.

Such "broad" objectives provide the policy-maker and the non-expert with clear and more general motivations. Complicated descriptions of objectives, which are difficult to grasp, would render the political discussion and promotion measures more difficult.

The Third Nuclear Energy Program (1968-1972) of the Federal Republic of Germany states, for instance, that the most important aim of promoting nuclear development is to further reduce the cost of power generation in nuclear power plants and to meet the long-term power demand in the Federal Republic of Germany by using nuclear energy. When the "broad" objectives have been established, more detailed sub-objectives, i.e. the structure of these objectives, have to be worked out. They will emerge from the discussions on the question as to which concrete measures can help to achieve the "broad" aims.

In the investment sector, such measures include for example the construction of experimental, prototype or demonstration plants. They can be of an economic or industrial policy nature, such as the pooling of the know-how of various industrial enterprises in a consortium. Concrete measures further include action to obtain knowledge and experience, for instance by training personnel or by participating in the operation of plants. Action and program alternatives have to be developed for these individual measures, which give planning experts "many a hard nut to crack".

2.2. Complete planning of the development of a new technology and its introduction into the market in competition with existing and proven techniques of equal value is hardly possible. The technical, financial, political and human factors exerting their influence are too manifold to be forecast or predetermined. Other new techniques of equal value may be developed somewhere else, overtaking national developments. Under the free market economy system, planners must be open to ideas which offer themselves as ideal solutions outside the planners' responsibilities. In the planning process, governments have to respect the particular interests and the freedom of decision of the various partners.

2.3. In view of the considerable government expenditure on nuclear energy in previous years (cf. Fig. 1), and in view of the plans for the future, the public has again and again inquired into the benefit of promotion measures, sometimes in critical terms. It is understandable that the question concerning the benefit of nuclear research and development promotion mainly refers to the benefit which society and national economy derive from such promotion. To point to the scientific or technological benefit or to technical progress as the only motivation for an annual expenditure of one thousand million DM does not suffice.

In the light of such questions, the program alternatives of planning are to be reviewed in order to find out whether the funds to be used and the total benefit to be derived from them are in the proper relation. Assessments of demand, systems analyses and expert opinions are essential tools in the planning and decision-making process. The forecasts on which program alternatives are based have to be continuously up-dated and corrected. Quite a number of such assessments of demand, systems analyses and expert opinions for nuclear engineering have been prepared in the Federal Republic of Germany in the last few years. Memoranda which have been prepared in cooperation between partners from industry and science are further aids that have been developed with considerable success.

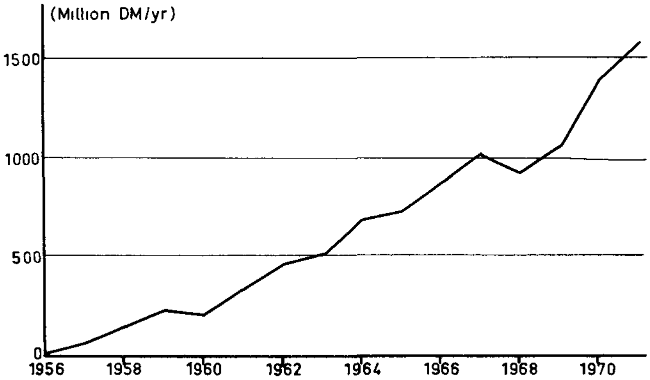

FIG.1. Governmental expenditure on peaceful nuclear research and development in the Federal Republic of Germany from 1956 to 1971.

2.4. The following are some of the questions presently discussed in the nuclear energy policy of the Federal Republic with respect to program alternatives: (a) Should back-up solutions for the sodium-cooled fast breeder reactor be developed, and if so, how much should be invested in their development? (b) Should the dual-cycle system for the high-temperature reactor be further developed, or should the direct-cycle system be aimed at as the next step? (c) Should both of the two fuel element types for the high-temperature reactor, i.e. the pebble and the rod or block element be pursued, or should only one type be continued, and if so, which one? (d) Is it desirable to look for access to another enrichment technique in addition to the gas ultracentrifuge process? (e) How can the sources of natural uranium supplies be geographically distributed in such a way as to ensure that, even during a political crisis in a supplier country or in the case of other obstacles, sufficient natural uranium is available?

2.5. The initial planning phase is characterized by the activities of stock-taking, forecasting, the definition of objectives and the drafting of program alternatives. At the conclusion of the planning process, there is a political decision. The process of political decision-making with a view to the large research and development promotion programs has become more differentiated in the Federal Republic, as government promotion has gradually become extended. The global decision to promote the peaceful exploration and utilization of nuclear energy was taken in 1955, and a Ministry of Atomic Affairs was established for this purpose. This ministry eventually became the Federal Ministry for Education and Science (BMBW). The Third Nuclear Program of the Federal Republic of Germany was the first to be included in the deliberations of the Federal Cabinet in draft form in 1967 and was approved by the Cabinet. It is common practice now to review again at the Cabinet level the most important decisions of a program, even after it has been approved, before these decisions are eventually put into practice. The German Bundestag and the competent parliamentary committees, i.e. the Committee for Education and Science and the Budget Committee, also contribute increasingly to the decision process by forming their own judgement

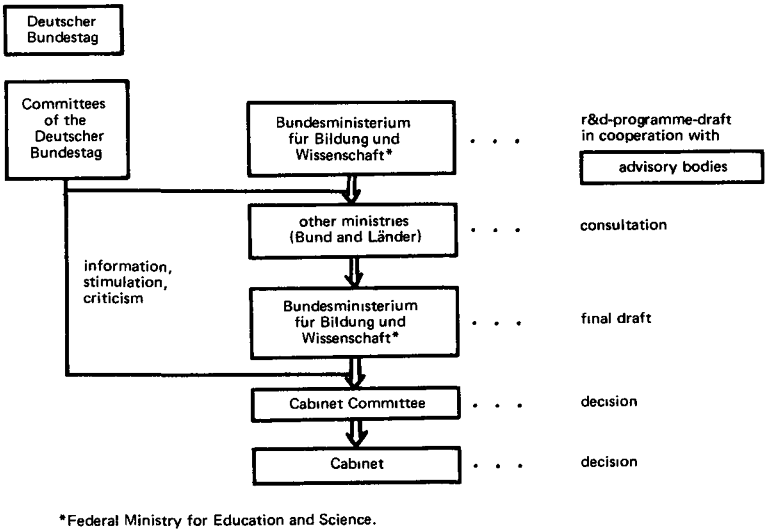

FIG.2. Path of political decisions on major research and development programs in the Federal Republic of Germany.

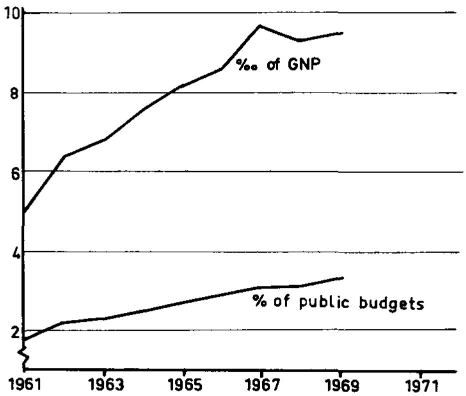

FIG.3. Public expenditure on research and development as part of the gross national product (‰) and of public budgets (%).

and voicing their criticism. Figure 2 shows the indicated process of political decision-making as it applies to a large-scale research and development program, e.g. in the fields of nuclear energy, data processing or space and aeronautical research in the Federal Republic of Germany.

3. PROBLEMS OF PLANNING

3.1. The definition of objectives as well as the drafting of program alternatives and the process of political decision-making are influenced by a large number of boundary conditions. They can only be mastered within a dynamic planning process.

3.2. An important planning aid and method is furnished by the Federal Government's medium-term financial planning. It defines the distribution of government expenditure, balanced with the revenue to be expected, over a period of five years at a time, and is extrapolated and revised annually.

One basis for determinating future funds for the promotion of science and research is formed by key figures indicated in terms of their per cent of public budgets or of the gross national product. Figure 3 shows the development of public expenditure on research and development, indicated as described above. In 1975, approx. 1.1% of the gross national product might be available for the promotion of research and development. In addition to these quantitative values, the financial planning contains, in its principles and explanations, qualitative judgments of the significance of individual fields or specific programs and their importance in relation to each other. On the basis of the total funds available and the qualitative principles, the Minister fixes the amounts of finance envisaged for the promotion programs, in consultation with those responsible for the individual sectors.

Long-term financial security regarding funds for promotion is a major prerequisite for programs and projects. If the annual budget is not passed until well after the beginning of the financial year and if there is no longer-term financial planning, those responsible for individual research and development projects are restricted in their activities because there is uncertainty as to the funds eventually available.

3.3. Admittedly, when drafting the financial planning, the planners are far more restricted by previous promotion measures than may appear desirable to some planners, or intelligible to outsiders. The financial margin regarding the planning of a program is reduced as a result of previous decisions, above all in the field of capital investment. For example, for every single D-Mark spent on capital investment – i.e. equipment and buildings – in the nuclear research centres of the Federal Republic, about 0.35 DM must be provided in terms of operational costs for each successive year. As long as available investments are therefore used to the full extent, significant portions of the promotion funds available every year are already tied up. It may well be a wise and far-sighted move to close down research plants ahead of schedule or, in an extreme case, even to refrain commissioning a plant that has been overtaken by developments.

3.4. Another quantity which reduces the margin of medium-term financial planning is the number of personnel available in industrial and government establishments. The overwhelming majority of problems in this connection arises from a surplus of personnel and not from a deficit. The transfer of personnel to other fields, including non-nuclear ones, is gradually becoming a necessity in industry as well as in government establishments as a result of the extraordinary increase in staff costs.

Figure 4 shows the development of staff costs per capita and year for the nuclear research centres of the Federal Republic in the past decade. During this period, staff costs for every staff member have trebled. In view of this development, the Federal Ministry has increasingly expanded non-nuclear activities in government laboratories in the past years while, at the same time, the number of staff was increasing only marginally, and taken account of this in the planning. In the two large centres at Jülich and Karlsruhe, about

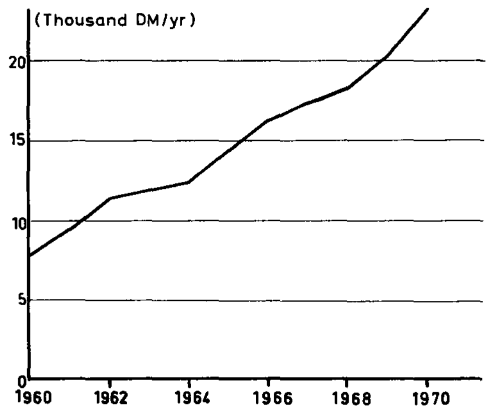

FIG.4. Personnel cost per capita in the nuclear research centres of the Federal Republic of Germany.

15% of the operational expenditure is accounted for by non-nuclear activities in 1971.

In highly industrialized countries, there is a sufficient number of trained scientists and technicians in the nuclear field today to cope with all the tasks assigned to them. This does not mean, however, that staff bottlenecks of a temporary nature cannot occur at certain periods of time or for certain development tasks. Nowadays, there is a tendency, however, to accept the fact that a project is delayed, rather than to put up with later difficulties resulting from peak staff requirements if the surplus staff cannot be reduced, or transferred, subsequently.

3.5. Two other sets of problems have gained significance in the Federal Republic in recent years: firstly, the problems of an adequate industrial participation in the development of nuclear technology, and secondly, the participation of staff in the decision-making process in research establishments.

By "industrial participation" is meant the financial participation of industry in research and development activities in their own laboratories and with their own development teams as well as in the realization of projects of the nuclear program of the Federal Republic.

Government expenditure in the Federal Republic on the promotion of the nuclear sector will amount to approximately ten thousand million DM between 1956 and 1971 inclusive. No statistics have been published on the corresponding financial contributions made by industry. However, a percentage of 10 to 20% of government expenditure is probably the correct amount. This may seem low at first sight. It must, however, be borne in mind that government expenditure on promotion includes funds for the financing of international cooperation and fundamental research in the nuclear field. The expenditure in these two sectors must be estimated at approximately 5.5 thousand million DM. If, furthermore, the considerable expenditure on the development of nuclear technology in research centres, which amounts to approximately two thousand million DM, is taken into consideration, it follows that approximately 2.5 thousand million DM have hitherto been spent on industrial research and development. This is matched by financial commitments of a comparable amount on the part of industry. In addition to the funds for research and development, capital investment in nuclear industry for the construction of manufacturing plants must be taken into consideration.

With regard to water reactors, the Federal Government exclusively promotes technological developments of a more general validity, and only if participation by industry amounts to at least 50%. With regard to the development programs of high-temperature and fast breeder reactors, a participation of at least 10% is aimed at.

Special considerations apply to the financing of large prototype plants. For these, complicated pricing models have been elaborated, which make use of the different possibilities, including fixed prices and cost reimbursement prices with a ceiling. They presume that no further government grants are required for the plant during normal operation. Admittedly, these prototype plants are predominantly financed from public funds but industry bears quite a significant proportion of the investment costs. It also gives guarantees for the construction of the plant according to schedule and for its efficiency. The financial commitment of industry is an indication of the confidence in the accuracy and significance of the research and development activities promoted; it is also necessary, however, to ease the taxpayer's burden. Even in the more advanced nuclear technologies, only those programs which can rely on the financial participation of industry can be realized in the Federal Republic.

3.6. Proceeding from considerations of the Federal Government regarding the reform of structures in the sectors of higher education and research, and as the result of a broad-based public discussion on democratic forms of decision-making, questions relating to the organization and structure of research centres, including their relationship with the Government have, as in other States, been re-evaluated in the past two years. The result of this discussion among all groups and associations involved was published by the Ministry in the form of guidelines applying to questions of principle, structure and organization of legally autonomous research establishments. The majority of establishments in the Federal Republic have been organized under the law as limited liability companies (GmbH). The guidelines, and the legal statutes of the establishments based on them secure for scientists and technicians a say in the decisions taken in the supervisory and management bodies of their establishments. They guarantee thorough information on processes of decision-making to all staff members. Research and development cannot be carried out successfully in large laboratories in the long run without the responsible participation of those immediately concerned and without their unrestricted identification with their responsibilities. This kind of thinking must enter into planning processes as well.

3.7. Regarding the planning of the activities of large scientific centres, the Federal Government sets great store by a streamlined and clearly defined organization of work as far as objectives, time schedule, and the use of personnel and financial resources are concerned. Quite a number of ventures have been organized as projects, the responsibility for which has been assigned to a project manager assisted by a project team and by working groups who have been assigned certain project tasks by written contract agreements.

3.8. The financial plans of international organizations as well as of agreed projects are fixed and relatively unchangeable elements within the national budgets. If, for reasons of overriding national considerations of financial policy, reductions have to be made or promotion funds have to be stretched, it is nearly always the national plans and programs that have to put up with those reductions. It is, of course, understandable that the financial plans have to be frozen at a certain time in the budgetary planning of international organizations, in particular if these organizations have a very large number of members, and that the budgets of international organizations cannot make allowance for national financial crises of greater or smaller significance; nevertheless it would be very desirable if the financial plans of international organizations could be modified even at a relatively advanced date.

3.9. Finally, some remarks should be made on the cooperation between government and advisers in the planning process. It has frequently been stated that in the Federal Republic a ministry with but a small staff is responsible for the promotion of peaceful nuclear research and nuclear engineering. In decision-making, this ministry has cooperated with a large number of unpaid advisers, the members of the Atomic Energy Advisory Commission. This Commission is divided into several sub-commissions, working groups and committees. At present in the ministry, twenty-six staff members with university degrees are concerned with the problems of nuclear energy promotion on a full-time or part-time basis. At present, the Federal German Atomic Energy Advisory Commission comprises 245 members. In our opinion, this advisory and decision-finding system, which is based on a division of efforts, has enabled us to pursue a flexible research policy which comprises the complete spectrum of national competence.

In order to cope with the continuously increasing responsibilities assigned to the Federal Ministry, a variety of advisory bodies was established in the past, a fact that makes the reorganization of our advisory system necessary. In the future, the advisory bodies will no longer be organized by specialized fields or subjects of work according to a rigid system, but will be summoned according to the respective demand for advice. The period of their appointment will be limited to the duration of the advisory assignment. In doing so, the Ministry hopes to make its advisory system even more efficient by drawing on those external advisers who are best qualified for a specific task, and to achieve greater flexibility as well.

It is a question of more general importance whether the Ministry should rely solely on the advice of experts, who do not come from industry and thus pursue no interests of their own, whenever industrial research and development projects are at stake. In another field, which has nothing to do with nuclear energy, we have gained the experience that such an attitude, if it were adopted, will in the long run not guarantee a successful advisory system. On the contrary: even the conscious or unconscious seeping of interests into the advisory system may serve to detect these interests and to form a correct estimate of them. It goes, however, without saying that the advisory body has to consist of members who guarantee a balance of interests. Furthermore, competence is also needed on the part of the government officials.

4. EFFICIENCY CONTROL OR ASSESSMENT OF RESULTS

4.1. The second important field of government activities in the promotion of technological research and development is the control of promotion measures. When saying this, we do not refer to the purely book-keeping control of expenditure, but to the problem of evaluating the scientific, technological or economic success of our promotion measures. Control in this sense means an efficiency control or assessment of results of research and development work which is to serve a more efficient implementation of this work.

4.2. As a measure of informing the public, efficiency control gets more and more important. This can be understood from the extremely large amount of public funds allocated to the promotion of nuclear energy as well as from the growing number of competitive tasks devolving upon the Government. One of the reasons why the public's attention is now drawn more often than before to the problems of an effective control is the past failure to inform the public sufficiently on the results, the success, and the problems of research and development work. In the past, many scientists and technicians, as well as management or sponsoring organizations, have not realized this aspect clearly enough and have not taken it into account in an appropriate manner.

Efficiency control requires thorough planning. Only this planning can be the yard-stick for a proper control. Afterwards, control results are again integrated into the planning process by way of a feedback or iteration process. Efficiency control and planning, including the prognosis, are interdependent and cannot be separated. The efficiency control of scientific and technological research and development activities starts as a "continuous" or "accompanying" control with the execution of these activities. Furthermore, there will have to be an "assessment of results", or a final control after the major sectors of the program have been completed. This will facilitate a decision on whether to continue or stop the activities. Apart from the efficiency control of projects, the efficiency control of promotion programs and research institutions as a whole is of great importance to a sponsoring Ministry.

4.3. One of the most important aspects of efficiency control is the problem of adequate control methods.

The problems relating to efficiency control do not reside in the industrial and commercial sector, where economic success, i.e. returns, can be compared with the expenditure incurred.

Concerning an individual research and development project, a comparison between plan targets and achieved results will be made. If the plan targets are defined precisely enough, this comparison will not be difficult. A streamlined and precisely characterized planning process is of great advantage for this procedure. The procedure of comparing plan targets and achieved results can above all be applied to work organized on a project basis.

The problem of adequate control methods becomes more difficult with research and development work whose target is to obtain results that have not or not yet been converted into hardware, particularly when it comes to the basic sciences. A wide range of criteria have to be applied in the evaluation process: publications in technical or scientific journals, papers delivered at expert meetings, invitations for a guest lectureship or other guest activities, quoting from publications, and perhaps patents; all this gives a very useful, but incomplete picture.

4.4. In evaluating research institutions as a whole, characteristic figures can successfully be applied. Such characteristic figures useful for planning as well as for control are, among others, the ratio between graduates and the total staff of a research installation; the per capita expenditure on personnel and equipment; the extent to which experimental and research facilities are used; the ratio between capital expenditure and operating costs; capital expenditure per employee; the share of infrastructure costs in the total costs. As an example, Fig. 5 shows the per capita operating costs, minus staff costs, in the Federal Republic's nuclear research centres in the year 1971.

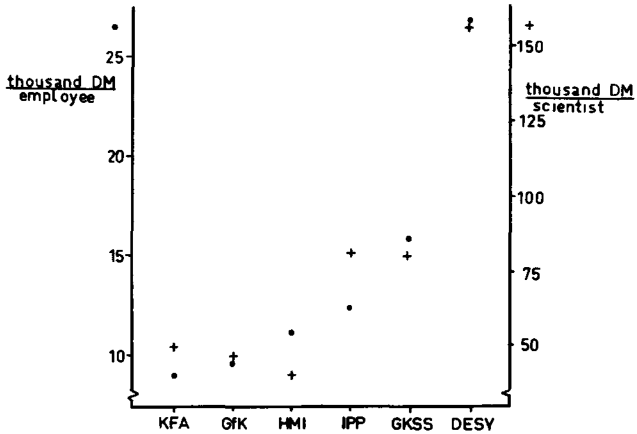

FIG.5. Per capita operating costs minus personnel costs in the Federal Republic nuclear research centres in 1970.

Cost calculation is an important tool of efficiency control. It means that all costs incurred by a certain project, even those incurred by the utilization of the technical infra-structure, are calculated and compiled. As a result of the increasing attention which is devoted to efficiency control, efforts are under way in the Federal Republic to abandon the system of classifying costs according to administrative and fiscal aspects, and to adopt a system of true preliminary and subsequent calculations for those research projects that are being promoted, calculations directly referring to the cost-bearing party.

4.5. Efficiency control is exercised as an "internal" and "external" control and thus at several levels of responsibility. "Internal" efficiency control ("self control") has naturally to be exercised by the working units themselves and their responsible staff. Concerning research and development programs which are promoted from public funds, "external" control has to be exercised by the government or the competent supervisory bodies or self-administered organizations.

4.6. Efficiency control as practised in the Federal Republic includes co-operation with expert bodies and project control by project committees. In the Federal Republic there are project committees to observe and control the most important projects in the field of nuclear development. They consist of persons working on the project, representatives of the partners concerned at the national and international level, and persons from the sponsoring Ministry. Since 1967, for instance, a project committee has been concerned with the fast breeder project and another one since 1969 with the development of high-temperature reactors.

In the future, closer attention will, no doubt, have to be paid to the training and encouragement of independent "science auditors" who can provide advice and assistance in the field of efficiency control acting for and on behalf of public authorities. Up to now there have been no such independent bodies in the Federal Republic. In view of the increasing public funds to be spent on research and development in the future, governments will need the advice and assistance of competent and independent experts organized in such bodies.

5. FINAL REMARKS

5.1. Planning and efficiency control are two elements of modern research policy which cannot be renounced. The government must avoid two mistakes if research policy is to be effective. These are: planning must not be so rigid that it must be followed at all events; and the assessment of results must neither be neglected, nor must it be used as a repressive instrument.

While a variety of planning methods have already been elaborated and applied, methods for efficiency control have still to be further developed and tested. This also applies to nuclear research and nuclear engineering, both of which have been developed and promoted for nearly three decades.

5.2. In view of the problems which still have to be solved by advanced nuclear systems, the peaceful utilization of nuclear energy will have to be supported by governments for at least another decade, probably even longer. During this period, the responsibility for planning and control as well as funding will shift more and more from government to industry, and will have to be adjusted in many respects to future developments.

ВЕНГЕРСКАЯ НАРОДНАЯ РЕСПУБЛИКА
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РОЛЬ ИССЛЕДОВАТЕЛЬСКОГО АТОМНОГО РЕАКТОРА В НАУКЕ, ТЕХНИКЕ И ПОДГОТОВКЕ КАДРОВ В ВЕНГРИИ

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Abstract–Résumé–Аннотация–Resumen

THE ROLE OF A RESEARCH REACTOR IN SCIENCE, TECHNOLOGY AND TRAINING IN HUNGARY.

The purpose of this paper is to show what influence the research reactor belonging to the Central Institute for Physical Research has had on the evolution of fundamental research and on the practical value of research results for industrial technology and training. As an organizational unit, the research reactor has stimulated research in radiochemistry and reactor physics and hastened progress in nuclear physics and electronics. The authors show how the instruments and methods evolved early on in the course of the Institute's reactor physics and nuclear physics program, together with the radiochemical data obtained, quickly found application in a practical research program and were effectively and successfully used to solve problems arising in the production of semiconductors, highly pure metals and steels. The method of financing the different stages of the program is described. The growing demands of the universities for training services and research work have now made it necessary to build a new low-power reactor. The experience gained in operating the Institute's present reactor will provide a good basis for the design of a new reactor adequate to meet all the present requirements of research and training. It will have the advantage of serving several universities and providing for the needs of both education and research.

ROLE DES REACTEURS NUCLEAIRES DE RECHERCHE DANS LA SCIENCE, LA TECHNOLOGIE ET LA FORMATION EN HONGRIE.

Les auteurs expliquent le rôle du réacteur de recherche de l'Institut central de physique dans le développement des études fondamentales, et l'intérêt que présentent les résultats obtenus pour la technologie industrielle et la formation de spécialistes. Un réacteur de recherche permet d'entreprendre des travaux de recherche en radiochimie et en physique des réacteurs, et contribue à faire avancer les études de physique nucléaire et d'électronique. Les auteurs montrent comment les instruments et procédés mis au point dans les recherches sur la physique des réacteurs et la physique nucléaire, ainsi que les données radiochimiques obtenues ont grandement contribué à résoudre les problèmes qui se posent dans l'industrie des semi-conducteurs, de l'affinage des métaux et dans la sidérurgie. Ils indiquent le mode de financement des diverses étapes de ce programme. Les besoins croissants des établissements d'enseignement supérieur en matière de formation et de recherche ont rendu nécessaire la fabrication de réacteurs de faible puissance. L'expérience acquise dans l'exploitation du réacteur de l'Institut central de physique sera précieuse pour la construction de réacteurs de ce type dont on a actuellement grand besoin pour la recherche et la formation spécialisée. Ce type de réacteur aura l'avantage de servir à plusieurs universités et d'être utilisé pour la recherche aussi bien que pour la formation.

РОЛЬ ИССЛЕДОВАТЕЛЬСКОГО АТОМНОГО РЕАКТОРА В НАУКЕ, ТЕХНИКЕ И ПОДГОТОВКЕ КАДРОВ В ВЕНГРИИ.

Целью доклада является показ влияния исследовательского реактора Центрального института физических исследований на развитие фундаментальных исследований и, как следствие, на плодотворность использования достигнутых результатов в промышленной технологии и подготовке кадров. Исследовательский реактор, как организационная единица, явился стимулом для начала исследований по радиохимии и реакторной физике, а также способствовал проведению исследований по ядерной физике и электронике. Авторы показывают, как первоначально в пределах реакторно-физических и ядерно-физических исследований созданные приборы и разработанные методы, а также радиохимические данные стали быстро применяться в программе прикладных исследований. Они нашли действенное и успешное применение для решения проблем производства полупроводников, высокочистых металлов, а также в сталеплавильной промышленности. Дается описание системы финансирования различных стадий программы. Растущие запросы университетов, связанные с подготовкой кадров и исследовательской работой, выдвинули необходимость создания реактора малой мощности. Опыт работы на реакторе ЦИФИ, послужит основой для создания такой конструкции реактора, которая будет отвечать современным требованиям научных исследований и подготовки кадров. Особенность данного реактора заключается в том, что он предоставлен в распоряжение нескольких университетов и должен обеспечить возможность проведения как учебной деятельности, так и научной работы.

PAPEL DE UN REACTOR DE INVESTIGACION EN LA CIENCIA, LA TECNOLOGIA Y LA EDUCACION EN HUNGRIA.

Esta comunicación detalla el alcance de la influencia que el reactor de investigación del Instituto ha ejercido en el desarrollo de la investigación básica en el mismo y cómo ha sido posible canalizar esta actividad hacia la tecnología y la educación. La puesta en marcha de un reactor de investigación dió origen a una investigación en los campos de la química nuclear y de la física de reactores y forzó el desarrollo de la física nuclear y de la investigación electrónica. Los dispositivos y métodos desarrollados inicialmente en estos campos de la física de reactores y de la física nuclear junto con los conocimientos de química nuclear desembocaron en un programa de investigación aplicada y fueron introducidos en la producción de semiconductores, aceros y purificación de metales no férreos. Se dan datos de financiación de las diferentes etapas de este programa. La segunda parte de la comunicación describe cómo, por una parte, las actividades educativas e investigadoras exigieron otro reactor de baja potencia y cómo, por otra parte, la experiencia adquirida en el reactor de investigación del Instituto ayudó al diseño de un reactor adecuado para el programa educativo y de investigación. Como tiene que adaptarse a las necesidades de diversas universidades, su principal característica es que tiene que realizar complejos programas educativos al mismo tiempo que asegurar un vasto campo a la investigación.

Исследовательский реактор, являющийся мощным источником нейтронов, позволяет решать самые разнообразные научные и технические задачи. Однако этим область его применения не исчерпывается. Хорошо известно, что реактор играет роль своеобразного "двигателя" и его влияние на научно-технический прогресс выходит далеко за пределы его назначения как "исследовательского средства". Весьма важная задача развивающихся стран, — которые уже располагают исследовательскими реакторами, — заключается в создании условий,при которых это влияние могло бы проявиться в наибольшей степени.

В данном докладе детально излагается одно из направлений развития, которое было вызвано к жизни исследовательским реактором Центрального института физических исследований (ЦИФИ), а именно — активационный анализ. Этот пример особенно поучителен потому, что ко времени возникновения потребности в активационном анализе выяснилось, что база для его быстрого осуществления уже обеспечена другими науками, развившимися опять-таки в результате использования реактора.

Исследовательский реактор Центрального института физических исследований

Реактор типа ВВР-С [1] был полностью поставлен Советским Союзом. Подготовка персонала также была осуществлена в Советском Союзе, поскольку Венгрия вообще не располагала опытом в области эксплуатации реакторов. С момента пуска в эксплуатацию (1959 год) до реконструкции, проведенной в 1967 году [2], рабочая мощность реактора составляла 2 МВт. В ходе реконструкции мощность реактора была повышена до 5 МВт. В реакторе используются обогащенные (36%) твэлы типа ВВР-М и бериллиевый отражатель. Реконструкция была осуществлена венгерскими специалистами. В настоящее время в реакторе имеется 11 горизонтальных, 34 вертикальных каналов и две пневмопочты, встроенные в вертикальные каналы с различным отношением потоков тепловых и быстрых нейтронов, что позволяет решать специальные аналитические задачи.

Влияние реактора на научно-исследовательскую деятельность

В результате создания реактора в ЦИФИ существенно расширился исследовательский профиль. Исследования начали проводить в новых областях: в ядерной химии, в области реакторных исследований. Появилась возможность для производства изотопов.

Нужно отметить, что решение о начале данных исследований было принято в 1956 году (одновременно с постановлением о создании реактора), следовательно, период учебы и изготовления приборов совпал с периодом создания реактора. В результате этого, фактически исследовательскую работу можно было начать непосредственно после пуска реактора, и эффект использования реактора в течение короткого периода приблизился к возможному максимуму [3]. В порядке оценки научной работы следует упомянуть, что до конца 1970 года было опубликовано 332 статьи, содержащих результаты, полученные в различных областях науки при использовании реактора. Реактор обеспечивает стопроцентное удовлетворение отечественных нужд в радиоактивных изотопах.

В данном докладе дается сравнительно подробное изложение только тех двух направлений развития, на базе которых сложился активационный анализ: развитие измерительной техники диффузионных параметров в реакторной физике и прогресс в ядерной химии.

Определение диффузионных параметров в органических жидкостях

В период начала сооружения реактора ВВР-С важной и многообещающей проблемой реакторной физики являлось исследование органических замедлителей и теплоносителей.

Первым этапом исследования явилось определение для нескольких веществ диффузионных параметров относительно тепловых нейтронов. Для этих измерений, вместо уже хорошо разработанного стационарного метода измерений, нами был избран считавшийся тогда еще новым импульсный метод. Преимущество импульсного метода по сравнению со стационарным заключается в том, что он дает возможность определять одновременно: диффузионную константу D, среднюю продолжительность жизни нейтронов ℓ_0 и константу замедления до тепловой энергии C. Кроме того, этот метод является быстрым и требует для измерения сравнительно небольшое количество вещества. Однако для проведения измерения необходимы импульсный источник нейтронов и анализатор времени. Поэтому важнейшей задачей явилось сооружение импульсного нейтронного генератора и изготовление анализатора времени.

В решении обеих задач большую помощь оказал опыт, которым располагали специалисты по ядерной физике. Нами был изготовлен нейтронный генератор типа НГ-200, представляющий собой устройство для получения быстрых нейтронов на основании реакции $^3T(d,n)^4He$, с ускоряющим напряжением 200 кВ и импульсным рабочим режимом. Ионный ток на мишени составлял 200-300 мкА, на 1 микрокулон получался выход нейтронов $3 \cdot 10^7$ нейтр/сек, продолжительность ионных импульсов можно было изменять в интервале 2-20 мксек, а частоту повторения – в интервале

50-1000 имп/сек [4]. Специалистами по электронике был изготовлен простой анализатор времени [5].

С помощью нейтронного генератора и анализатора времени мы осуществили измерение диффузионных параметров на следующих веществах: вода, бензол, циклогексан, н-гексан, толуол, ксилол и дифенил. Результаты измерений были представлены на Третьей Женевской конференции [6] и на международной конференции в Карлсруэ, организованной Международным агентством по атомной энергии [7].

Исследования по ядерной химии

После пуска реактора появились возможности для начала проведения исследований в различных областях ядерной химии. В 1956 году были начаты приготовления к производству радиоактивных изотопов, причем, в первую очередь были разработаны новые методы, позволяющие производить значительные количества радиоактивных изотопов, обладающих высокой удельной активностью и пригодных для медицинских целей. Был приобретен опыт в области различных радиохимических разделений, например, применение ионообменных и экстракционных методов, ядерных измерений, работы в условиях горячей лаборатории, что необходимо для обращения с веществами высокой радиоактивности. На базе реактора начали проводиться исследования по радиационной химии, во время которых использовался опыт, накопленный в ходе изучения веществ, потенциально пригодных для применения в качестве органических замедлителей и теплоносителей, при определении изменений, возникающих под влиянием радиоактивного излучения в органических веществах и воде. Реактор обеспечил условия и для начала исследований по химии горячих атомов. Накопленный опыт с успехом использовался в ходе последующих работ по активационному анализу.

Пуск реактора позволил, чтобы нейтронный активационный анализ был внедрен в техническую и научную жизнь Венгрии в качестве одного из наиболее современных и эффективных физико-химических методов, который в течение последних 15 лет играет постоянно возрастающую роль как в научных исследованиях, так и в решении множества практических проблем в промышленности. Этот метод, использующий мощный поток нейтронов реактора, отличается высокой чувствительностью и, в отдельных случаях, быстротой.

Возникла необходимость проведения следующих исследований:

1) Определение следов примесей в полупроводниковых материалах (кремний, германий, арсенид галлия), см. табл. I; выполнение серийных анализов (несколько сот определений в год) в соответствии с нуждами промышленности и научно-исследовательских институтов.

2) Определение следов примесей в чистых металлах (медь, алюминий, никель, вольфрам и т.д.), см. табл. I; разработка методов, пригодных также и для серийного анализа.

3) Определение примесей в различных химических продуктах (нефтепродукты, медикаменты, высокочистые химические реактивы и т.д.).

4) Анализ биологических и медицинских образцов в соответствии с нуждами сельского хозяйства и медицинской науки.

5) Определение основных и микроэлементов пород и руд, принимая во внимание запросы горнорудной промышленности и геохимических исследований.

ТАБЛИЦА I. ПРАКТИЧЕСКОЕ ПРИМЕНЕНИЕ АКТИВАЦИОННОГО АНАЛИЗА В ВЕНГРИИ

Исследуемое вещество	Определяемые элементы
Кремний	Cu, As, Sb, Na, Au, P, La, Ge, Ga
Германий	Cu, Au, Mo, W, Sb, As, Cl
Арсенид галлия	Cu, Hg, Cd, Zn, Co, Au, Se, Te, Mn, Ni, Fe, Ge
Сульфид цинка	Cl, Mn, Cu, Sr, Al, Na
Никель	Cu, As, Sb, Bi, Zn, Mg, Al, Mn
Вольфрам	Al, K, Na, Si, Re, Ni, Cu, As, In, Ga, C, Se
Медь	O, Ag, Sb, Sn, Se, Mn, As, P, V
Алюминий	O, Cu, Co, Mn, Ni, Fe, Se, Ag, Au, Cd, U, W, Zn Os, Ba, Pt
Молибден	Cu, Zn, Mn, Co, Fe, Cd, Ag, Hg
Индий	Cu, Zn, Au, As, Sb
Окись итрия	La, Eu, Dy, Tb, Ce, Nd, Gd, V, Ca, Mn, Cu,Co, Fe, Ni
Окись урана	Cu, Ag, Cd, Mo, Cr, Co, Ni, Mn, Fe, P, Au
Окись (нитрат) тория	Cd, Cu, Mn, Cr, Zn, Co
Нитрат циркония	Cd, Mn, Cu, Co, Cr, Zn

В качестве иллюстрации приводим два конкретных примера. В настоящее время при металлургических процессах получения стали изменение количества кислорода в расплавах в ходе производства имеет решающее значение, поскольку как декарбонизация, так и удаление отдельных нежелательных примесей происходит с помощью кислорода. Поэтому процессом производства можно управлять путем регулирования количества кислорода. В начале 1968 года с помощью нашего метода начали определять содержание кислорода во взятых из расплава образцах стали. Для проведения анализов мы изготовили комплектную автоматическую лабораторию: нейтронный генератор, пневмопочта, анализатор (рис.1); организовали курс для 12 сотрудников специальной лаборатории, созданной на Дунайском металлургическом комбинате. Благодаря применению данного метода в производстве успокоенных сталей был получен трехпроцентный прирост продукции.

В результате был не только достигнут значительный экономический эффект, – который, естественно, положительно влияет на развитие центра ядерных исследований, – но также возрос технический уровень в отдельных областях. Так, например, разработанный и внедренный нами способ дозировки восстановителя,основанный на анализе кислорода, имел большое хозяйственное значение. Освоение этого современного способа дозировки явилось важным шагом в развитии производства стали на научной основе.

В ЦИФИ с 1965 года проводятся серийные анализы по определению следов примесей в кремниевых материалах, служащих для производства полупроводников. Качество высокочистого кремния определяется путем активационного анализа. Заинтересованное предприятие на основании этих результатов выбирает те фирмы, которые поставляют

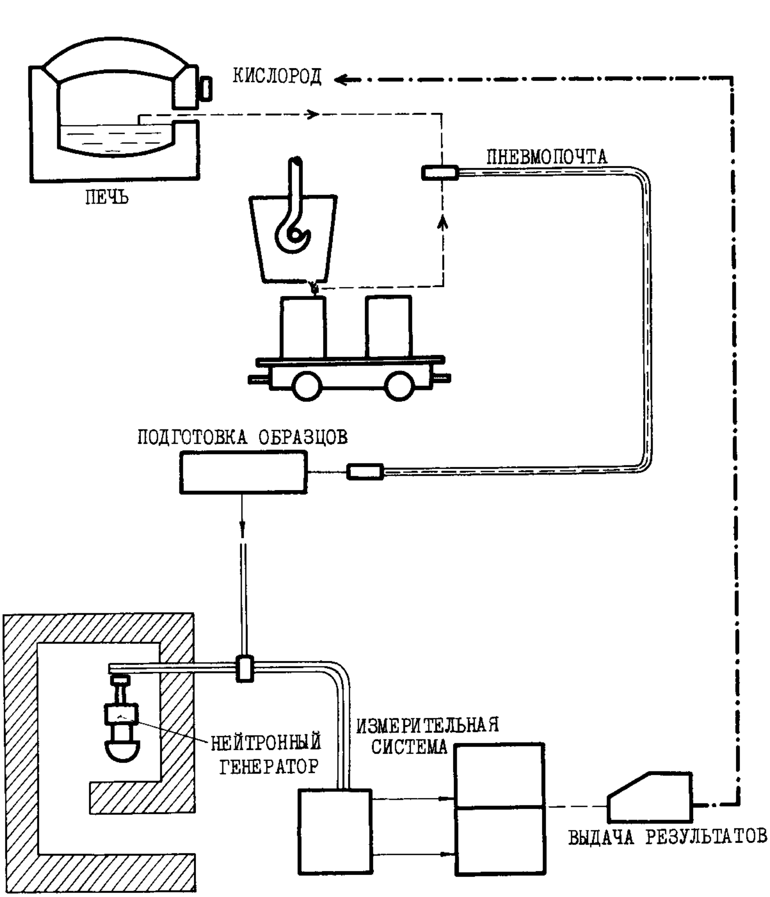

Рис.1. Установка для анализа кислорода в стали.

удовлетворительный по качеству кремний. Благодаря исключению из производства недоброкачественного сырья было достигнуто сокращение брака, дающее годовую экономию в размере 10 млн.форинтов.

Из сказанного следует, что в период после пуска венгерского исследовательского атомного реактора наступил прогресс в области исследований по активационному анализу. Каким бы большим ни был спрос на эти исследования, сам по себе он не мог бы объяснить этот прогресс.

Если проследить за деятельностью исследовательского центра и находящегося в непосредственной близости от него атомного реактора, то можно увидеть то положительное влияние, которое они оказывают друг на друга. Так, например, проектирование и сооружение служащего целям нейтронно-активационного анализа нейтронного генератора типа НА-2 в течение десятимесячного срока стало возможным лишь потому, что конструкторы могли опираться на опыт, полученный в ходе создания генераторов типа НГ-200 для измерений по нейтронной физике. Параметры генератора типа НА-2: ускоряющее напряжение – 120 кВ, ионный ток на мишени – 1,0 мА, $^{3}T\,(d,n)\,^{4}He$ – реакция дающая нейтроны с выходом $(1\text{-}5)\cdot 10^{10}$ нейтр/сек [8].

Другой основной прибор для активационного анализа – многоканальный амплитудный анализатор – уже имелся в распоряжении, поскольку он был разработан несколько лет назад для исследований в области ядерной физики.

Финансирование

Финансирование сооружения реактора и основных реакторных исследований, естественно, было осуществлено за счет средств государственного бюджета. В переходный период, когда велась разработка методов активационного анализа, исследования на реакторе также финансировались государством. Этот этап продолжался до тех пор, пока институт не поднялся до уровня, позволяющего ему с гарантией и ответственностью удовлетворять нужды постоянных заказчиков. С этого времени финансирование обеспечивается за счет договорных соглашений с заинтересованными предприятиями. Эта форма сотрудничества является выгодной для обеих сторон, заключающих договор.

Реактор Будапештского технического университета

В ходе работ на реакторе ВВР-С выяснилось, что венгерские специалисты приобрели достаточный опыт для проектирования атомного реактора малой мощности и его оснащения приборами для проведения экспериментов, а венгерская промышленность может изготовить значительную часть оборудования для таких объектов. Именно в этот период отечественные исследования вызвали необходимость соорудить многоцелевой, учебный исследовательский реактор.

Развитие ядерной техники, ядерной электроники, применение изотопов в Венгрии требует все больше новых специалистов в этой области. Решить проблему подготовки кадров мешало отсутствие учебного, исследовательского реакторного центра, который обеспечивал бы современные условия для обучения как в области физики, химии и биологии, так и в области атомной энергетики. Такой реактор, наряду с этим, обеспечивал бы возможность использовать научные кадры университетов для проведения исследовательской работы в упомянутых областях, повышая тем самым ее эффективность.

Учитывая эти обстоятельства, было вынесено решение о сооружении в крупнейшем в стране Будапештском техническом университете учебно-исследовательского реактора (рис.2). Пуск реактора был произведен весной 1971 года.

При проектировании данного реактора исходили из следующих соображений:

– реактор должен удовлетворить педагогические запросы других вузов в этой области;
– реактор должен обеспечить возможность преподавателям, научным сотрудникам и студентам старших курсов проводить исследовательские работы;
– на реакторе и в примыкающих к нему лабораториях следует обеспечить обучение большого числа студентов, не располагающих практическими знаниями, или располагающих ими в незначительной степени; поэтому одним из важнейших предъявленных к проектированию требований являлась повышенная безопасность и простота.

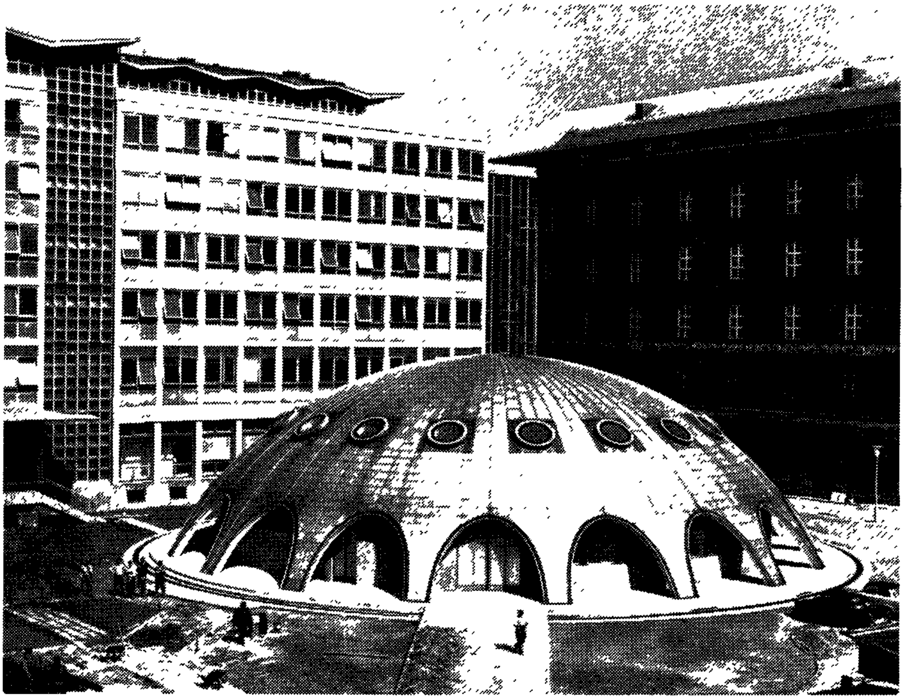

Рис.2. Здание учебного реактора.

Охлаждаемый водой, использующий в качестве горючего обогащенный уран, реактор в пределах возможного диапазона температур имеет отрицательный тепловой коэффициент. Используемые твэлы типа ЕК-10 можно применять и в случае бо́льших на два порядка мощностей, безопасность таких твэлов общеизвестна. Максимальная допустимая рабочая мощность атомного реактора составляет 10 кВт, максимальный поток тепловых нейтронов в центре активной зоны и каналах равен в среднем $2{,}4 \cdot 10^{11}$ нейтр/см^2·сек. Запас реактивности – 0,7 $. Разрез зоны реактора показан на рис.3.

К реактору подключено несколько каналов, три из которых пневматической почтой связаны с примыкающими лабораториями. Две горячие камеры позволяют обрабатывать полученные изотопы. С реактором соединено 5 горизонтальных каналов, в том числе 4 радиальных и 1 тангенциальный. В реакторном блоке имеется большой туннель, который предоставляет возможность, например, для измерений, связанных с биологической защитой, для облучения объектов больших размеров и т.д.

С атомным реактором связан ряд, так называемых, приканальных радиохимических лабораторий и измерительный центр. Каждая лаборатория имеет кабельную связь с измерительным центром.

Данный реактор используется для учебных и исследовательских целей, в первую очередь Будапештским техническим университетом и факультетами естественных наук. О своей заинтересованности проводить

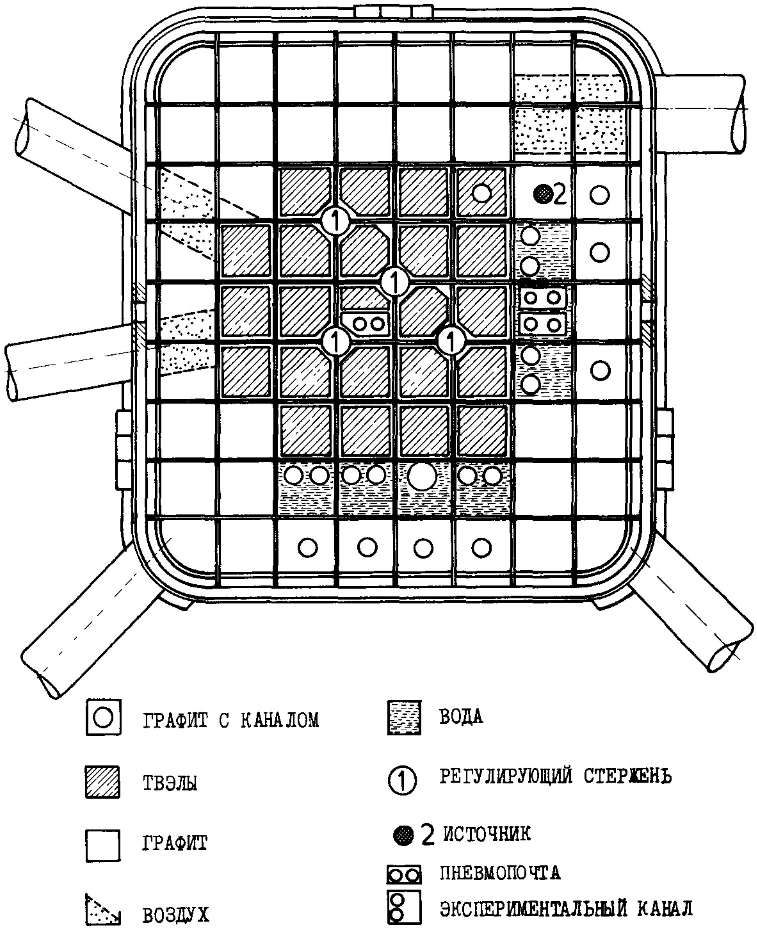

Рис.3. Активная зона учебного реактора.

на нем исследования заявили также медицинские и аграрные университеты страны. Не подлежит сомнению, что атомный реактор в значительной мере повысит уровень учебно-исследовательской работы на соответствующих кафедрах названных университетов.

Согласно нашим планам, реактор в первую очередь должен использоваться для обучения специалистов. При его использовании в учебной деятельности университетов следует предусматривать:

а) Включение на заинтересованных факультетах в материал существующих курсов нескольких измерительных задач; задание по объему измерений должно быть небольшим, но затрагивать широкий круг студентов.

б) Проведение специальных курсов, охватывающих узкий круг студентов (6-12 человек), но с расширенной измерительной тематикой.

в) Индивидуальные занятия со студентами; целесообразно, чтобы эта учебная форма составляла часть исследовательской деятельности.

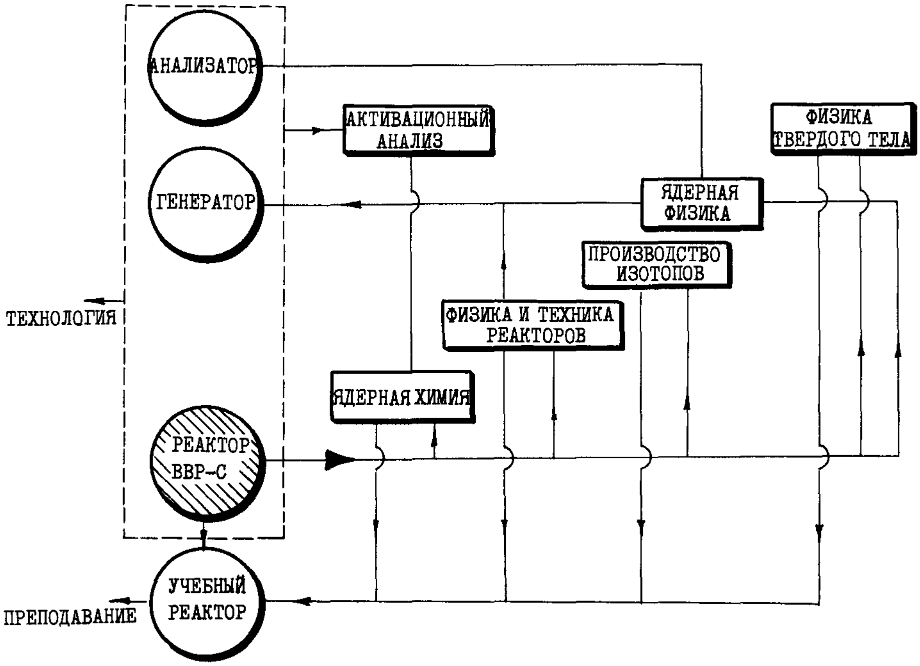

Рис.4. Схема воздействия исследовательского реактора на промышленность, науку и преподавание.

Помимо этого, работа на реакторе должна быть включена в специальную систему повышения квалификации инженеров и других лиц с высшим образованием.

Из сказанного следует, что созданию специальных курсов придается весьма большое значение. Хотя эти курсы являются составной частью учебной программы отдельных факультетов, они организуются по темам. При организации того или иного курса принимаются во внимание, в первую очередь, нужды определенного факультета, однако предоставляется возможность окончить его также и студентам других факультетов. В настоящее время планируются следующие курсы: реакторная физика, реакторная техника, активационный анализ, ядерная измерительная техника, дозиметрия.

Хорошей иллюстрацией сказанного является следующее: курс по реакторной физике объявлен в первую очередь для теплотехников и во вторую – для энергетиков и специалистов по электронике, но в порядке исключения его могут изучать также студенты-физики. Это означает, что, исходя из учебного материала теплоэнергетического факультета (лекции по атомной технике, практика в изотопной лаборатории), программа соответствует его требованиям. Запланированная программа этого курса: дозиметрическая практика, измерение нейтронного потока, измерение реактивности, практика на моделе реактора, снятие характеристик стержней управления, калибровка стержней защиты, практика по управлению реактором, измерение коэффициентов мощности и температуры, определение радиоактивности охлаждающей воды. Такая практика, дополненная ведущимся на факультете теоретическим обучением, обеспечивает основу подготовки по реакторной технике.

Конструкция атомного реактора, а также примыкающие к нему лаборатории и их оборудование обеспечивают особенно благоприятные условия для проведения обучения и исследовательской работы по активационному анализу. Система пневматической почты обеспечивает возможность для быстрой транспортировки образцов между реактором и находящимся в лаборатории измерительным центром. Современные полупроводниковые детекторы, многоканальные анализаторы и электронные вычислительные машины обеспечивают проведение надежных и быстрых измерений. До настоящего времени университетские кафедры удовлетворяли потребности такого рода (сокращая их до минимума) в Центральном институте физических исследований. Это обстоятельство весьма сужало их возможности: с одной стороны, из-за большой нагрузки реактора института и, с другой стороны, из-за большого расстояния между университетами и институтом. Созданный учебно-исследовательский реактор позволяет расширить данную деятельность кафедр.

В заключение приводим схему (рис.4), весьма упрощенно отражающую влияние, которое оказывают проводимые на реакторе исследования на промышленность и подготовку кадров. Схема не отражает роли ядерной электроники; рассмотрение этого вопроса потребовало бы специального доклада.

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THE DEVELOPMENT OF NUCLEAR ENERGY AND THE ROLE OF CNEN

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Abstract–Résumé–Аннотация–Resumen

THE DEVELOPMENT OF NUCLEAR ENERGY AND THE ROLE OF CNEN.

CNEN, the Italian Commission for Nuclear Energy, has outlined its programs on Italy's economical and industrial potential, as well as all the technological aspects involved. Effort and research have been concentrated on a few special programs which could find the widest common interest both for industry and for ENEL, the Italian Electricity Generating Board. In the development of power reactors CNEN judged that it was convenient to concentrate on only one line of reactors in the field of advanced converters and to pursue a long-term program on fast breeders. In collaboration with ENEL, CISE and Italian industries, CNEN is constructing the Cirene - a 40-MW(e) pressure-tube heavy-water-moderated reactor prototype cooled by light water in a two-phase water-steam mixture. CNEN's fast reactor program is now finalized in the construction of PEC (a fuel element testing reactor) with 140 MW(th) maximum power and of an experimental plant of sodium cooling circuits. CNEN is collaborating with FIAT and others in the construction of the "Enrico Fermi", an 18 000-ton nuclear ship powered by an 80-MW(th) PWR. CNEN and the major Italian industries are developing a single-purpose reactor, called ROVI, for desalination. The activities developed in the entire fuel cycle field should provide, in a more or less early stage, national alternatives to foreign solutions. ENI, the Italian State-owned industrial group, is active in mineral research in collaboration with CNEN. CNEN and Italian industries have accumulated satisfactory know-how in fuel fabrication. CNEN is running two reprocessing pilot plants. A full-size industrial reprocessing plant will be constructed in the near future by CNEN, and Italian industry is carrying out research and development in uranium enrichment.

LE DEVELOPPEMENT DE L'ENERGIE NUCLEAIRE ET LE ROLE DU CNEN.

Le CNEN, Comité national italien pour l'énergie nucléaire, a tenu compte, dans l'établissement de ses programmes, du potentiel économique et industriel de l'Italie, ainsi que de tous les aspects techniques intéressés. Ses efforts et ses recherches se sont concentrés sur quelques programmes particuliers susceptibles d'intéresser au maximum à la fois les industries et l'ENEL, l'Organisme italien de production d'électricité. Dans le domaine du développement des réacteurs de puissance, le CNEN a estimé qu'il était de son intérêt de concentrer ses efforts sur une seule filière de réacteurs dans le secteur des convertisseurs avancés et de poursuivre un programme à long terme dans le secteur des surgénérateurs rapides. Le CNEN, en collaboration avec l'ENEL, le CISE et les industries italiennes, construit actuellement le réacteur CIRENE, réacteur prototype de 40 MW(e), à tubes de pression, ralenti par l'eau lourde et refroidi par l'eau légère en condition de changement de phase. Le programme de réacteurs rapides s'est concrétisé par la construction du PEC, réacteur d'essai pour éléments combustibles de 140 MW(th), et d'une installation d'essai pour les circuits de refroidissement au sodium. Le CNEN collabore, entre autres avec la FIAT, à la construction de l'Enrico Fermi, navire nucléaire de 18000 tonnes doté d'un réacteur à eau sous pression de 80 MW(th). Le CNEN et les plus importantes industries italiennes collaborent à la construction du réacteur ROVI, conçu pour le dessalement de l'eau de mer. Les activités développées dans tout le secteur du cycle du combustible devraient permettre de remplacer, à plus ou moins brève échéance, les solutions étrangères par des solutions nationales. L'ENI, Organisme national des hydrocarbures, poursuit, en collaboration avec le CNEN, des activités dans le domaine de la recherche minière. Le CNEN et les industries italiennes ont acquis un know-how satisfaisant en matière de fabrication des combustibles. Le CNEN exploite deux installations pilotes de retraitement; en outre, une installation de retraitement à l'échelle industrielle va être prochainement construite par le CNEN et les industries italiennes. Enfin, le CNEN et les industries italiennes mènent une activité de recherche et de développement dans le domaine de l'enrichissement de l'uranium.

РАЗВИТИЕ РАБОТ ПО ЯДЕРНОЙ ЭНЕРГИИ И РОЛЬ НАЦИОНАЛЬНОГО КОМИТЕТА ПО ЯДЕРНОЙ ЭНЕРГИИ ИТАЛИИ.

Национальный комитет по ядерной энергии Италии разрабатывает свои программы, в которых рассматривается экономический и промышленный потенциал страны, а также все

связанные с этим технические аспекты. Усилия и исследования сосредоточены на нескольких специальных программах, которые могли бы представить интерес как для промышленных фирм, так и для Национального энергетического управления Италии. В области разработки энергетических реакторов Национальный комитет по ядерной энергии считает целесообразным сконцентрировать внимание на одном типе реакторов из усовершенствованных конверторов и осуществлять долгосрочную программу в области реакторов-размножителей на быстрых нейтронах. В сотрудничестве с Национальным энергетическим управлением, Информационным центром экспериментальных исследований и итальянской промышленностью Национальный комитет строит прототип тяжеловодного реактора мощностью 40 МВт(эл) с трубами под давлением, охлаждаемый обычной водой в виде двухфазовой пароводяной смеси. Программа Национального комитета по реакторам на быстрых нейтронах завершается в настоящее время строительством реактора PEC мощностью 140 МВт(тепл) для испытания твэлов и экспериментальной установки с контурами натриевого охлаждения. Национальный комитет по ядерной энергии сотрудничает с фирмой "ФИАТ" и другими учреждениями в части строительства ядерного транспортного судна "Энрико Ферми" водоизмещением 18 000 т, с реактором с водой под давлением и мощностью 80 МВт(тепл). Национальный комитет и крупные итальянские промышленные фирмы разрабатывают одноцелевой реактор ROVI для опреснения воды. Деятельность в области разработки топливных циклов должна рано или поздно привести к решению вопросов на национальной основе в противовес существующим иностранным вариантам. Государственное промышленное объединение ENI в сотрудничестве с Национальным комитетом проявляет активность в области минеральных ресурсов. Национальный комитет по ядерной энергии и итальянские промышленные фирмы накопили значительный опыт в производстве топлива. Национальный комитет использует две опытные установки по переработке облученного топлива. В ближайшем будущем планируется построить промышленную установку по переработке облученного топлива; промышленные фирмы ведут научно-исследовательские и опытно-конструкторские работы по обогащению урана.

EL DESARROLLO DE LA ENERGIA NUCLEAR Y EL PAPEL DEL CNEN.

La Comisión Italiana de Energía Nuclear (CNEN) ha planeado sus programas considerando la potencia industrial y económica de Italia, así como todos los aspectos tecnológicos implicados. El esfuerzo y las investigaciones se han concentrado en unos pocos programas especiales que pudiesen tener el mayor interés común tanto para la industria como para el Organismo Italiano de Producción de Electricidad (ENEL). Acerca del desarrollo de reactores de potencia, CNEN juzgó que era conveniente concentrarse sólo en una familia de reactores en el campo de los convertidores avanzados y dedicarse a un programa a largo plazo en el de los reproductores rápidos. En colaboración con ENEL, CISE y las industrias italianas, CNEN está construyendo el Cirene, un prototipo de reactor, de 40 MW(e), de tubos de presión, moderado por agua pesada y refrigerado por agua ligera en una mezcla bifásica agua-vapor. Los objectivos actuales del programa de reactores rápidos de CNEN se centran en la construcción de PEC (un reactor de ensayo de elementos combustibles) de 140 MW(t) de potencia máxima y de una instalación experimental de circuitos de refrigeración por sodio. CNEN colabora, entre otros, con FIAT en la construcción del «Enrico Fermi», un barco nuclear de 18000 toneladas, movido por un reactor del tipo PWR de 80 MW(t). CNEN y las industrias italianas más importantes están desarrollando un reactor especializado para la desalación, llamado ROVI. Las actividades desplegadas en el campo del ciclo completo del combustible debieran proporcionar, en plazo más o menos largo, alternativas nacionales a las soluciones extranjeras. El Organismo Nacional de Hidrocarburos (ENI), en colaboración con CNEN, se ocupa de la investigación minera. CNEN y las industrias italianas han acumulado una práctica satisfactoria en la fabricación de combustible. CNEN explota dos instalaciones piloto de reelaboración de combustibles. En un próximo futuro, CNEN construirá una instalación de tamaño industrial de reelaboración, junto con la industria italiana, con la que también lleva a cabo trabajos de investigación y desarrollo en el campo del enriquecimiento del uranio.

1. INTRODUCTION

The Comitato Nazionale per l'Energia Nucleare – CNEN (National Committee on Nuclear Energy) was established in Italy in 1960 for the purpose of developing nuclear energy and its applications, and of contributing to the nation's scientific, technological, economic and social progress. In the last decade, therefore, CNEN's efforts have been devoted on the one hand to the creation of infrastructures and to the training of scientific and technical personnel, and on the other to the framing and starting of research programs in the various areas connected with nuclear research and its applications, with the object of promoting and developing the Italian nuclear industry.

CNEN's action is essentially based on technological development programs connected with the utilization of nuclear energy sources, in particular for power generation purposes, these programs being formulated in such a way that the results achieved can be usefully transferred to industry.

The objectives laid down by national economic planning for the energy sector are: an increasing degree of self-sufficiency, the continuity and diversification of the energy supply, a low cost of raw materials, and therefore a decrease in power generation costs. Nuclear energy may contribute to the achievement of such aims, even on a short- and medium-term basis, considering that in the longer run it is bound to constitute the only way to the solution of the problem of energy, both from the economic standpoint and from that of the necessary expansion of primary energy sources.

Unlike some other countries, whose financial resources permit a plurality of alternative lines of development, as well as a plurality of industrial projects, for a country with Italy's economic resources it is necessary on the one hand to operate through a limited number of programs selected in accordance with the main lines of international nuclear development, and on the other to concentrate efforts on programs which have an industrial interest.

CNEN, in fixing its program objectives, follows the guidelines laid down by the Comitato Interministeriale della Programmazione Economica, CIPE (Interministerial Committee on Economic Planning).

2. PROVEN REACTORS

In the development of nuclear reactors and of the fuel-cycle services, the program choices were made with special reference to the current international situation.

Regarding PWR reactors, which have already gained an established market position, follow-up research in Italy has been considered inadvisable. It is therefore to be expected that in the near future these proven water reactors will continue to be built largely under foreign licences. Nevertheless, CIPE has set as an objective the future gradual disengagement from the licensing system. CNEN is thus already engaged in some activities connected with water reactors, as regards both design techniques and fuel-element fabrication technologies, and in support activity for the development of the nuclear propulsion system for the ship Enrico Fermi, which will be discussed further on in this report.

3. CONVERTER REACTORS

CNEN, and therefore the Italian nuclear industry, is able to assume a more determinant role in the sector of advanced converters and fast reactors.

With respect to these two generations of reactors, no country is yet so far advanced as to be able to monopolize the field, nor can we expect an immediate commercial introduction of these two reactor generations, which could dictate the choice of the various reactor designs now.

Between the two possible types of advanced reactors now being developed on an international scale (heavy-water reactors and high-temperature gas reactors), we have recognized in Italy the soundness of the concept of the heavy-water-moderated, light-water- and steam-cooled reactors (CIRENE) [1]. This decision was made because of the advantages accruing from a possible broader diversification of the supply sources of natural uranium, which is much more easily obtainable, since such reactors use natural uranium directly, and since they produce about twice as much energy as the proven-type plants equipped with light-water reactors.

The supply of plutonium, in effect, could prove a decisive factor for the presence of fast reactors on the market.

The Cirene Program is based on the construction, already approved, of a prototype producing about 40 MW(e), the development of which constitutes a joint venture by CNEN and ENEL (National Electric Power Agency), with the active participation of CISE, under which the program originated. Design work on this reactor is being done by a joint CNEN-ENEL team, with the participation of an industry of the IRI Group, "Progettazioni Meccaniche Nucleari", while the reactor system will be built by "Ansaldo Meccanico Nucleare", also of the IRI Group. The reactor is scheduled to go into operation by 1974-75. The decision to continue with the development of this reactor design after the completion of the prototype will depend not only on the results and the prospects opening up, but also on the degree of development achieved in the meantime by proven reactors and fast reactors.

4. FAST REACTORS

The objective of independence of nuclear fuel supply sources will be fully achieved at the time when it will prove possible to meet the new demand for nuclear power with a self-supporting system of fast reactors, ensuring the full utilization of natural uranium for the generation of power. The highly interesting features of these reactors have induced Italy, like all the more industrialized countries, to devote great efforts to their development. CNEN has set itself the task of acquiring in Italy the necessary knowledge to enable fast reactor nuclear power plants to be designed and built within the country.

In selecting the lines to be followed for the development of a program in this sector, allowance was made for the fact that the feasibility and economic profitability of fast reactors is heavily dependent on certain essential elements, such as the fuel element and the steam generator.

With these points in mind, it was decided to base the Italian program on the development of (a) a fuel element capable of achieving high burnup rates, (b) sodium loops, and (c) the steam generator and intermediate exchanger. It was also decided to build the PEC reactor, a facility capable of testing fuel elements under predictable operating conditions [2]. PEC, which is due to go into operation by 1975, is a liquid-sodium-cooled fast reactor, developing an initial operating power of 80 MW(th) and a final peak power of 140 MW(th). The core is divided into two zones, the experimental zone and the normal operation zone. The reactor will be able to operate in both the stationary and transient modes and its design will allow one to test the melting, for research purposes, of some fuel rods in the test section. The PEC reactor, for the construction of which an industrial Consortium was specially established by SNAM PROGETTI (ENI) and Società Italiana Impianti (IRI), represents Italy's first industrial experience with the development of a prototype fast reactor in addition to constituting an essential facility for the development of the fuel element.

CNEN's Fast Reactor Program is also concerned with the building of a 1-MW sodium loop for research and steam generators and with the construction of an experimental area for a sodium-water test.

For the future development of fast reactors, it seems appropriate to consider first the possibility of cooperation with Euratom and with third countries.

In this connection, CNEN hopes that the international situation will evolve towards an extensive European cooperation, for example through a joint program for the development of a large demonstration reactor. In any event, with a view to enabling Italian industry to play a role in such a cooperative effort, it was deemed essential to achieve in the meantime the highest degree of independent national development, although following a few well-defined lines (core design, fuel element, sodium components, safety problems, etc.), up to the deadline for a decision on the construction of a demonstration plant. If at this point the hoped-for broader-based cooperation agreements have not been reached, there should be room for cooperation at least on a bilateral basis. Following the lines indicated above, Italy will in any case be able to offer to a prospective partner independent experience and her own stock of know-how and patents.

5. SHIP PROPULSION

In the last few years the nuclear propulsion of merchant vessels has undergone a considerable evolution, although not one comparable to that of nuclear power plants.

This is also of major interest for all countries like Italy that possess an advanced shipbuilding industry, because of the possible future implications of nuclear technological development on the economics of this sector. Future prospects are generally regarded as favourable, even though the experts disagree on how soon nuclear ship propulsion will become competitive with conventional propulsion systems.

In view of these facts, in the last few years CNEN has promoted several meetings among the leading Italian experts from different sectors of the economy to assess the advisability of undertaking a concrete program, to determine the real extent of individual interests and to throw light on the various problems and difficulties involved in such a program. These meetings have confirmed the existence of a general interest in nuclear applications in the marine sector and the desirability of moving beyond the research stage into a construction project. It was thus decided to concentrate the studies on a ship powered with a PWR reactor; the program also calls for the construction of the service station, the carrying out of a number of supporting research and development activities, and the training of the crew needed for the experimental operation of the ship.

The 18 000-ton ship will be named Enrico Fermi and will be powered with an 80-MW(th) PWR achieving a top speed of 20 knots [3]. The Fiat Co. will be responsible for designing and building the nuclear reactor and 90% of the nuclear plant components will be Italian-built. CNEN will be primarily responsible for the technical and scientific aspects of the program, including the development of the fuel; to this end CNEN has developed at its Casaccia Center the "critical experiment" for research on the core of the Enrico Fermi reactor.

6. DESALINATION

For some time, a number of countries have been working systematically on the problem of sea-water desalting by nuclear processes. The resources invested by the technologically more advanced countries reflect the enormous importance being attached to the water supply problem. In relatively recent times, studies and research have been applied to the designing of plants capable of simultaneously producing electric power and fresh water. Recent studies, however, have shown the limitations of such dual-purpose plants, whose economics are strictly dependent on problems of scale. The conditions prevailing in the majority of the countries located in arid and semi-arid regions indicate a demand for a plant designed for fresh-water production only; this is the underlying concept of the Italian desalination program named ROVI [4].

The ROVI program calls for the construction of a distillation desalination plant powered by a nuclear reactor, ROVI, organic cooled and moderated, developing 200 MW(th), which can produce some 100 000 m^3 of water (approx. 26.4 million gal (US)) per day.

CNEN, after conducting studies and research on the reactor concept, promoted the establishment of an industrial consortium comprising the leading Italian companies (Breda, Fiat, Montecatini Edison, Snam Progetti, Snia Viscosa, Società Italiana Impianti, Sorin), for the purpose of designing and developing the plant, so that it can ultimately be offered on the national and international market. ROVI, which is designed to fit into a plant so simple and safe as to require a limited investment for its construction, effectively meets the economic requirements of the developing countries for which this project is primarily intended; it also represents a potential contribution to plans for the industrialization of southern Italy, where the age-old shortage of fresh water is now, as never before, a major bottleneck to growth.

7. THE FUEL CYCLE

The economy of nuclear energy is linked in particular to improvements in the fuel cycle. CNEN, therefore, in addition to its reactor development programs, has made great efforts to obtain knowledge on all the various aspects of the fuel cycle, aiming at building a strong base for future advances. CNEN's program calls for work in the fields of natural uranium supply, fuel fabrication, uranium enrichment and fuel reprocessing.

As regards the supply of natural uranium, CNEN is conducting a prospecting program in Italy, with a view to preparing an inventory of uranium ore resources. It also cooperates with ENI in the programs in many foreign countries which this Agency is conducting in prospecting for and working uranium ore deposits. The problem of natural uranium, apart from the domestic exploration efforts, is for Italy essentially a problem of procurement abroad. It may be ensured through long-term contracts with foreign suppliers and/or through prospecting programs in foreign countries.

In the last few years in the sector of fuel-element fabrication [5] Italy has acquired, through the efforts of CNEN and industry, a satisfactory stock of knowledge and know-how on the problems of design and fabrication of metal rod elements for gas reactors and ceramic rod elements for water reactors.

Italy is now in a position not only to fabricate fuel elements under licence but also to introduce new fabrication processes using novel and original methods such as the sol-gel process developed through Italian research.

The present programs are directed towards the acquisition of fuel-design know-how that would constitute a national and more economical alternative to the purchasing of foreign licences, ultimately leading to an industrial policy in the fuel area based on a rational concentration of production activities.

This program for the development of an independent know-how plays a major role in CNEN's Plutonium Program [6], whose main objective is to acquire in the shortest possible time the knowledge required for the development of a plutonium fuel element. To this end, CNEN has developed the chemical, metallurgical and fabrication techniques for the production of fuel elements containing mixed uranium and plutonium oxides, as well as specific methods for designing and testing these elements. The techniques have been tried, with highly satisfactory results, in reactor performance tests on fuels fabricated in CNEN's laboratories.

As with natural uranium, Italy tends to adopt a policy of reliability and continuity of supply also with enriched uranium.

Enriched uranium is now indispensable for water reactors; also, the possibility cannot be completely overlooked that the stage of marketing of heavy-water converter reactors (using natural uranium) may be skipped altogether, and that therefore we may witness an extended useful life of water reactors, or that we may be forced to start the fast reactor line on enriched uranium. For these reasons, Italy is interested in participating in Euratom or in other multinational organizations or enterprises concerned with enrichment processes, so as to avoid being forced into a condition of total dependence, with the attendant economic and technological consequences. The aims that Italy pursues are the creation of international cooperation on a European gaseous-diffusion plant and the extension to all Euratom countries, including Italy, of the three-country cooperation on the ultracentrifugation process. The developments in this possible international cooperation will obviously affect future national research and development activity.

CNEN's action on a domestic level tends to expand the capacity of Italian industry, with which it has established an extensive cooperation, to produce uranium enrichment plants, so as to enable it to participate adequately in the construction of a possible multinational plant, as well as to develop in Italy the know-how required for the construction of a future national plant, should such a decision be found advisable.

CNEN's program is oriented towards the two processes, gaseous diffusion and ultra-centrifugation. At this time, it is impossible to make a choice between the two processes on purely technical and economic grounds; there is also a possibility that both of them may be adopted jointly in Europe. Cooperating in this program are ENEL and the leading Italian industries (FIAT, ENI, IRI, Montedison, EFIM, Snia Viscosa), which have also underwritten part of the cost of the implementation of research and development.

CNEN has been working for many years on the problem of reprocessing and this activity has led to the designing and building of two pilot plants, EUREX and ITREC [7] which, over the next decade, will make it possible to conduct a complete experimental program on a pre-industrial scale and on different fuel types. This program will have, in particular, to take into account the possible coexistence of three reactor types, a fact which might substantially affect the industrial reprocessing program.

The know-how that has been and will be acquired from these plants, and that which CNEN is obtaining from its participation in the Eurochemic European joint venture, ensures the most complete independent acquisition of knowledge by our country. This will make it possible to participate in a possible plan for a large-size European-level commercial enterprise that might take shape in the coming years, and at the same time make feasible an independent national alternative.

In this connection, it should be noted that the quantity of fuel which will be discharged from Italy's predicted power plants might well be large enough to warrant the beginning of construction of an Italian reprocessing plant in the late 1970s.

CNEN and ENI have already established a joint working group charged with studying the design and cost estimate of an industrial plant called "EUREX 2", where the know-how and experience of CNEN from the operation of the pilot plant will be integrated and consolidated.

8. OTHER ACTIVITIES

CNEN is also active in other sectors of the peaceful utilization of nuclear energy. For example, in controlled nuclear fusion CNEN is developing, in cooperation with Euratom, a program for the construction of a toroidal machine (Tokamak type).

The start of operation of the 1500-MeV Adone electron and positron storage ring and the tests conducted with other existing accelerators have constituted a main part of CNEN's basic research work in high-energy physics.

In the applications of radiation in agriculture, results of major scientific and economic interest have been achieved [8].

The responsibilities assigned to CNEN by law have resulted in major efforts by the Committee in safety and health protection. Such activities have concerned the monitoring and control of nuclear plants, radioactive materials in industrial and research activities, and transportation of radioactive materials. Research has also been conducted on radiation's harmful effects to man, as well as on the conservation and protection of the environment.

9. CONCLUSION

This brief review of CNEN's activities leads to the conclusion that nuclear energy is becoming one of the essential factors in the economic development and industrial progress of our country. This process of evolution, however, may receive further and decisive impetus from a true and effective international cooperation, which we sincerely desire as a means towards the common end of contributing to the welfare of the people.

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URUGUAY
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CONTRIBUCION DE LA INSTALACION DEL CENTRO DE INVESTIGACIONES NUCLEARES AL DESARROLLO TECNOLOGICO DEL URUGUAY

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Abstract–Résumé–Аннотация–Resumen

THE CONTRIBUTION OF THE NUCLEAR RESEARCH CENTRE INSTALLATION TO THE TECHNOLOGICAL DEVELOPMENT OF URUGUAY.

One of the main reasons of the Uruguayan authorities for deciding to establish a Nuclear Research Centre (CIN) was the need to create a national infrastructure which would serve as a basis – in terms of human and material resources – to meet future requirements for introducing nuclear power into the country. These requirements lead to the rapid training of specialized personnel in power reactor and fuel cycle technologies and economics, because the time available for taking decisions concerning nuclear strategies is short and, moreover, the possibility of a regional strategy is envisioned. To introduce modern technology effectively and to obtain the benefits of an early preparation of local industry to the needs and specifications of the nuclear industry, it was decided that a large share of the Centre's equipment – particularly that for the associated research reactor – should come from domestic suppliers. The CIN reactor is the result of upgrading a former 10-kW(th) reactor, purchased by the Uruguyan Government some years ago, to 1 MW(th). The new design was made by Uruguayan engineers. The decision taken to concentrate national resources for designing and financing the CIN installation has helped to introduce a modern technological potential which is important to the country's development. In addition, it has helped develop the professional skills of a national team of engineers and technicians, thus giving more self-assurance, and confidence to the policy makers, which is a benefit that should not be overlooked at the various stages of national development.

CONTRIBUTION DU CENTRE D'ETUDES NUCLEAIRES AU DEVELOPPEMENT TECHNOLOGIQUE DE L'URUGUAY.

L'une des raisons principales de la décision prise par le Gouvernement uruguayen de construire un centre d'études nucléaires a été la nécessité de créer une infrastructure nationale qui permette de répondre aux besoins en hommes et en ressources matérielles auxquels il faudra faire face lors de l'introduction de l'énergie d'origine nucléaire dans le pays. Ces besoins exigent la formation rapide de personnel spécialisé dans la technologie et l'économie des réacteurs de puissance et du cycle du combustible, car le temps dont on dispose pour prendre les décisions en matière de stratégie nucléaire est plus court que prévu et, en outre, la possibilité d'une stratégie régionale peut être envisagée. Afin de rationaliser l'introduction de la technologie moderne dans le pays et d'obtenir les avantages d'une préparation précoce de l'industrie locale aux besoins et aux spécifications propres à l'énergie nucléaire, il a été décidé que, pour s'équiper, le Centre s'adresserait surtout à des fournisseurs nationaux – notamment pour ce qui est du réacteur de recherche annexe. Le réacteur actuel du centre est le résultat de travaux qui avaient pour but de porter de 10 kW(th) à 1 MW(th) la puissance d'un réacteur acheté il y a quelques années par le Gouvernement. Ces travaux ont été menés à bien par des ingénieurs uruguayens. La décision de faire un effort national pour étudier et financer la construction du Centre a eu pour effet d'introduire, avec des moyens relativement faibles, un potentiel technologique moderne pour le développement du pays. Cette décision a en outre contribué à développer les capacités professionnelles d'une équipe nationale d'ingénieurs et de techniciens, ce qui a eu pour résultat d'augmenter chez eux la confiance en soi et chez les planificateurs la confiance dans leurs avis. Il s'agit là d'un bénéfice qu'il convient de ne pas négliger aux divers stades du développement national.

ЗНАЧЕНИЕ СОЗДАНИЯ ЦЕНТРА ЯДЕРНЫХ ИССЛЕДОВАНИЙ ДЛЯ ТЕХНИЧЕСКОГО РАЗВИТИЯ УРУГВАЯ.

Одной из основных причин принятия уругвайскими властями решения о строительстве Центра ядерных исследований (CIN) явилась необходимость создать национальную инфраструктуру, которая служила бы основой (с точки зрения людских и материальных ресурсов) развития в стране ядерной энергетики в будущем. Это требует быстрой подготовки квалифи-

цированных специалистов по технологии и экономике энергетических реакторов и топливного цикла, поскольку времени для принятия решений по ядерной стратегии имеется меньше, чем предполагалось, и, более того, поскольку может быть рассмотрена возможность разработки региональной стратегии. Для эффективного внедрения в стране современной технологии, с учетом выгоды заблаговременной подготовки местной промышленности к потребностям и особенностям ядерной промышленности, было решено, что бо́льшая часть оборудования и материалов для Центра, особенно для его исследовательского реактора, должна поступить от уругвайских поставщиков. Реактор CIN – это купленный правительством несколько лет тому назад реактор на 10 кВт(тепл), мощность которого была увеличена до 1 МВт(тепл). Новая конструкция была разработана уругвайскими инженерами. Решение о концентрации национальных ресурсов для конструирования и финансирования установки CIN содействовало использованию современного технического потенциала, что имеет актуальное значение для развития страны. С другой стороны, оно способствовало повышению квалификации инженеров и техников страны. Возросло также доверие политических кругов к их деятельности, чем не следует пренебрегать на данной стадии национального развития.

CONTRIBUCION DE LA INSTALACION DEL CENTRO DE INVESTIGACIONES NUCLEARES AL DESARROLLO TECNOLOGICO DEL URUGUAY.

Al decidir la instalación de un Centro de Investigaciones Nucleares (CIN), las autoridades del Uruguay consideraron, como uno de los elementos fundamentales, la necesidad de crear una infraestructura nacional que, tanto humana como materialmente, sirviera de base a los requerimientos futuros de la introducción de la generación nucleoeléctrica en el país. Dichos requerimientos imponen la preparación inmediata de personal especializado en la tecnología y la economía de los reactores de potencia así como de los ciclos de combustible, ya que los plazos para las decisiones de estrategias nucleares no son tan amplios como pudiera parecer a simple vista, máxime si se contempla una estrategia a nivel regional. Para introducir en forma efectiva la tecnología moderna al país, con la consecuencia beneficiosa de una preparación temprana de la industria local a efectos de hacer frente a las necesidades y exigencias de la industria nuclear, se decidió por una participación importante de las firmas nacionales en los suministros del Centro y, en particular, en los del reactor de investigación asociado. El reactor del CIN es el resultado de un diseño hecho por técnicos nacionales, adaptando un pequeño reactor de 10 kW(t) que fuera adquirido hace algunos años por el Gobierno, a una nueva capacidad de 1 MW(t). La decisión de realizar un esfuerzo nacional para diseñar y financiar la instalación del CIN ha servido para introducir, con inversiones relativamente reducidas, un potencial tecnológico moderno interesante para el desarrollo del país. Por otra parte, ha contribuido al desarrollo de las posibilidades técnico-profesionales de un equipo de ingenieros y técnicos nacionales, con el consiguiente resultado de seguridad en su propio juicio y, por parte de los planificadores, de confianza en su criterio, siendo ésta una capitalización que no debe descuidarse en las etapas del desarrollo nacional.

1. INTRODUCCION

Al cabo de un año del comienzo de la construcción del Centro de Investigaciones Nucleares (CIN) del Uruguay, las autoridades que han decidido por la opción de realizar un esfuerzo nacional, para instalarlo conjuntamente con el reactor asociado al mismo, están aún más convencidas de que se ha elegido el camino más adecuado para cumplir con los objetivos de desarrollo tecnológico nuclear del país, teniendo en cuenta los recursos humanos, industriales y financieros locales [1].

El Uruguay, país en desarrollo, ha entendido que un programa nuclear prudente, basado en el esfuerzo propio, podrá contribuir a la introducción de la tecnología moderna, con la adopción consecuente por parte de la incipiente industria doméstica de las exigencias y las estrechas tolerancias requeridas por los standards de las técnicas nucleares [2].

La confianza en el éxito de este programa está basada en la existencia de un buen nivel de capacitación en ingeniería y de una mano de obra ingeniosa y experimentada para solucionar problemas fuera de lo convencional, aspecto muy común en los países en desarrollo.

El proyecto del CIN consta de un reactor de investigación del tipo piscina de 1 MW(t) de potencia. El diseño del reactor ha sido realizado por ingenieros locales, en base a una revisión completa de un pequeño reactor de 10 kW(t) adquirido por el gobierno del Uruguay hace algún tiempo. Ello ha permitido desarrollar las posibilidades técnico-profesionales de un equipo de ingenieros y técnicos nacionales, con el resultado auspicioso de crear un grupo bien calificado y con suficiente confianza propia para estudiar y considerar, oportunamente, las especificaciones, las propuestas y las ofertas de centrales nucleares. La seguridad, por parte de los encargados de las decisiones político-económicas de contar con un asesoramiento competente y confiable, proveniente de profesionales compatriotas, es un elemento esencial para un país en desarrollo, que deberá adquirir en el extranjero sus centrales de energía eléctrica, o gran parte de las mismas, ya que esas decisiones implican inversiones muy importantes a escala nacional.

La planificación de la instalación de centrales nucleoeléctricas en el país, a más largo plazo, ligada a la estrategia de los ciclos de combustible, ha impuesto una cierta urgencia en el fomento activo del desarrollo de las actividades nucleares. Teniendo en cuenta que una central nuclear necesita 4 a 5 años para su construcción e instalación y unos 3 años para el establecimiento de las especificaciones, el llamado a ofertas, la adjudicación, y la obtención de una financiación adecuada, el tiempo disponible para preparar a los responsables nacionales que intervengan en estas etapas es escaso, si se prevé la necesidad de contar con energía nucleoeléctrica en la próxima década. Esta urgencia es aún mayor al considerar la posibilidad de encarar soluciones a nivel regional, con las economías resultantes de la repetición de diseños y de la instalación de plantas de mayor capacidad para distintos procesos del ciclo de combustible. En este caso, el personal especializado del país debería intervenir a nivel regional mucho más temprano.

2. PROYECTO

2.1 Reactor

El proyecto del CIN comprende el diseño e instalación de un reactor del tipo piscina de 1 MW(t) de potencia. Este reactor ha resultado de la adaptación de un reactor original de 10 kW(t) exhibido en Montevideo hace algunos años, fabricado por la Cía. Lockheed de los Estados Unidos. Este reactor completamente desarmado fue adquirido por el gobierno del Uruguay y se decidió aumentar su potencia mediante un nuevo diseño, primero a 100 kW(t) y, posteriormente, a 1 MW(t). Los elementos combustibles del tipo MTR, con uranio enriquecido al 20 %, fueron donados por los Estados Unidos a través del OIEA. Aunque existía la exigencia de utilizar el equipo y los elementos combustibles del reactor original, las autoridades responsables coincidieron en que un esfuerzo de este tipo debería conducir a un reactor de mayor capacidad, ya que sería el único que por

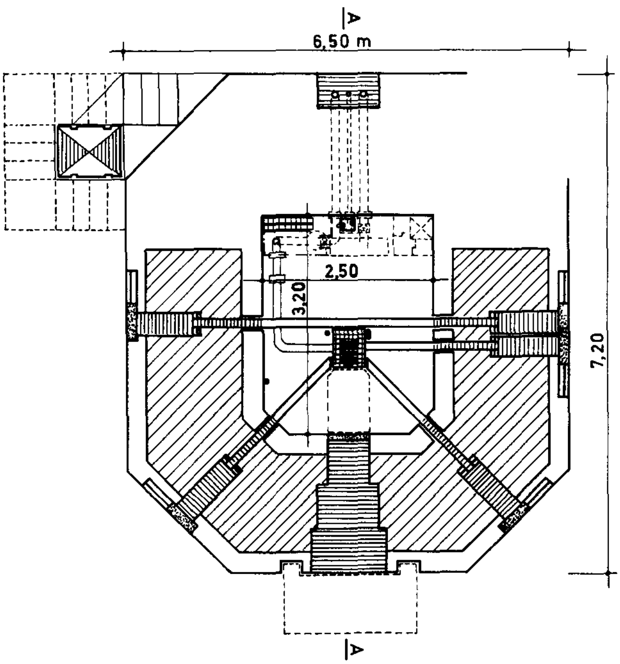

FIG. 1. Planta del reactor.

cierto tiempo iba a tener el país. De ahí que el nuevo diseño se aparta fundamentalmente del original, aunque se ha tratado de utilizar al máximo los elementos recuperables de éste.

La piscina del reactor será de acero inoxidable y tendrá las dimensiones siguientes: 3,2 m x 2,5 m x 7,6 m de profundidad (figs. 1 y 2). El blindaje tendrá 2 m de espesor en la parte inferior. Estará constituido por dos paredes de hormigón ordinario armado, de 30 cm de espesor cada una, dispuestas a 1,4 m de distancia. El espacio existente entre ambas se llenará de hormigón pesado de densidad 3,5 g/cm^3. El mineral de hierro que constituirá al hormigón pesado es ilmenita y proviene de una mina ubicada a unos 100 km de Montevideo.

Tres tubos radiales para haces neutrónicos y uno tangencial pasante serán instalados para experiencias. Serán de aluminio y tendrán un diámetro de 15 cm. Todos los tubos podrán retirarse con el objeto de permitir que, en caso en que no se utilicen, se tenga libre acceso a las caras del núcleo del reactor. Se les fijará a una platina, ubicada dentro del blindaje a 1 m del borde exterior, mediante bulones (fig. 3).

Se instalará además una columna térmica de sección cuadrada. Sus dimensiones pasarán de 0,6 m x 0,6 m contra la cuba a 1,1 m x 1,1 m sobre el lado exterior. Inicialmente el espacio de la columna térmica se llenará de ladrillos de hormigón pesado, hasta tanto las necesidades experimentales no exijan su utilización con grafito.

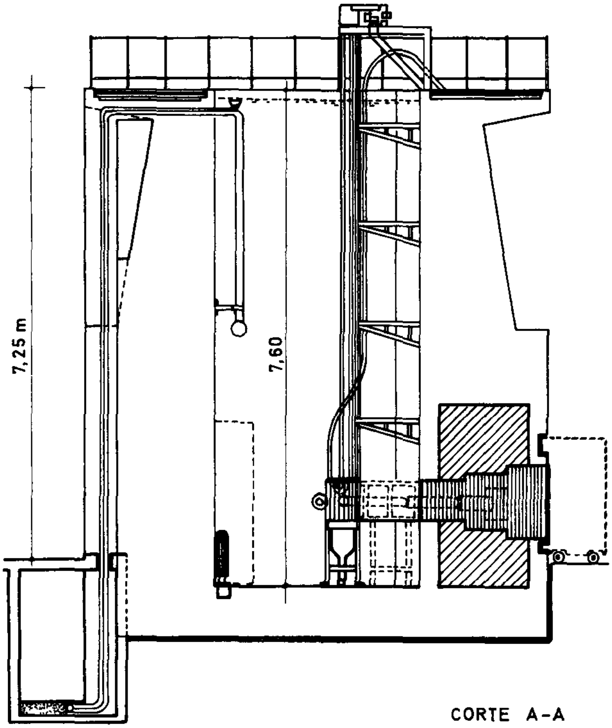

FIG. 2. Corte del reactor.

El sistema de refrigeración constará de un colector en forma de embudo ubicado en la parte inferior del núcleo que conducirá el agua del enfriamiento al intercambiador de calor. La cañería de succión de 12,5 cm de diámetro atravesará la cuba en la parte superior con el objeto de crear un sistema de sifón por razones de seguridad y para evitar perforaciones del blindaje en las zonas de mayor presión. Todo el sistema de refrigeración primaria será de acero inoxidable.

Dentro de la cuba se ha previsto, en el circuito de succión, un tanque de decaimiento de ^{16}N de 1,5 m^3 de capacidad, de modo que la actividad del agua de enfriamiento baje a los límites permisibles, al lograrse un retraso equivalente a 7 períodos, antes de que salga de la cuba.

Dos bombas centrífugas impulsarán cada una 75 m^3/h del agua primaria a través de un intercambiador de calor que se refrigerará con agua del circuito secundario. El intercambiador será del tipo tubular, permitiendo un salto de temperatura de 10°C. La cañería de impulsión retorna el agua primaria a la piscina. Esta cañería atraviesa la cuba por la parte superior y descarga a través de un difusor para evitar turbulencias importantes en la piscina.

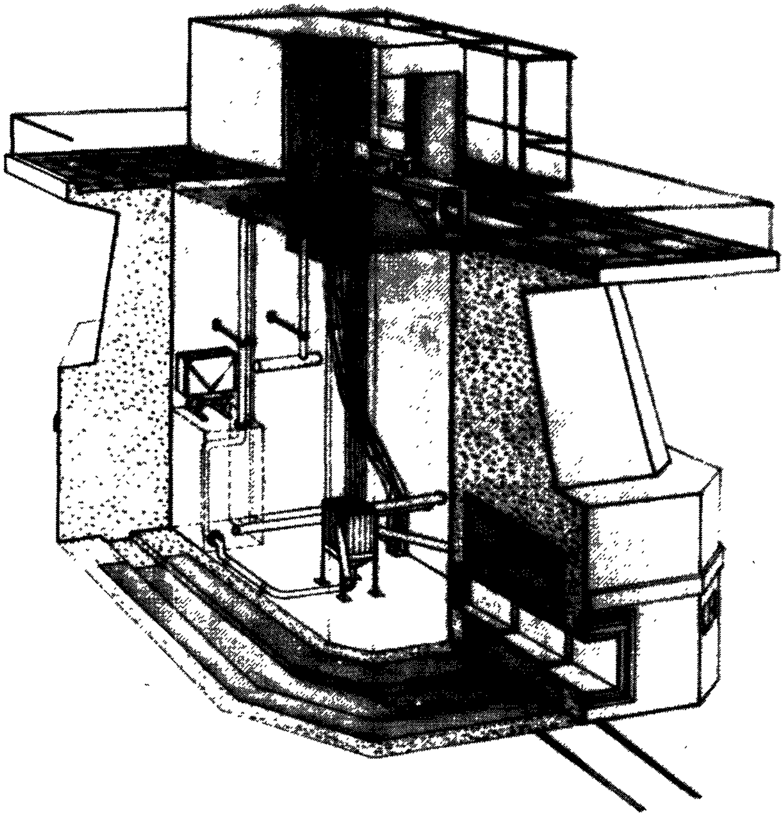

FIG. 3. Corte perspectivo del reactor.

El circuito secundario de refrigeración contará con una torre de enfriamiento que circulará unos 175 m^3/h de agua con un salto de temperatura de 5°C. El sistema de funcionamiento es por tiraje inducido y corrientes cruzadas.

Parte del agua de refrigeración del circuito primario, será derivada para su procesamiento y reposición. Un 5% del caudal primario se hará pasar por un sistema de resinas aniónicas y catiónicas para evitar la acumulación de productos de corrosión en el agua de la piscina.

2.2 Hall

El reactor estará ubicado en un hall de 18 m x 18 m de superficie y 15 m de altura (fig. 4). De este modo, se tendrán cerca de 6 m libres frente a cada salida de los haces neutrónicos y de la columna térmica. La altura del hall ha sido elegida para poder introducir a la piscina elementos de unos 7 m de longitud mediante una grúa-puente de 10 t de capacidad.

Este edificio estará en depresión por razones de seguridad, aunque no será hermético. La presión se mantendrá a 10 mm de columna de agua por debajo de la atmosférica. El sistema de ventilación permitirá efectuar cuatro renovaciones de aire por hora. El aire será evacuado a través de una chimenea a 20 m por encima del nivel del suelo. Se han previsto filtros absolutos que se conectarán al sistema solamente en caso de emergencia. En condiciones normales, el aire se derivará directamente a la chimenea para evitar colmataciones innecesarias de los filtros absolutos.

Las cañerías del circuito primario de refrigeración del reactor atraviesan el hall por dentro de un túnel que comunica con la Sala de auxiliares. Esta sala está situada fuera del hall para separar el ambiente de experimentación del de los equipos auxiliares del reactor. Los equipos que se instalarán en esta sala serán: las bombas de circulación del agua de refrigeración de los circuitos primario y secundario, el intercambiador de calor principal y el sistema de procesamiento y reposición del agua.

En la parte superior del reactor se colocará una plataforma de trabajo unida por una pasarela a la sala de comando. La plataforma podrá contener , en una esquina, una celda caliente a la que se accederá desde la piscina con elementos combustibles irradiados (fig. 3).

2.3 Laboratorios

Adosado al hall del reactor, se construirá un edificio de cuatro niveles para contener a los laboratorios, talleres, sala de máquinas, sala de comando, oficinas y sala de filtros.

Los laboratorios de física y radioquímica así como los talleres mecánico y electrónico (fig. 4), estarán a nivel del piso del hall. Esta zona estará en depresión de 5 mm de columna de agua. El sistema de ventilación está integrado al del hall del reactor.

La sala de comando se encuentra a nivel de la plataforma de trabajo del reactor. Esta ubicación tiene la ventaja de estar cerca de los dispositivos de control y de los mecanismos de comando de barras que irán colocados sobre una viga en ménsula a 1 m por encima del nivel de agua de la piscina. Además, desde la sala de comando se puede dominar visualmente la plataforma superior y las salidas experimentales del reactor a nivel del piso del hall (fig. 5).

En el subsuelo de este edificio se ha ubicado la sala de máquinas. En la misma se instalarán los equipos convencionales para el acondicionamiento térmico de los locales, los ventiladores y filtros primarios del sistema de ventilación y los grupos electrógenos de emergencia.

2.4 Vestuarios y administración

Los vestuarios forman parte de un edificio de una planta situado contra la pared del hall opuesta a la de los laboratorios. Los vestuarios comunican directamente con las zonas activas por un corredor de pasaje.

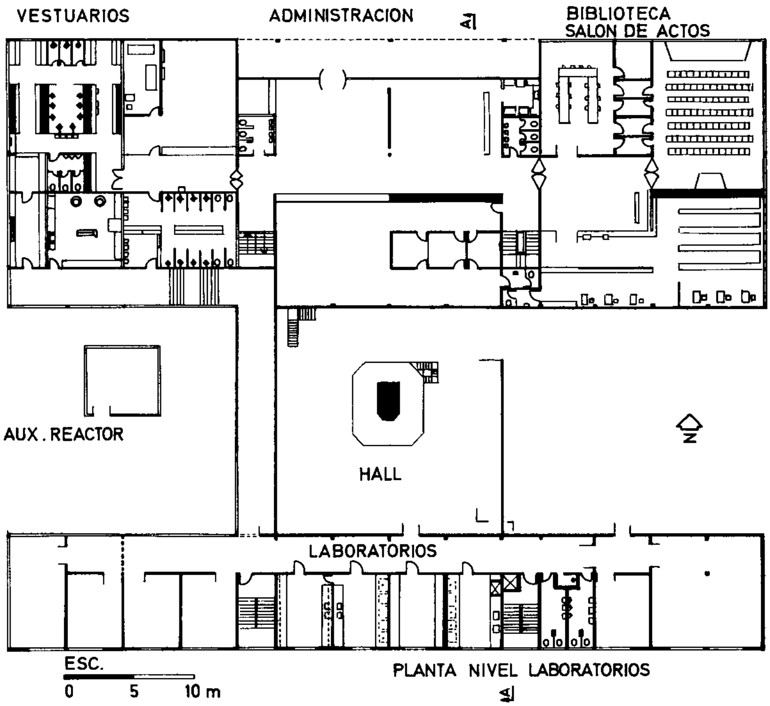

FIG. 4. Planta del CIN.

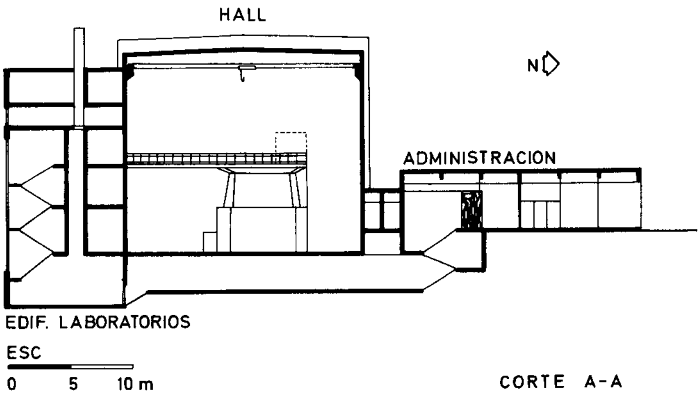

FIG. 5. Corte del CIN.

La parte de administración contará con biblioteca, sala de actos y sala de reuniones, oficinas administrativas y de control radiosanitario (fig. 4).

3. ORGANIZACION

El proyecto del CIN fue realizado mediante un convenio firmado entre la Universidad de la República y la Comisión Nacional de Energía Atómica (CNEA). Este convenio impone a la Universidad la responsabilidad de proyectar y supervisar la construcción del Centro, dando énfasis a la instalación del reactor, mientras que la CNEA aporta el reactor original de 10 kW(t) desarmado y financia parte de las obras. El convenio, además, encarga a la Universidad, mediante un control adecuado de la CNEA, la tarea de operar el Centro una vez que se ponga en marcha.

Para cumplir con su cometido y teniendo en cuenta que contaba con un presupuesto limitado, la Universidad utilizó al máximo a sus propios profesionales para confeccionar el proyecto creando la Oficina del Proyecto del CIN.

Esta Oficina seleccionó un grupo de ingenieros mecánicos, electrotécnicos, químicos y radioquímicos bajo la dirección de un ingeniero nuclear para abordar las tareas de definir los siguientes aspectos: física del reactor; blindaje, seguridad e ingeniería civil del reactor; refrigeración del reactor; ventilación y acondicionamiento térmico del Centro; laboratorios de radioquímica; eliminación de residuos radiactivos, e ingeniería civil, sanitaria y eléctrica del Centro. Para gran parte de estos temas que tienen relación con la disposición arquitectónica del Centro se contó con el apoyo sustancial de la Oficina de Arquitectura de la Universidad, mientras que la responsabilidad de la construcción de las obras recayó sobre el Ministerio de Obras Públicas.

La ejecución de la obra está siendo controlada por la Oficina del Proyecto del CIN, conjuntamente con arquitectos de la Oficina de Arquitectura de la Universidad. La Oficina del Proyecto mantiene informada a la CNEA, semanalmente, de la marcha de la obra. Este sistema ha resultado bastante ágil y ha operado satisfactoriamente, a pesar de la multitud de organismos involucrados. Ello se ha debido fundamentalmente al espíritu de colaboración individual entre los responsables directos de la obra.

Las condiciones locales existentes al comenzarse el proyecto impusieron este tipo de organización. Las condiciones favorables eran: las buenas relaciones existentes entre la Universidad y la CNEA, el deseo de evitar duplicaciones innecesarias y antieconómicas en el desarrollo de la investigación nuclear del país, la existencia de un buen nivel profesional en las ramas básicas de la ingeniería y de una concentración de personal especializado en problemas nucleares en la Universidad, la posibilidad de contar con una mano de obra y personal mecánico capacitado y bien entrenado para resolver ingeniosamente las dificultades inherentes a las exigencias de la tecnología moderna, y la necesidad de ahorrar al máximo los escasos recursos financieros destinados a la obra.

Por otra parte, las deficiencias locales que hubo que tener en cuenta eran: el escaso número de científicos e ingenieros especializados en ciencias nucleares, la falta de desarrollo y tradición industrial y, como se ha indicado, el presupuesto limitado.

Una gran parte de los problemas resultantes de estas deficiencias fue solucionada mediante la generosa cooperación de las Comisiones de Energía Nuclear de otros países, en particular de Argentina, Francia y España. Varios técnicos de dichas comisiones examinaron las soluciones elaboradas por el grupo encargado del proyecto, y sugirieron correcciones y cambios basados en su mayor grado de desarrollo en este tipo de actividades. Este intercambio, muchas veces informal, permitió que el grupo estableciera un diálogo con técnicos y profesionales más experimentados y adquiriera, entonces, una mayor seguridad en su propio criterio técnico, lo que resultó fundamental para el éxito del proyecto. En lo relativo al equipamiento del Centro se utilizará, análogamente, la cooperación de los programas de asistencia técnica de los Organismos internacionales, como ser: PNUD, OIEA y OEA.

4. DESARROLLO TECNOLOGICO

El proyecto y la instalación del CIN han estado contribuyendo al desarrollo de la industria nacional y de la mano de obra especializada necesaria para cumplir con las exigencias de la tecnología moderna. Ello ha resultado de las condiciones impuestas inicialmente en el sentido de que se utilizará al máximo los recursos humanos, la industria y la financiación local.

Uno de los elementos de mayor importancia en la instalación será la cuba de acero inoxidable del reactor. Por sus dimensiones y peso, aproximadamente 2,2 t, resultará una pieza de equipamiento que se construirá por primera vez en el país. La cuba servirá de encofrado interno a la pared interior de hormigón armado del blindaje. Para ello, deberá ubicarse en posición antes de comenzar el vaciado del hormigón. Para evitar esfuerzos importantes sobre las paredes de la cuba, se irá llenando con agua metro a metro, a medida que se levanta la pared de hormigón.

La forma de ejecutar el blindaje mediante dos paredes de hormigón armado ordinario de escaso espesor que encierran una masa de 1,40 m de ancho de hormigón pesado es el resultado de una adaptación a las condiciones constructivas locales. El hormigón pesado es un material desconocido por los obreros de la construcción. Este método no los obligará a trabajar con encofrados especiales para el hormigón pesado. Además, el hormigón pesado sólo soportará su propio peso ya que todo esfuerzo adicional será descargado por las paredes de hormigón armado. Ello traerá como consecuencia que disminuirá la proporción de hierro en el hormigón pesado, lo que permitirá evitar el peligro de aparición de fisuras importantes por contracción de fraguado. También, los obreros verán su tarea simplificada en las tareas de terminación de las paredes exteriores del blindaje por tratarse de materiales conocidos.

El sistema de control del reactor y de sus equipos auxiliares ha sido elaborado por ingenieros nacionales, en base a las exigencias de seguridad y protección de la técnica nuclear. Se ha tratado de utilizar el máximo de los elementos de control y comando del reactor original y adaptar sistemas coherentes adicionales para lograr el aumento de potencia. Ello ha requerido que se prevea el agregado de un nuevo canal de medida y de una barra de control más. Además, debido al aumento de la altura de agua por encima del núcleo del reactor, la longitud de los soportes de los elementos originales de control y medida ha tenido que incrementarse.

Los sistemas de refrigeración primario y secundario, el circuito de procesamiento, el sistema de ventilación, así como los controles correspondientes, han sido diseñados por ingenieros de la Universidad.

La instalación sanitaria y la de ventilación serán realizadas localmente, con el uso de materiales de plaza. Ello es posible para todos los elementos, salvo los filtros absolutos y de carbón activado, los instrumentos de control y medida y los registros especiales. Los tanques de decaimiento para el agua proveniente de las zonas activas serán de hormigón pintado con epóxida.

La terminación de las superficies y los recubrimientos de pisos y paredes se han especificado con materiales que se fabriquen en plaza, de modo que el mantenimiento pueda hacerse con elementos fácilmente asequibles.

Los elementos de acero inoxidable, como bombas primarias e intercambiador de calor principal, deberán importarse. Se tratará que estos suministros provengan de fabricantes vecinos para asegurar una fuente de repuestos y de servicio de reparación de fácil acceso, así como para contribuir al desarrollo industrial regional que, a la postre, será beneficioso también para el país.

Estos ejemplos señalan el objetivo principal perseguido para contribuir al desarrollo tecnológico nacional: la creación de un grupo de profesionales y obreros especializados cuyo conocimiento de las exigencias de la técnica moderna, a través de la experiencia adquirida por el proyecto y la instalación del centro y del reactor nuclear, pueda utilizarse en las etapas relacionadas con la incorporación de centrales nucleoeléctricas en el país; la introducción de las necesidades y especificaciones de la tecnología moderna en la industria nacional de modo de darle la oportunidad de mantener al día su capacidad y pericia para poder competir económicamente, en particular, en posible suministro de elementos de las futuras centrales; y la plena utilización de los recursos locales, tanto humanos como financieros y técnicos, a la resolución de un problema complejo aumentándose así el poder de decisión nacional en la rama de la generación nuclear, en forma análoga a lo realizado en otros países de la región [3].

5. ASPECTOS ECONOMICOS

El costo del proyecto e instalación del CIN, con el reactor nuclear de 1 MW(t), resultará del orden de la mitad o un tercio de lo que han costado en otros países la importación de instalaciones semejantes [4]. Las razones principales para un presupuesto tan bajo han sido:

-el uso del personal de la Universidad para realizar el proyecto y efectuar la dirección de la obra,
-la utilización de un organismo estatal, como lo es el Ministerio de Obras Públicas, para las construcciones del Centro,
-la ágil organización del proyecto que ha permitido una relación armoniosa y eficiente entre los diversos organismos interesados,
-el establecimiento de diseños y soluciones técnicas acordes con las condiciones existentes en el país, que ha conducido a conceptos que mejor satisfacen económicamente a los requerimientos tecnológicos y a las limitaciones locales,
-el uso de materiales existentes en plaza, en la medida de lo posible, sin recurrir a suministros exóticos y difíciles de obtener,
-la modulación de la estructura de los edificios con elementos que se repiten mediante locales cuyas dimensiones son múltiplos de un módulo básico,
-el concepto del proyecto que permite una gran latitud para la introducción de cambios y agregados a medida que sean requeridos por los usuarios, y
-la coordinación de los programas de asistencia técnica de diversos organismos internacionales y el establecimiento de contactos estrechos con profesionales y técnicos de centros nucleares más desarrollados.

De este modo, los honorarios de los proyectistas y los salarios de los obreros se han establecido en base a las condiciones locales, provocándose un ahorro importante frente a la alternativa de contratar asesoramiento extranjero.

Las necesidades de equipo han sido estudiadas para que las inversiones correspondientes puedan espaciarse en el tiempo. Ello ha podido conseguirse gracias a la latitud que posee el proyecto para introducir cambios y agregados. Los siguientes son ejemplos de esta latitud:

-La columna térmica no será rellenada de grafito hasta tanto no se justifique su uso por los usuarios; mientras tanto se introducirán ladrillos de hormigón pesado en el espacio correspondiente.

-Se ha previsto una instalación en dos etapas del circuito de refrigeración del reactor; inicialmente se operará a 10 kW(t) y se procederá a la calibración del instrumental y a la determinación de las curvas de flujo neutrónico, lo que puede llevar algunos meses, siendo la refrigeración por circulación natural; posteriormente, se elevará la potencia a 100 kW(t) y se agregarán las cañerías y equipos necesarios para la refrigeración forzada a esta potencia; finalmente, se pasará a 1 MW(t) y se instalará el tanque de decaimiento de ^{16}N y una segunda bomba de circulación. Todos los soportes fijos de los diversos elementos que irán en la cuba se colocarán inicialmente de modo que el agregado de los mismos sea rápido y fácil.

-La estructura de la plataforma de trabajo llevará refuerzos en una esquina, para poder instalar encima una celda caliente. Esta celda está prevista para una etapa posterior en que se requiera manipular elementos combustibles irradiados (fig. 3). Este dispositivo ha sido incluido últimamente como resultado de discusiones con expertos de otros países [2] y, gracias a que el proyecto estaba en manos de personal local, una vez tomada la decisión, el agregado pudo hacerse sin mayor inconveniente y en forma sumamente rápida. Es muy probable que si no se hubiera obrado de este modo, no se hubiese podido tomar ninguna decisión al respecto.

-Hay previstas varias posibilidades de ampliación de los edificios del CIN. En particular, el hall del reactor podrá ser agrandado mediante el agregado de nuevos pórticos y la eliminación de una pared, calculada para que no tenga funciones resistentes. Mediante la prolongación de los rieles, la grúa-puente podrá utilizarse en el total de la nave ampliada.

6. GENERACION NUCLEAR

Las perspectivas de la generación nucleoeléctrica en el Uruguay han sido estudiadas en forma general y los resultados iniciales indican una posibilidad favorable, en un lapso de unos 10 a 15 años, para la introducción competitiva de centrales nucleares.

El sistema eléctrico del país está integrado con centrales térmicas convencionales e hidroeléctricas. Actualmente, el tamaño unitario que se ha licitado por la administración nacional de electricidad (UTE) es de 100 MW(e).

En el sistema interconectado de UTE la potencia total vale unos 500 MW(e) y se prevé, en los próximos diez años, un índice de crecimiento acumulativo de la demanda del orden del 7 % anual, lo que permite prever para 1985 una potencia instalada de 1100 MW(e) en el sistema. Ello si no se considera la interconexión con el sistema argentino del Gran Buenos Aires-Litoral. En este caso, ya en 1980 el sistema tendrá más de 6000 MW(e) instalados.

Debido a la característica de los sistemas hidráulicos de los ríos uruguayos, el factor promedio de utilización de las centrales térmicas es del orden de las 5000 h anuales. No es de prever que en los próximos diez años este valor varíe sustancialmente.

El petróleo crudo importado cuesta C.I.F. Montevideo 17 US$/t, sin incluir costos de almacenamiento. Este valor es el que existía antes de la entrada en vigencia de los nuevos precios acordados a principios de año entre los países productores y exportadores de petróleo.

Los estudios efectuados en base a datos sobre costos de instalación, de combustible y de operación y mantenimiento de centrales nucleares publicados en los últimos 3 años, así como a los correspondientes a centrales térmicas convencionales, han permitido confeccionar el Cuadro I. En este cuadro, se indican en mills/kWh los costos de la generación eléctrica, en base a un coeficiente de cargas fijas del 11,8 % (10 % de interés y 20 años de amortización), 6500 h anuales de utilización de la unidad y un costo del crudo de 17 US$/t. Los valores se indican para varias potencias unitarias. Las centrales nucleares estudiadas han sido las que utilizan reactores con agua liviana y uranio enriquecido (LWR) y reactores con agua pesada y uranio natural (HWR).

CUADRO I. COMPARACION DEL COSTO DEL kWh

Centrales convencionales		MW(e) 125	250	350	550
mills/kWh		9,4	8,1	7,7	7,5
Centrales nucleares		**100**	**200**	**300**	**500**
mills/kWh	LWR	12,4	8,9	7,5	6,0
	HWR	14,3	10,7	9,3	7,5

Se observa que existe un umbral de competitividad alrededor del tamaño unitario de 250 MW(e). Este umbral podría desplazarse hacia menores tamaños si el factor de utilización de la central se incrementa por encima de 6500 h anuales, o si el interés del capital necesario para la instalación de la central es menor al valor del 10% utilizado en esta comparación, o si el precio CIF del petróleo aumenta por encima del valor de 17 US$/t existente a comienzos de 1971.

Teniendo en cuenta que el tiempo necesario para seleccionar e instalar una central nuclear oscila entre los 6 y 8 años, quedan escasamente unos 4 a 6 años para crear la infraestructura nacional, humana y material, necesaria para elaborar las especificaciones, seleccionar y controlar la construcción de dicho tipo de plantas. Por otra parte, la urgencia en tomar decisiones de fomento activo del desarrollo nuclear en el país se hace más notoria al observar la importancia que implica una planificación de una estrategia de los ciclos combustibles a largo plazo. Ello, ligado a las posibilidades de interconexión eléctrica con otros países, podría influir en la elaboración de una política nuclear más amplia a nivel regional, con la posibilidad de la implantación en la zona de usinas de conversión, de fabricación de elementos combustibles, de reprocesamiento y, eventualmente, de agua pesada, para servir a un gran número de plantas, con las consiguientes economías de escala.

La oportunidad de la instalación del CIN resulta así aún más evidente al tener en cuenta el tiempo necesario para la preparación de profesionales competentes en el campo de la generación nucleoeléctrica.

7. CONCLUSIONES

Se ha indicado que la prioridad que se asigne al establecimiento de una infraestructura científica y tecnológica en un país en desarrollo es una de las condiciones especiales para la obtención de financiación de las centrales nucleoeléctricas [5]. Esto debe ser entendido por los responsables de la planificación del desarrollo energético en los países que requieran financiación extranjera para lograrlo. En el Uruguay, mediante la instalación del CIN en particular, se está tratando de cumplir con dicho requerimiento.

La decisión del fomento de las actividades nucleares del país utilizando sobre todo el esfuerzo local está permitiendo desarrollar el potencial técnico existente para lograr un conocimiento directo de la técnica nuclear y acceder así a los requerimientos de la tecnología moderna.

La forma de resolver con recursos propios el problema de la instalación de un reactor de investigación ha sido muy económica porque ha permitido combinar las exigencias de la tecnología actual con las limitaciones locales, obteniéndose soluciones ingeniosas y satisfactorias. Por otra parte, todos los detalles de la instalación, aún los menores, serán conocidos exhaustivamente, lo que no es tan fácil de conseguir al importar totalmente un reactor de este tipo.

Finalmente, se ha podido crear un grupo de ingenieros y técnicos con autoridad para encarar problemas relacionados con reactores nucleares, y cuyo criterio y asesoramiento podrán ser seguidos con confianza por los responsables de tomar decisiones relativas a los programas energéticos nacionales e influir, por lo tanto, en la calidad del desarrollo del país.

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ORGANISATION DE LA RECHERCHE AU CENTRE D'ETUDES NUCLEAIRES DE GRENOBLE EN LIAISON AVEC L'INDUSTRIE ET L'UNIVERSITE

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Abstract–Résumé–Аннотация–Resumen

THE ORGANIZATION OF RESEARCH IN THE GRENOBLE NUCLEAR CENTRE, IN CONJUNCTION WITH INDUSTRY AND THE UNIVERSITY.

One of the purposes of the CEA when founding the Centre d'études nucléaires de Grenoble (CEN-G) was to develop close connections with industry and the University. The authors show how, owing to a specially favourable situation, the various laboratories of the CEN-G have come to play an important role as an intermediary between the University and industry. The research teams of the CEN-G laboratories include an important proportion of University scientists, among whom are several professors who act as scientific advisers. Many research contracts are made by the CEN-G with the University. The CEN-G participates in University teaching and, like a specialized training school, gives complementary scientific training to students coming from the University. The extensive application of research results is actively encouraged. This is demonstrated by the existence of more than 150 contracts with public or private bodies. New structures have been and are being created to obtain more efficient collaboration: the creation of the Electronics and Information Technology Laboratory (LETI), and the presence in the CEN-G of laboratories and researchers from industry. Principally concerned are desalination, new materials for electronics and metallurgy, low temperatures, and irradiation devices. On the international level, the CEN-G welcomes each year about one hundred foreigners from every country, activates study groups, notably in Brazil and Peru, and carries out missions of scientific cooperation for the IAEA, particularly in Morocco.

ORGANISATION DE LA RECHERCHE AU CENTRE D'ETUDES NUCLEAIRES DE GRENOBLE EN LIAISON AVEC L'INDUSTRIE ET L'UNIVERSITE.

L'un des objectifs du CEA en créant le Centre d'études nucléaires de Grenoble était de développer d'étroites liaisons avec l'université et l'industrie. Les auteurs montrent comment, grâce à un contexte particulièrement favorable, les divers laboratoires du CEN-G sont amenés à jouer un rôle très important de relais entre la recherche et l'industrie. Les équipes des laboratoires de recherche du CEN-G comportent une forte proportion d'universitaires; parmi eux se trouvent plusieurs professeurs de l'université qui assurent le rôle de conseillers scientifiques. De nombreux contrats d'étude sont passés par le CEN-G à l'université. Le CEN-G participe à l'enseignement universitaire et apporte, comme le ferait une école d'application, un complément de formation scientifique aux jeunes élèves sortant de l'université. La valorisation de la recherche y est activement menée. Elle se traduit par plus de 150 contrats avec des organismes publics ou privés. Des structures nouvelles sont mises en œuvre pour obtenir une collaboration plus féconde: création du Laboratoire d'électronique et de technologie de l'informatique (LETI), accueil d'équipes et de laboratoires de l'industrie. Les domaines suivants sont principalement concernés: le dessalement, les matériaux nouveaux pour l'électronique et la métallurgie, les basses températures, les dispositifs d'irradiation. Sur le plan international, le CEN-G accueille en moyenne une centaine d'étrangers de toutes nationalités chaque année, anime des groupes de recherche notamment au Brésil et au Pérou, et effectue des missions de coopération scientifique pour le compte de l'AIEA, en particulier au Maroc.

ОРГАНИЗАЦИЯ НАУЧНО-ИССЛЕДОВАТЕЛЬСКИХ РАБОТ В ЯДЕРНОМ ЦЕНТРЕ В ГРЕНОБЛЕ СОВМЕСТНО С ПРОМЫШЛЕННЫМИ ПРЕДПРИЯТИЯМИ И УНИВЕРСИТЕТОМ.

Одной из задач Комиссариата по атомной энергии при создании Центра ядерных исследований в Гренобле было развитие тесных связей с Университетом и промышленными предприятиями. Авторы доклада сообщают о том, как в результате очень благоприятной обстановки различные лаборатории Центра ядерных исследований в Гренобле стали играть важную роль в качестве связующего звена между Университетом и промышленностью. В исследовательские группы лабораторий Центра входит соответствующее число ученых Университета; несколько профессоров работают в качестве научных консультантов. Большое количество контрактов на проведение научно-исследовательских работ было выполнено Центром совместно с Университетом. Центр принимает участие в учебной деятельности Университета и как специализированная школа дает возможность студентам получить специальную подготовку. Активно поощряется использование результатов исследований в будущем. Это подтверждается заключением более чем 150 контрактов с государственными или частными организациями. Разрабатываются новые организационные формы для обеспечения более эффективного сотрудничества: создание LETI (Лаборатория электроники и технической информации), участие в деятельности Центра ядерных исследований в Гренобле групп специалистов с промышленных предприятий. Рассматриваются, главным образом, следующие области: опреснение соленой воды, производство новых материалов для электроники и металлургии, низкие температуры, радиационное оборудование. В области международного сотрудничества Центр ежегодно принимает около ста иностранных специалистов из различных стран, участвует в работе исследовательских групп, особенно в Бразилии и Перу, и командирует через МАГАТЭ специалистов по линии научного сотрудничества, особенно в Марокко.

ORGANIZACION DE LA INVESTIGACION EN EL CENTRE D'ETUDES NUCLEAIRES DE GRENOBLE EN COLABORACION CON LA INDUSTRIA Y LA UNIVERSIDAD.

Uno de los objetivos del CEA al crear el Centre d'études nucléaires de Grenoble era establecer vínculos estrechos con la Universidad y la Industria. Los autores cuentan cómo una situación particularmente favorable lleva a los diversos laboratorios del CEN-G a jugar un papel muy importante de enlace entre la investigación y la industria. Los grupos de trabajo de los laboratorios de investigación del CEN-G incluyen una proporción elevada de universitarios, entre los que se encuentran varios profesores de la Universidad que cubren el papel de consejeros científicos. El CEN-G pasa a la Universidad numerosos contratos de estudios. El CEN-G participa en la enseñanza universitaria y aporta, como lo haría una escuela de aplicación, un complemento de formación científica a los alumnos jóvenes que salen de la Universidad. Allí se efectúa una activa valoración de la investigación que se traduce por más de 150 contratos con organismos públicos o privados. Se establecen estructuras nuevas para obtener una colaboración más fecunda; por eso se creó el Laboratoire d'Electronique et Technologie de l'Informatique (LETI) y se acoge a grupos y laboratorios de la industria. Los campos en que se tiene mayor interés son, la desalación, los nuevos materiales para la electrónica y la metalurgia, las temperaturas bajas y los dispositivos de irradiación. En el plano internacional, el CEN-G acoge un promedio de 100 extranjeros de todas las nacionalidades al año, anima grupos de investigación, concretamente en Brasil y Perú y efectúa misiones de cooperación científica por cuenta del OIEA, particularmente en Marruecos.

Parler dans une conférence internationale de l'organisation de la recherche au Centre d'Etudes Nucléaires de Grenoble et de ses liaisons avec l'Université et l'Industrie peut paraître présomptueux. En effet, ce Centre n'est pas en France le plus important du Commissariat à l'Energie Atomique. Il peut paraître modeste comparé à bon nombre de Centres atomiques existant de par le monde. Néanmoins, sa large imbrication avec l'Université et l'effort que l'on y a fait pour établir une collaboration aussi étroite que possible avec l'Industrie nous ont paru dignes d'être signalés.

Le Professeur NEEL, Prix Nobel de Physique en 1970, qui prit la direction de ce Centre dès sa création en 1956, a eu l'occasion d'exprimer ses vues sur le rôle que devaient jouer les Centres d'Etudes Nucléaires, lors de la Conférence Générale de l'Agence Internationale de l'Energie Atomique en 1966. A son avis, les Centres d'Etudes Nucléaires doivent garder une place de choix à la recherche fondamentale. Elle profite ainsi de la solide organisation administrative et du puissant soutien technique que peuvent, en général, fournir ces Centres. Réciproquement, elle apporte à la technologie et aux recherches de développement un soutien scientifique indispensable. Il disait notamment :

"Par son essence même, la recherche fondamentale n'est jamais achevée, elle est une, en ce sens que les travaux menés dans des lieux différents et dans des disciplines différentes sont étroitement solidaires. Elle implique des contacts constants entre chercheurs de disciplines variées. Elle est essentiellement polyvalente dans ses débouchés. On ne fait pas de la recherche fondamentale pour telle ou telle application, mais on fait de la recherche pour valoriser le potentiel scientifique et industriel général d'un pays tout entier."

"La solide organisation des Centres d'Etudes Nucléaires qui aurait pu paraître un peu lourde aux physiciens d'autrefois, avec leurs services généraux, administration, cantines, services médicaux et sociaux, services de sécurité, leurs services techniques, ateliers, entretien, bureaux de calcul, électronique, leurs services spécialisés, protection contre les radiations, laboratoires chauds, réacteurs de recherche, accélérateurs, leur permet, en réalité, de jouer le rôle de laboratoire d'accueil et de donner des moyens de travail à des équipes extérieures au bénéfice de la collectivité."

Dans ces quelques lignes se trouvent énoncés les principes essentiels dont l'application devait faire du CEN.G ce qu'il est aujourd'hui : un centre résolument tourné vers l'extérieur, s'appliquant à faire déboucher dans l'industrie les résultats obtenus en recherche fondamentale, ayant établi des liens étroits avec l'Université, collaborant avec les organismes publics ou privés, développant sur le plan international des coopérations scientifiques et techniques basées sur une intégration poussée des coopérants.

La réalisation de ces principes fut grandement facilitée par le contexte particulièrement favorable qui a toujours existé à Grenoble. Il faut y voir l'une des raisons majeures pour lesquelles le C.E.A. décida, en 1956, de choisir Grenoble comme site pour son troisième Centre d'Etudes Nucléaires.

L'environnement scientifique et industriel de Grenoble

Le potentiel scientifique et industriel, déjà très important à l'époque du choix de Grenoble pour y installer un Centre de recherche du C.E.A., n'a cessé de croître. Grenoble se classe au premier rang des villes de province en ce qui concerne le potentiel en chercheurs et en universitaires : 6 000 personnes travaillent à la recherche dont 2 500 ingénieurs ou universitaires diplômés.

Les trois nouvelles universités, issues de la réforme universitaire, y sont fortes de près de 25 000 étudiants. Les disciplines scientifiques en intéressent 7 000 parmi lesquels 650 étrangers et sont dotées d'une trentaine de laboratoires.

En Pharmacie et en Médecine, on compte 2 500 étudiants dont 70 étrangers.

La formation d'ingénieurs y a été, de tout temps, assurée par de solides écoles d'ingénieurs, actuellement regroupées dans l'Institut National Polytechnique de Grenoble. Elles délivrent un diplôme des ENSI (Ecoles Nationales Supérieures d'Ingénieurs) à environ 260 élèves par an.

Enfin, une mention particulière doit être faite des laboratoires du Centre National de la Recherche Scientifique (C.N.R.S.), Electrostatique et Physique du Métal, Centre de Recherche des Basses Températures qui, avec 350 personnes, ont été un moteur puissant dans le domaine du magnétisme et de la physique du solide, ainsi qu'en a témoigné le congrès international du magnétisme qui s'est tenu à Grenoble en 1970.

De longue date, des relations s'étaient établies entre l'Université, le C.N.R.S. et les industries régionales. Elles ont suscité la création d'entreprises nouvelles. On peut citer parmi bien d'autres :

- la Société d'Etudes et de Recherches Magnétiques (SERMAG) filiale d'Ugine-Allevard,
- la Société Anonyme des Machines Electrostatiques (SAMES),
- le Centre d'Etudes Cryogéniques de Sassenage, centre de l'Air Liquide,
- la Société "Le Moteur Linéaire", filiale de Merlin-Gérin.

C'est dans ce cadre que s'est développé peu à peu le CEN.G et la tradition déjà établie des relations Université-Industrie s'est tout naturellement étendue au nouveau Centre de Recherche créé par le C.E.A.

Liaisons Université-C.E.A.

A l'origine, le Directeur du Centre, le Professeur NEEL, exerçait, et il exerce encore, de très nombreuses fonctions à l'Université : Directeur des écoles d'ingénieurs, des laboratoires du C.N.R.S., Président de nombreux directoires et Comités Scientifiques. Son adjoint était un cadre supérieur à plein temps du Commissariat à l'Energie Atomique[1]. Ceci assurait d'emblée, au niveau de la Direction du Centre, une osmose totale entre le C.E.A., le C.N.R.S. et l'Université.

Cette conjonction Université-C.E.A. se retrouve dans la composition du Conseil Scientifique, créé spécialement pour harmoniser les relations avec l'Université. Ce conseil Scientifique rassemble le Haut Commissaire du C.E.A., sept directeurs centraux, le directeur du CEN.G et son adjoint et un nombre équivalent de professeurs de l'Université de Grenoble, conseillers scientifiques du CEN.G. Il se réunit une fois l'an. Il est saisi des projets de recherche proposés par la Direction du Centre, donne son avis sur l'intégration de ces projets dans le programme général du C.E.A., en propose d'autres, envisage les moyens et méthodes à mettre en oeuvre pour les poursuivre, les moyens étant naturellement, en définitive, attribués lors de la discussion annuelle du budget à Paris.

Une des liaisons les plus importantes est assurée par un certain nombre d'universitaires qui jouent le rôle de conseillers scientifiques et assument dans quelques disciplines la direction de laboratoires du CEN.G. Ces conseillers sont choisis pour leur compétence dans les spécialités qui intéressent le C.E.A. Certains d'entre eux participent, comme cela a été signalé précédemment, au Conseil Scientifique. Chaque laboratoire scientifique en possède un ou plusieurs et se trouve, de ce fait, plus ou moins lié à un ou plusieurs laboratoires universitaires.

(1) Récemment, M. le Professeur Néel est devenu Délégué du Haut Commissaire auprès du Centre d'Etudes Nucléaires de Grenoble, son adjoint, M. Balligand, a été nommé Délégué à la Mission Programmes d'Intérêt Général, M. Pascal a pris les fonctions de Directeur du Centre d'Etudes Nucléaires de Grenoble.

Parfois, les laboratoires universitaires se sont eux-mêmes installés au Centre. Il en est ainsi pour les laboratoires de Physique Nucléaires et de Chimie Nucléaire. Par contre, l'Université a construit sur un terrain adjacent au CEN.G un Institut des Sciences Nucléaires, doté d'un cyclotron à énergie variable jusqu'à 70 MeV autour duquel travaillent aussi bien les universitaires que les chercheurs du CEN.G.

En Biologie, la Faculté de Médecine, créée il y a quelques années à Grenoble, a obtenu l'accord du C.E.A. pour établir au Centre des laboratoires mixtes dirigés par des Professeurs de la Faculté de Médecine. Les disciplines suivantes y sont représentées : biologie cellulaires, biochimie, hématologie. Non seulement ces laboratoires profitent de la solide organisation du Centre, mais l'implantation de biologistes à proximité de physiciens, de chimistes, d'électroniciens, de spécialistes des radioisotopes, s'est révélée extrêmement fructueuse.

Deux autres laboratoires universitaires se sont également implantés au Centre : l'un de chimie organique physique, l'autre d'électrochimie organique analytique. Comme dans les cas précédents, les équipes sont presque en totalité composées d'universitaires. Sur un effectif total de 88 chercheurs, trois seulement appartiennent au C.E.A. Mais le programme scientifique de ces laboratoires est complètement intégré avec ceux des laboratoires de disciplines voisines du Centre. Là encore, le rendement de ces laboratoires a été multiplié grâce aux contacts scientifiques étroits noués entre chercheurs.

Un dernier exemple intéressant de liaisons complémentaires entre le C.E.A. et le C.N.R.S. est fourni par le laboratoire de Diffraction Neutronique. Un laboratoire de rayons X existait au C.N.R.S. L'installation au Centre de réacteurs de recherche, fournisseurs de neutrons, amena la création d'un laboratoire de diffraction neutronique. Le mariage entre les deux était évident et a donné d'excellents résultats. La mise à disposition en 1971 du Réacteur à Haut Flux de l'Institut Laue-Langevin donnera des prolongements bénéfiques à cette union.

Ces quelques exemples nous montrent la fécondité dans les deux sens des liaisons ainsi établies : les deux partenaires y trouvent avantage.

Comme nous l'avons déjà fait observer, les laboratoires du CEN.G hébergent un nombre élevé de chercheurs n'appartenant pas au personnel contractuel du C.E.A. Sur les 3 000 personnes recensées au CEN.G à la fin de 1970, il y a 1 625 agents proprement C.E.A. et plus de 1 400 personnes provenant de l'extérieur. Cet afflux de chercheurs non C.E.A. est assurément bénéfique pour le CEN.G. Il s'agit pour la plupart de jeunes gens venant de l'Université, d'écoles d'ingénieurs, de pays étrangers qui complètent nos propres équipes et assurent en permanence la jeunesse et le dynamisme nécessaire au corps des chercheurs. Dans les années passées, ils ont constitué une source de recrutement de grande valeur. A l'heure actuelle, le C.E.A. ne recrute plus; toutefois, pour assurer un renouvellement à la base, quelques contrats en nombre limité, peuvent être conclus pour une durée déterminée (un an renouvelable jusqu'à un maximum de cinq ans). Ils s'adressent à de jeunes scientifiques désireux de s'orienter dans la recherche fondamentale. Le Centre dispose, en outre, chaque année, d'une vingtaine de stages de longue durée (maximum un an) pour de jeunes universitaires ayant terminé leurs études, d'une vingtaine de bourses-thèses (durée de 3 à 5 ans, en moyenne) pour des jeunes gens préparant un doctorat d'état ou une thèse d'ingénieur-docteur. Enfin, un bon nombre de jeunes diplômés de l'Université travaillent au CEN.G sous contrat.

Ces séjours de plus ou moins longue durée qu'effectuent ces jeunes chercheurs au CEN.G constituent pour eux un excellent complément de formation avant leur orientation définitive vers la recherche ou l'industrie. En ce sens, l'on peut dire que le CEN.G joue un rôle d'"école d'application". Les avantages qu'en retire le CEN.G sont importants : 350 thèses d'état et de docteur-ingénieur ont été soutenues depuis la création du Centre. En permanence, chaque année, une centaine de thèses sont en préparation auxquelles s'ajoutent, en moyenne, cinquante thèses de troisième cycle.

Le CEN.G complète ses relations avec les laboratoires universitaires au moyen de contrats d'étude. Ces contrats, passés initialement avec l'Université de Grenoble, s'étendent maintenant à celles de Paris, Lyon, Strasbourg, Nancy, Nice. Nous comptons ainsi aujourd'hui une soixantaine de ces contrats universitaires. Leurs objets sont très divers. Ils permettent de faire faire à l'Université ou au C.N.R.S. des recherches fondamentales dont les résultats serviront de base à la progression de certaines recherches technologiques poursuivies au CEN.G.

En Biologie, ces contrats permettent d'intensifier les échanges avec la Faculté de Médecine et de faire progresser des recherches de grand intérêt. Citons l'étude de la morphologie des chromosomes dans les cas d'irradiation, l'étude des facteurs inducteurs de leucémie et de cancer chez les souris, l'étude des propriétés enzymatiques des membranes mitochondriales, etc.

En Electronique, la complexité des études est telle que, malgré la présence de solides équipes C.E.A., il est indispensable de faire appel à des équipes universitaires familiarisées avec certains domaines particuliers de la recherche : utilisation des cristaux liquides dans le domaine de la microélectronique, réalisations de couches minces épitaxiales sur silicium en vue de leur application à des circuits logiques intégrés très rapides, etc.

Réciproquement, ces contrats permettent de faire participer à nos recherches technologiques certains universitaires en leur donnant ainsi la possibilité de faire déboucher leurs recherches fondamentales sur des réalisations concrètes. Ces recherches concernent aussi bien des dispositifs d'irradiation que des réalisations électroniques ou des problèmes d'échange thermique : construction de la source froide du réacteur à haut flux, réalisation de cibles tritiées neutronigènes, usine de dessalement, générateurs d'électricité radioisotopique, etc.

A ce tableau des relations du CEN.G avec les laboratoires de l'Université, il convient d'ajouter les liaisons d'ordre personnel, les contacts humains qui s'établissent dans de nombreuses occasions : séminaires, soutenances de thèses, demandes de renseignements, fréquentation mutuelle des bibliothèques. Des ingénieurs du Centre, en moyenne une quarantaine par an, participent aux activités d'enseignement de l'Université de Grenoble sous des formes diverses : cours de spécialités à l'Ecole Nationale Supérieure d'Electronique et de Radioélectricité, à l'Institut Polytechnique, à l'Institut des Sciences Nucléaires ou encore, accueil au Centre, pour leurs travaux pratiques, des élèves des Instituts Universitaires de Technologie. Les rencontres fréquentes auxquelles elles donnent lieu sont à l'origine de collaborations fécondes.

Liaisons Industrie-CEN.G

Elles ont existé pour ainsi dire de fondation. En effet, dès la création du Centre, il a paru souhaitable d'associer à son développement un laboratoire de l'Institut Français du Pétrole. Aux termes du contrat qui liait l'I.F.P. et le C.E.A., ce laboratoire, qui compte actuellement une cinquantaine de personnes, devait consacrer 30 % de ses activités à des recherches radiochimiques pour le compte du C.E.A. Une telle collaboration s'est avérée des plus intéressantes par les résultats obtenus : mise au point de graisses résistant à l'effet dégradant des rayonnements, de polymères thermostables et radiorésistants. Cette première implantation au CEN.G d'un laboratoire extérieur au C.E.A. préfigurait une des formes que devaient prendre les liaisons CEN.G/Industrie.

Les premières manifestations de ces liaisons se sont cantonnées à des activités purement nucléaires et se traduisirent par des contrats d'études avec des organismes publics comme EURATOM, la Délégation Générale à la Recherche Scientifique et Technique, la Direction des Recherches et Moyens d'Essais des Armées. De ces contrats devaient naître les premiers contacts industriels.

Très rapidement, la Direction et les laboratoires du CEN.G se rendaient compte de l'importance que représentait pour l'extérieur le potentiel scientifique du Centre en chercheurs et en matériel et s'attachaient à apporter leur soutien, tant aux organismes publics de recherche qu'à l'industrie nationale.

C'est ainsi que, très tôt, quoique ce ne fût pas alors reconnu officiellement comme une mission du C.E.A., le CEN.G a commencé à travailler pour des organismes n'ayant pas de vocation ou d'intérêt nucléaire. Il était, en effet, apparu très intéressant de le faire quand les deux conditions suivantes étaient réunies simultanément :

- quand le CEN.G se trouvait bien placé pour mener une étude grâce à l'expérience acquise, les brevets pris, l'équipement scientifique disponible, mais ne pouvait y consacrer les moyens suffisants pour la voir aboutir assez rapidement ou lui donner l'envergure nécessaire,
- quand cette même étude intéressait un organisme extérieur sans que celui-ci ait l'envie ou la possibilité de créer le groupe de recherche correspondant.

Comme il n'existait pas de doctrine officielle en la matière, le CEN.G eut toute latitude pour rechercher les formes les mieux adaptées à son action.

Ce furent d'abord des contrats ordinaires dont le contenu demeurait très variable, allant de la simple étude dans un domaine déterminé à l'accueil d'une équipe complète de l'industrie venant se former pour assurer le développement ultérieur d'une réalisation. Une autre formule rencontra rapidement la faveur de nos partenaires. L'industriel, venu pour traiter une question, découvre bien souvent que le Centre est en mesure de résoudre bien d'autres problèmes qui l'intéressent. La solution consiste alors dans la rédaction d'un contrat-cadre comportant fréquemment l'implantation au CEN.G d'un laboratoire de recherche de la société contractante. Nous en avons une dizaine actuellement dans les domaines les plus variés : bâtiment, pétrole, chimie, électronique. L'objet de ces contrats-cadres reste très général mais permet de fixer les modalités générales d'accord (location de locaux, problèmes de responsabilité civile, d'assurance, de propriété industrielle). Chaque action précise envisagée fait ensuite l'objet d'un contrat particulier.

Une nouvelle étape va être franchie sous peu avec la constitution de groupements d'intérêt économique associant encore plus étroitement l'industrie au développement de certaines techniques du CEN.G, notamment dans le domaine des composants électroniques. La transformation en Sociétés Anonymes de certains secteurs d'activité, déjà largement tournés vers l'extérieur, est même envisagée.

La recherche des contractants est laissée à l'initiative de chaque laboratoire, la Direction du Centre intervenant au stade de la décision, la décision finale étant, bien entendu, prise au niveau national dans un souci d'homogénéité avec les actions des autres Centres. La grande diversité des activités du CEN.G lui permet d'aborder toute la gamme des problèmes industriels. Souvent le problème posé nécessite l'intervention de plusieurs laboratoires. Il n'est pas rare, dans ce cas, de trouver réunis autour d'une même table sept à huit chefs de laboratoires, animés du même esprit d'équipe, pour résoudre au mieux l'affaire présentée.

Du point de vue financier les termes des contrats sont variables. Ils prévoient, soit le financement total, soit un financement partiel par le contractant du CEN.G. En règle générale, il n'est pas admis un financement extérieur inférieur à 50 % et encore cette règle n'est-elle valable que pour des organismes publics comme la Délégation Générale à la Recherche Scientifique et Technique. Chaque contractant stipule la façon dont sera partagée la propriété des brevets. Ce partage se fait selon une double considération :

- champ d'application des brevets,
- participation au financement du contrat.

Il convient de noter que le laboratoire chargé de l'étude d'un problème posé par un industriel effectue à ses propres frais les recherches préliminaires, ce que nous pourrions appeler l'étude de "feasibility". Le contractant ne commence à payer que lorsque le choix du procédé est parfaitement défini. S'il s'agit de la réalisation d'un appareil, notre action s'arrête à la livraison du prototype. Nous laissons à notre contractant le soin d'en assurer le développement industriel. Notre rôle n'est pas, en effet, de concurrencer l'industrie mais, au contraire, de l'aider à développer et acquérir des techniques de pointe ou encore à bénéficier des résultats des recherches de base obtenues au CEN.G.

L'un des aspects originaux de cette collaboration avec l'industrie ou, plus exactement, de cette "valorisation de la recherche", est qu'elle touche les domaines les plus variés.

Notre service des Transferts Thermiques a pu très facilement faire bénéficier les études de dessalement par distillation des compétences qu'il avait acquises dans les études menées sur le refroidissement des réacteurs à eau. Dans ce domaine, il a certainement contribué pour une part importante aux études concernant la fourniture au Koweït d'une usine de 113 000 m^3/jour. Les essais du pilote ont été menés en liaison très étroite avec l'industrie dans la station d'essais que le C.E.A. a installée sous contrat avec la Marine Nationale dans l'Arsenal de Toulon.

Ce service a également de nombreux contrats avec l'industrie pétrolière et chimique pour des problèmes de transfert de chaleur dans le génie chimique en application directe des recherches qu'il poursuit sur les échanges en "lit dense".

Le génie biomédical constitue un domaine de choix pour la valorisation de la recherche. La présence au Centre de biologistes, chimistes, physiciens, électroniciens nous permet d'aborder des problèmes tels, entre autres, que les détecteurs d'hémorragie pour rein artificiel, la mesure des débits sanguins, la stérilisation en milieu hospitalier, les coeurs artificiels.

En agronomie, des études conduites en liaison avec les spécialistes de la Société Nationale des Pétroles d'Aquitaine ont permis de trouver en emploi au D.M.S.O. (diméthyl-sulfoxyde), sous-produit du gaz de Lacq, comme agent facilitant l'assimilation des engrais dans les espaces de grande culture.

La technologie industrielle se montre également un secteur privilégié. Nous traitons pour le compte de sociétés d'"engineering" ou d'industries spécialisées des problèmes aussi divers que les mesures de température, d'épaisseur de revêtement, de rugosité en continu, sans contact sur des lignes de traitement de bande d'acier dans les laminoirs, la polymérisation de peintures sous rayonnement, la mesure de l'humidité dans les corps gras, etc.

Le cas du Laboratoire d'Electronique et de Technologie de l'Informatique (LETI) est sans doute la meilleure illustration de cette collaboration.

Pour développer au profit des chercheurs l'instrumentation la plus adéquate et en assurer la maintenance, il avait été créé dès l'origine du Centre, un service d'électronique. Ses activités l'ont amené à tirer le meilleur parti des composants nouveaux apparus sur le marché, que ce soit en électronique nucléaire ou en instrumentation générale et, même, à participer à l'évolution des nouvelles technologies comme l'électronique intégrée (microélectronique).

Ce service a progressivement consacré une part de plus en plus importante de son potentiel à des activités de recherche dont l'intérêt débordait le cadre de la seule électronique nucléaire, à la suite de contrats passés avec des organismes publics ou privés que des travaux intéressaient. Pour consacrer cet état de fait et l'encourager, nous avons obtenu la création, il y a 3 ans, du Laboratoire d'Electronique et de Technologie de l'Informatique qui regroupe, autour de notre ancien service d'électronique, divers laboratoires de recherche interdisciplinaires dont l'un est notamment constitué avec l'Institut de Mathématiques Appliquées de l'Université de Grenoble.

Grâce à une large autonomie de gestion, le LETI peut discuter et négocier des contrats de recherche, recruter le personnel contractuel nécessaire à leur exécution, accueillir sous contrat des équipes de recherche appartenant à d'autres organismes publics ou privés. Un contrôle "a posteriori" est assuré par un Conseil de Gestion qui se réunit deux fois par an afin d'examiner les aspects administratifs et financiers de la gestion des contrats.

Cette grande souplesse d'action lui a permis de donner une grande expansion à son programme orienté vers l'étude des composants électroniques, mémoires et circuits logiques ainsi que vers les études d'automatisme, d'informatique et d'instrumentation. Depuis peu, deux activités nouvelles ont pris une grande importance : la magnétométrie des champs faibles et la cristallogenèse, synthèse et étude de matériaux nouveaux. Dans tous ces domaines, un réseau de liens contractuels ou de simple collaboration a été tissé avec la plupart des grandes administrations et des industries de l'électronique (plus de quarante).

Arrivé à ce stade de collaboration, la définition des axes de recherche prend une grande importance. Il est nécessaire d'associer à leur élaboration les représentants des principaux organismes avec lesquels nous travaillons. Les grandes orientations des programmes du LETI sont ainsi définies, une fois par an, par un Conseil Scientifique auquel participent, outre des personnalités scientifiques du C.E.A., le Directeur de la Délégation Générale à la Recherche Scientifique et Technique, le Délégué à l'Informatique, le Directeur des Recherches et Moyens d'Essais des Armées, le Président de la Fédération Nationale des Industries Electroniques.

Les résultats de cette "valorisation de la recherche" sont significatifs. En 1970, les rentrées budgétaires engendrées par l'ensemble des quelque 150 contrats passés avec l'extérieur se sont élevés à plus de 20 millions de francs, soit 21 % du budget du CEN.G, main d'oeuvre comprise.

L'effort fait par le CEN.G pour coopérer avec l'industrie non nucléaire a été bientôt remarqué ; ses représentants ont été appelés à collaborer à une organisation locale "Association pour la Zone Industrielle Scientifique et Technique de Grenoble" qui s'est fixé pour objectif de faire passer dans l'industrie les brevets et connaissances acquises en technologie avancée dans les organismes de recherche de la région.

Coopération Internationale

Le CEN.G participe, bien entendu, à l'effort de coopération mené par le Commissariat à l'Energie Atomique avec d'autres pays, effort qui se concrétise par l'envoi d'experts en mission, l'échange d'informations, l'accueil de stagiaires, parfois même de dons de matériel.

Il s'agit, le plus souvent, d'actions isolées limitées dans le temps : faute de moyens suffisants en matériel et en personnel, de programme à long terme, le pays intéressé ne peut tirer tout le bénéfice de l'échange. Toutefois, nous avons pu, dans plusieurs cas, établir des liens étroits et durables avec des organismes étrangers, profitables aux deux parties. L'origine en est toujours modeste ; la coopération a débuté par une simple mission destinée à une aide déterminée sur un problème concret. La poursuite du programme a permis aux chercheurs de nouer des liens personnels et spontanés ; la coopération s'est amplifiée et fait l'objet d'un échange permanent d'informations et d'hommes qui se connaissent. Le succès est incontestable. Il semble que l'on ait mis en place une collaboration durable, sinon définitive.

Notre but a été d'assurer un "suivi" dans la politique d'échange et d'essayer, en quelque sorte, de créer des liens permanents entre laboratoires en mettant sur pied le système de "laboratoires frères" que l'on a bien souvent prôné sans y parvenir. Il nous semble d'ailleurs que l'instauration de ces liens ne nécessite pas une aide matérielle énorme mais plutôt beaucoup d'assiduité et de bonne volonté des deux côtés.

Au Brésil, un groupe mixte franco-brésilien de physiciens du solide, dénommé "GRESIL" (Grenoble + Brésil) a été créé à la suite d'une mission d'un de nos professeurs conseillers et du séjour à Grenoble, depuis 5 ans, d'un éminent professeur de chimie nucléaire de Belo Horizonte. Les jeunes chercheurs français qui y participent sont détachés au Brésil durant leur temps de service national (ex-service militaire) après avoir été stagiaires ou boursiers au CEN.G ou au C.N.R.S. Des échanges continus se développent entre ce groupe et notre laboratoire de physique du solide à l'occasion de missions, de stages de chercheurs brésiliens au CEN.G. La base de la réussite vient de l'intégration de chercheurs brésiliens et français dans une même équipe.

Un processus du même ordre s'amorce avec d'autres villes du Brésil (Rio de Janeiro, Belo Horizonte) et avec d'autres pays d'Amérique Latine (Argentine, Pérou).

Avec l'Uruguay, dans un cadre similaire, les ingénieurs de Grenoble apportent un concours actif, sous forme de conseils au développement du nouveau Centre Atomique de Montevideo.

Le Maroc offre également un exemple de coopération intéressante à la suite de l'envoi dans ce pays, par l'intermédiaire de l'A.I.E.A., d'un expert du laboratoire de biologie végétale du CEN.G. Cet expert avait pour mission de prêter son concours à la planification et à l'exécution d'un programme d'étude sur la nutrition minérale des agrumes. Ce programme a conduit l'expert à utiliser au Maroc des techniques mises au point à Grenoble et à faire appel à ses collègues de laboratoire. Un climat favorable s'est créé et un groupe d'universitaires et de chercheurs marocains s'est formé pour poursuivre l'étude du problème en liaison avec Grenoble. Cette opération qui avait un but précis, obtenir une meilleure connaissance de la physiologie des arbres fruitiers au Maroc, a non seulement profité au Maroc, mais aussi au laboratoire de biologie végétale du CEN.G qui a pu mettre à l'épreuve sur un problème concret la valeur de ses méthodes et de son expérience.

Conclusion

En conclusion, le Centre d'Etudes Nucléaires de Grenoble constitue aujourd'hui un organisme de recherche polyvalent dont les structures mixtes C.E.A.-Université-Industrie sont bien adaptées au développement harmonieux de la recherche fondamentale et appliquée dans la région. Ses activités intéressent, non seulement le secteur des applications nucléaires, mais, en réalité, l'ensemble de l'économie. La part de son activité qu'il consacre à la recherche fondamentale contribue à vivifier l'ensemble et à créer une large plate-forme de rencontre, indispensable à la création et à l'entretien de liens étroits avec les autres organismes extérieurs de recherche, qu'ils soient français ou étrangers.

Il se trouve que cette action d'ouverture et de valorisation de la recherche réunies par le CEN.G vient d'être officiellement recommandée au C.E.A. En effet, par le nouveau décret du 29 septembre 1970, le C.E.A. peut "dans les limites fixées par le gouvernement, prolonger certaines de ces activités de recherche et de développement dans des domaines non nucléaires soit à des fins économiques soit en vue de participer à des programmes d'intérêt général".

Dans la nouvelle organisation de l'état-major du C.E.A., qui comprend sept délégations, deux d'entre elles sont chargées :

- l'une des programmes de coopération industrielle non nucléaire,
- l'autre des programmes d'intérêt général.

Elles doivent accentuer la mise à la disposition de l'extérieur des moyens du C.E.A. et développer des actions de coopération avec l'industrie non nucléaire et avec les grands organismes d'état : Université, CNEXO, Ministère de l'Environnement, etc.

DISCUSSION ON AGENDA ITEM 5.4.

Organization of national atomic energy commissions and their relationship with other bodies and institutions

DISCUSSION ON THE FOLLOWING PAPER:

P/166 Canada Presented by D.G. Hurst

E. MAURER: I have two questions that I should like to ask Mr. Hurst about the new Canadian law on liability for a nuclear incident. Firstly, under United States law if a nuclear incident occurs in the United States of America, damage in Canada is also covered and is compensable. If a nuclear incident should occur in a nuclear installation in Canada, would damage occurring in the United States be covered under the new Canadian law?

D.G. HURST: Under the Act an operator is not liable for any injury or damage occasioned outside Canada unless there is an arrangement between Canada and the other country. An arrangement may be made when the other country has satisfactory provisions for compensation for injury and damages in Canada.

E. MAURER: My second question relates to the availability of $75 million as cover for a nuclear incident, with the possibility of more being made available under further procedures. Could you give us some idea of the procedures for making more than $75 million available?

D.G. HURST: When the Governor in Council is of the opinion that the liability of an operator could exceed $75 million, a commission will be established to deal with claims for compensation. Compensation in excess of $75 million will require authorization by Parliament.

DISCUSSION ON THE FOLLOWING PAPER:

P/417 FRG Presented by G. Schuster

D.E.H. PEIRSON: How does the Federal Ministry for Education and Science determine what proportions of its budget should be allocated for different purposes, for example nuclear energy and space?

G. SCHUSTER: First of all, the relevant Departments of the Ministry for Education and Science develop their proposals for the programs and projects (including alternatives) in close collaboration with advisers to Science and Industry.

Then teams of experts, particularly in the Research Centres of Jülich and Karlsruhe, and the planning group within the Ministry, make available on request something approaching a systems analysis or cost-benefit analyses.

Finally, the Minister, together with his three State Secretaries, and aided by the planning group of the Ministry, evaluate the proposals and make the final decision as to how the different departments and programs are to be funded, paying particular regard to the question of benefits to society and the political demarcation.

E. SAELAND: Could Mr. Schuster comment further on efficiency control. Who exercises it, for example; what are the criteria employed to measure efficiency, and what has been learnt from experience?

G. SCHUSTER: In evaluating research institutions as a whole, profitable use can be made of characteristic figures. Characteristic figures that are useful for planning as well as for control are, for example: the ratio between graduate staff and the total staff of a research facility, the per capita expenditure on personnel and equipment, the extent to which experimental and research facilities are used, the ratio between expenditure and operating costs, capital expenditure per employee and the share of infrastructure costs in the total costs.

Similar ideas have been developed within OECD, and Mr. King has presented a very valuable report in this connection.

Efficiency control comprises both internal and external control, and is thus exercised at several levels of responsibility. Internal efficiency control ("self-control") has naturally to be exercised by the working units themselves and the staff responsible for them.

With respect to research and development programs which are supported by public funds, external control has to be exercised by the Government or the competent supervisory bodies, or by self-administering organizations.

A further method of efficiency control is project control by project committees. Project committees observe and control the most important projects in the field of nuclear development. They consist of persons working on the project, as well as of representatives of the partners concerned at the national and international levels and of the sponsoring Ministry. It is very important that the efficiency control should not be used as a repressive instrument.

F.C. BOYD: Mr. Schuster, I believe you stated that in your research organizations provision is made for the research staff to participate in decision-making. If this is so, could you elaborate a little on how this is done?

G. SCHUSTER: The participation of scientists and technicians in the decision-making process takes place at two levels.

Firstly, decisions on the programs and projects of the nuclear research centres have to be taken in deliberations between both the administrative and the technical managers and the Scientific Councils. Members of the Scientific Councils are the directors of the institutes. Scientists and technicians of the centre who have been elected by their colleagues make up one third of the number of members.

Secondly, close collaboration has been established at the institute between its directors and their collaborators within the so-called "institute council".

I am afraid that time does not allow me to go into further details.

DISCUSSION ON THE FOLLOWING PAPER:

P/326 Hungary Presented by F. Szabo

There was no discussion on this paper.

DISCUSSION ON THE FOLLOWING PAPER:

P/169 Italy Presented by C. Salvetti

V.A. SARABHAI: The development of reactors for industry and utilities by one agency and of the fuel cycle by another might lead to chaotic conditions. Initiatives in atomic energy have a long period of gestation (5-10 years) and I suggest that it is desirable to have a single authority that can plan for 10-15 years in all aspects of atomic energy. That is how we have decided to organize the nuclear sector in India, where the AEC has overall responsibility.

C. SALVETTI: I was referring to Western European conditions, where one has to take into account the existence of the three components: governmental organizations (atomic energy commissions), the manufacturing industry and the utilities. My remarks obviously do not apply to countries such as India. In the context of Indian conditions I would agree with Mr. Sarabhai's remarks, but I am sure he agrees that such conditions are substantially different from those in the United States of America or Western Europe.

E. MAURER: I was intrigued by Mr. Salvetti's comparison between the nuclear energy industry and the motor industry and the recommendation that more matters be left to the discretion of the industry. In the United States we have seen the increasing intrusion of the people, for example Nader's raiders, in the development of safety standards and pollution standards. Could Mr. Salvetti comment on this element of the regulatory process in Italy?

C. SALVETTI: In my brief comments I stressed the importance of the regulatory functions of atomic energy commissions; as far as Italy is concerned, safety aspects, ecology, radiation problems and environmental and related matters will take a predominant place among the tasks of CNEN.

J.I. VARGAS: Being a professor himself, Mr. Salvetti perhaps felt that the relationship between the CNEN and the universities in Italy was too obvious to comment upon. I should be grateful if he would say a few words on the subject.

C. SALVETTI: University professors are well represented in our Commission, and university activities are not overlooked. CNEN is currently sponsoring specialized post-graduate courses at various Italian universities. Moreover, it awards research contracts to academic institutions; some engineering schools (such as those of Pisa and Milan) are currently engaged in a number of activities, mainly connected with reactor safety, under CNEN contracts.

A significant example of cooperation with universities is the work in progress at Montecuccolino (Bologna) in the field of experimental reactor physics (including the operation of three zero-power critical facilities). The work is jointly sponsored by the University of Bologna and CNEN.

P. BALLIGAND: Mr. Salvetti has already stated his intention of being provocative. I think he will admit that atomic energy commissions cannot withdraw completely from reactor development research and leave everything to the manufacturer by analogy with the motor industry. The construction of even a small prototype reactor entails a substantial investment.

In France the present policy is to arrange close cooperation between the CEA, Electricité de France and industry right from the start of a project and to make the maximum use of CEA resources and equipment. Occasionally an existing CEA centre may be used to provide an initial site, as in the case of PHENIX.

C. SALVETTI: I did not say that atomic commissions should withdraw from reactor development.

I agree that, as in France, the Commission, the utilities and industry must work together: discussion may eventually concern the role of the different partners and their respective responsibility in bringing reactors to full industrial maturity.

It is not my view that CNEN should not be involved at all in this fundamental task. I only wanted to draw attention to the problem of selecting the tasks reserved to CNEN in reactor development.

As an example, I would refer to the fast breeder program: CNEN, instead of embarking itself on the costly task of building an FBR prototype, has decided to construct a fast fuel test facility (PEC reactor) and so provide a useful tool for our nuclear industry.

I want to reaffirm that in my view the present role of an atomic energy commission is to promote the steady and safe development of nuclear energy and to contribute directly to it.

J. SPITALNIK: I should like to say a few words on how nuclear research has been tackled in a developing country, namely Uruguay.

We have heard today that a wisely formulated nuclear program based on self-help will contribute effectively to the introduction of modern technology in a country. In that context a group of Uruguayan technicians, scientists and engineers has designed a research reactor that will have a capacity of 1 MW(th). In this way the group has gained confidence in its own judgement, and has thus succeeded in creating a source of competent and reliable advice in the country. This is very important if development is to proceed at a high level of quality.

As regards international or bilateral assistance, it should be stressed that the investment of the countries granting assistance will be used more efficiently if developing countries have themselves made the initial effort to introduce in a thorough and competent manner the technology concerned, in this case nuclear technology. Experience has shown that the sudden injection of an advanced technology into a country unprepared to assimilate it entails the importation of foreign staff on a large scale to ensure the success of the project. Conditions of underdevelopment are thereby prolonged, and that should be borne in mind when technical cooperation is being planned.

DISCUSSION ON THE FOLLOWING TWO PAPERS:

P/108 Uruguay

P/638 France

There was no discussion on these papers.

AGENDA ITEM 5.5

International cooperation in nuclear projects
and exchange of information

Coopération internationale dans des entreprises nucléaires
et échange de documentation

Международное сотрудничество в осуществлении ядерных
проектов и обмене информацией

Cooperación internacional en proyectos nucleares
e intercambio de información

Chairmen

B. GOLDSCHMIDT, France (First Session)
J. M. OTERO, Spain (Second Session)

Vice-Chairman

F. MALU, Democratic Republic of the Congo (Second Session)

Scientific Secretaries

H. T. DAW, IAEA (Both Sessions)
Y. NISHIWAKI, IAEA (Both Sessions)

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THE ROLE OF INTERNATIONAL COOPERATION IN PROMOTING THE DEVELOPMENT OF THE PEACEFUL USES OF NUCLEAR ENERGY

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Abstract–Résumé–Аннотация–Resumen

THE ROLE OF INTERNATIONAL COOPERATION IN PROMOTING THE DEVELOPMENT OF THE PEACEFUL USES OF NUCLEAR ENERGY.

International cooperation in the peaceful uses of the atom has been developing since 1953 when President Eisenhower proposed to the United Nations General Assembly an Atoms for Peace Program. The manner in which the technically advanced countries have shared nuclear technology and information among themselves and with the developing countries has been unprecedented. International arrangements have been a crucial factor in the exchange of technical and scientific information, supply of nuclear material and equipment, and financing of power plants. The United States role in these international arrangements is described. Technical and scientific information has been shared through visits and participation in conferences, provision of training opportunities, presentation of exhibits, and technical exchange arrangements. The fields covered by the information exchanges include the use of radioisotopes in agriculture, medicine, industry and research, food irradiation, insect eradication, high-energy physics, nuclear desalination, etc. Through technical information exchange arrangements covering light-water reactors, advanced converters, and fast reactors, duplication of effort has been avoided and economies obtained. Many nations have necessarily relied on international arrangements for nuclear equipment and materials for the many varied nuclear applications. Irradiators have been loaned; various types of laboratory equipment, ranging from isotopic standards to mobile isotope laboratories, have been provided; and research contracts have been negotiated. Nuclear fuel for research and power reactors has been made widely available to cooperating partners on a nondiscriminatory basis under safeguards. Loans from national and international lending institutions play an important role in the development of nuclear power, especially in the developing and less industrialized nations. The United States Export - Import Bank has been providing loans for the construction and fuelling of nuclear power plants abroad and, by the end of 1970, had authorized approximately 25 projects involving United States-supplied materials and equipment. In the nuclear power area, the nature of cooperative relationships has been changing. especially among the developed countries. Cooperative activities have become more commercial in character, especially in reactor manufacture and in fuel-supply services. Governments still set overall policies and negotiate covering agreements for cooperation. Day-to-day activities, however, are conducted on an industry-to-industry basis. Greater activity on the part of governments is still required, however, in the case of developing countries. The developed countries, therefore, continue to provide substantial information and assistance directly and through the International Atomic Energy Agency. The IAEA has become the focal point for international nuclear cooperation, because of its global involvement in many areas, including radiation applications in agriculture and medicine, the effective use of research reactors, desalination studies, the exchange of information on nuclear power, and the establishment of international research centres, such as the laboratories at Seibersdorf and at Monaco and the International Centre for Theoretical Physics at Trieste.

LE ROLE DE LA COOPERATION INTERNATIONALE DANS LE DEVELOPPEMENT DES UTILISATIONS PACIFIQUES DE L'ENERGIE NUCLEAIRE.

La coopération internationale pour les utilisations pacifiques de l'atome s'est développée depuis qu'en 1953 le Président Eisenhower a proposé à l'Assemblée générale des Nations Unies un programme d'utilisation pacifique de l'atome. La manière dont les pays techniquement avancés ont mis en commun leur technologie

nucléaire et ont partagé les informations acquises, entre eux ainsi qu'avec les pays en voie de développement, a été sans précédent. Les accords internationaux ont été un facteur crucial pour l'échange d'informations scientifiques et techniques, la fourniture d'équipements et de matériaux nucléaires et le financement des centrales nucléaires. Le rôle des Etats-Unis d'Amérique dans ces accords internationaux est décrit. Des informations scientifiques et techniques ont été mises en commun par des visites et des participations à des conférences, par la création de possibilités de stages, la présentation d'expositions et des accords d'échanges techniques. Les domaines couverts par les échanges d'information comprennent l'utilisation des radioisotopes dans l'agriculture, la médecine, l'industrie et la recherche, l'irradiation des aliments, l'éradication des insectes, la physique des hautes énergies, le dessalement nucléaire de l'eau de mer. Par les accords portant sur l'échange d'informations techniques relatives aux réacteurs à eau légère, aux convertisseurs de pointe et aux réacteurs rapides, une duplication des efforts a été évitée et des économies ont été réalisées. De nombreuses nations ont forcément compté sur les accords internationaux pour leurs équipement et leurs matériaux nucléaires, nécessaires aux applications nombreuses et variées de l'énergie nucléaire. Des dispositifs d'irradiation ont été prêtés; divers types d'équipements de laboratoire, allant des échantillons d'isotopes jusqu'aux laboratoires mobiles, ont été fournis; et des contrats de recherche ont été négociés. Du combustible nucléaire pour les réacteurs de recherche et de puissance a été mis largement à la disposition des partenaires de la coopération sur une base non discriminatoire respectant les garanties. Des prêts accordés par des organismes de prêt nationaux et internationaux ont joué un rôle important dans le développement de la production d'énergie d'origine nucléaire, particulièrement pour les nations en voie de développement et moins industrialisées. La Banque américaine import-export a fourni des prêts pour la construction et l'approvisionnement en combustible de centrales nucléaires à l'étranger, et, à la fin de 1970, elle avait approuvé environ 25 projets impliquant la fourniture par les Etats-Unis de matières et d'équipement. Dans le domaine de la production nucléaire d'énergie, la nature des relations de coopération a changé, surtout entre pays développés. La coopération a pris une tournure plus commerciale, en particulier en ce qui concerne la fourniture de réacteurs et de combustible. Les gouvernements certes établissent les règles générales et négocient les accords de coopération. Mais les activités au jour le jour sont menées d'industrie à industrie. Une plus grande activité, cependant, est encore exigée des gouvernements dans le cas des pays en voie de développement. Les pays développés continuent donc à fournir des informations et une assistance importante, directement et par l'intermédiaire de l'Agence internationale de l'énergie atomique. L'AIEA est devenue le foyer de la coopération nucléaire internationale, avec ses activités globales dans de nombreux domaines tels que les applications des rayonnements à l'agriculture et à la médecine, l'utilisation efficace des réacteurs de recherche, les études sur le dessalement de l'eau de mer, l'échange d'informations sur la production nucléaire d'énergie et l'installation de centres internationaux de recherche tels que les laboratoires de Seibersdorf et de Monaco et le Centre international de physique théorique de Trieste.

РОЛЬ МЕЖДУНАРОДНОГО СОТРУДНИЧЕСТВА В СОДЕЙСТВИИ РАЗВИТИЮ МИРНОГО ИСПОЛЬЗОВАНИЯ ЯДЕРНОЙ ЭНЕРГИИ.

Международное сотрудничество в области мирного использования атома стало осуществляться с 1953 года, когда президент Эйзенхауэр предложил Генеральной Ассамблее ООН программу "Атомы для мира". Тот путь, по которому развитые в техническом отношении страны стали обмениваться между собой и с развивающимися странами достижениями в области ядерной техники и информацией, является беспрецедентным. Заключение международных соглашений явилось решающим фактором в обмене технической и научной информацией, поставке ядерных материалов и оборудования и финансировании энергетических установок. В докладе говорится о роли США в этих международных мероприятиях. Обмен научно-технической информацией осуществлялся путем визитов и участия в конференциях, предоставления возможностей для стажировки, проведения выставок и мероприятий по техническому обмену. Обмен информацией осуществлялся по таким вопросам, как использование радиоизотопов в сельском хозяйстве, медицине, промышленности и исследованиях, облучение пищевых продуктов, уничтожение вредных насекомых, физика высоких энергий, опреснение с помощью атомной энергии и др. Мероприятия по обмену технической информацией по реакторам на обычной воде, усовершенствованным реакторам-конверторам и реакторам на быстрых нейтронах позволили избежать дублирования в работе и достичь экономического эффекта. Многим странам неизбежно пришлось полагаться на международные соглашения по поставке ядерного оборудования и материалов для различных аспектов ядерного применения. Предоставлялись займы на приобретение излучателей; поставлялось различных типов лабораторное оборудование: от изотопных стандартов до передвижных изотопных лабораторий; проводились переговоры о заключении исследовательских контрактов. Сотрудничающим партнерам широко предоставлялось ядерное топливо для исследовательских и энергетических реакторов. Поставка осуществлялась на равноправной основе при соблюдении гарантий. Предоставление займов национальными и международными кредитными учреждениями играет важную роль в развитии ядерной энергетики, особенно в развивающихся и менее индустриально развитых странах. Экспортно-импортный банк США предоставляет займы на строительство и топливо для атомных электростанций за границей и к концу 1970 года санкционировал около 25 проектов, включающих поставку Соединенными Штатами материалов и оборудования. В области ядерной энергетики характер связей по сотрудничеству претерпевает изменения, особенно среди развитых стран. Сотрудничество стало носить более коммерческий характер, особенно в области строительства реакторов и оказания услуг по поставке топлива. Правительства все еще определяют общую политику и ведут переговоры о заключении соглашений о сотрудничестве. Повседневная деятельность осуществляется на основе промышленность – промышленности. Однако, со стороны правительств необходима бо́льшая активность по отношению к развивающимся странам. Поэтому развитые страны продолжают предоставлять обширную информацию и оказывать помощь непосредственно или через Международное агентство по атомной энергии. МАГАТЭ стало центральным учреждением по международному сотрудничеству в области атомной энергии в связи с тем, что его деятельность охватывает в мировом масштабе многие области, включая применение излучений в сельском хозяйстве и медицине, эффективное использование исследовательских реакторов, работы по опреснению, обмен информацией по ядерной энергетике, а также создание таких международных исследовательских центров, как лаборатории в Зайберсдорфе и Монако, Международный Центр теоретической физики в Триесте.

FUNCION DE LA COOPERACION INTERNACIONAL PARA PROMOVER EL DESARROLLO DE LAS APLICACIONES PACIFICAS DE LA ENERGIA NUCLEAR.

La cooperación internacional en las aplicaciones pacíficas de la energía atómica se viene desarrollando desde el año 1953 en que el Presidente Eisenhower propuso a la Asamblea General de las Naciones Unidas el «Programa de Atomos para la Paz». La manera en que los países técnicamente adelantados han compartido la tecnología y la información nucleares entre sí y con los países en desarrollo, no tiene precedentes. Los convenios internacionales han desempeñado un papel decisivo en el intercambio de información técnica y científica, suministro de equipo y materiales nucleares, y financiamiento de plantas de potencia. Esta memoria describe el papel que los Estados Unidos han representado en estos convenios internacionales. La información técnica y científica se ha compartido por medio de visitas y participación en conferencias, creación de oportunidades para la formación especializada, presentación de exhibiciones, y convenios de intercambio técnico. Los campos abarcados por los intercambios de información incluyen el empleo de radioisótopos en agricultura, medicina, industria e investigación, la irradiación de alimentos, la erradicación de insectos, la física de las altas energías, la desalación nuclear, etc. Por medio de convenios de intercambio de información técnica, que abarcan a los reactores de agua ligera, convertidores avanzados y reactores rápidos, se ha obtenido grandes economías y se han evitado duplicaciones de esfuerzos. Numerosas naciones han contado necesariamente con los convenios internacionales para aprovisionarse de equipos y materiales nucleares para muchas y variadas aplicaciones nucleares. Se han concertado préstamos de irradiadores y proporcionado diversos tipos de equipo de laboratorio, que van desde muestras isotópicas hasta laboratorios móviles de isótopos, e igualmente, se han negociado contratos de investigación. Sobre una base no discriminatoria relativa a las salvaguardias, se han suministrado a las partes de los acuerdos de cooperación, considerables cantidades de combustibles nucleares para investigación y reactores de potencia. Los préstamos facilitados por instituciones nacionales e internacionales de crédito desempeñan un papel importante en el desarrollo de la energía nuclear, especialmente en las naciones en desarrollo y menos industrializadas.
El Banco de Importación y Exportación (Export-Import Bank) de los Estados Unidos ha facilitado préstamos para la construcción y aprovisionamiento de combustible de centrales nucleoeléctricas en otros países; hasta finales de 1970, había autorizado aproximadamente 25 proyectos que suponían suministros de materiales y equipos de los Estados Unidos. En el sector de la energía nucleoeléctrica, el carácter de las relaciones de cooperación ha sufrido cambios, especialmente entre los países en desarrollo. Las actividades cooperativas han adquirido un carácter más comercial, especialmente en lo que se refiere a la fabricación de reactores y a los servicios de suministro de combustible. Los Gobiernos siguen estableciendo la política general y negociando los acuerdos de cooperación, pero las actividades ordinarias se llevan a cabo por medio de contactos directos entre las industrias. A pesar de todo ello, en el caso de países en desarrollo, es todavía necesaria una mayor actividad por parte de los Gobiernos. Los países desarrollados, por consiguiente, continúan suministrando importantes informaciones y ayudas, bien directamente o a través del Organismo Internacional de Energía Atómica. El OIEA ha llegado a ser el punto clave de la cooperación nuclear internacional con su implicación global en numerosos sectores, incluyendo las aplicaciones de las radiaciones en la agricultura y la medicina, el empleo eficaz de reactores de investigación, los estudios de desalación, el intercambio de información sobre energía nuclear y el establecimiento de centros internacionales de investigación tales como los laboratorios de Seibersdorf y Mónaco y el Centro Internacional de Física Teórica de Trieste.

INTRODUCTION

It appears particularly appropriate on the occasion of the Fourth Geneva Conference to review the contribution that international cooperation has played, and will play, in fostering the peaceful uses of nuclear energy. The Geneva Conferences in themselves have become an impressive symbol of the remarkable spirit of internationalism that has accompanied the expansion of this technology over the past two decades.

Since the end of the last world war, the world has witnessed revolutionary advances in many fields of science, technology, medicine, and agriculture. To varying degrees, these advances have entered the world-wide pool of knowledge, and have spread from nation to nation. The field of nuclear energy, however, is unique in both the intensity and the nature of the international efforts which have been made to ensure that its benefits would be available on a world-wide basis.

While the diffusion of knowledge in most fields of science and technology has taken place largely through traditional channels of scientific and commercial interchange, international cooperation in the peaceful uses of nuclear energy has resulted directly from deliberate policy decisions made at the governmental level in various nations. One major consequence of this has been the establishment of an international organization devoted exclusively to cooperation in the peaceful uses of nuclear energy -- the International Atomic Energy Agency. The Geneva Conferences themselves, which have been unique in their scope and intensity of coverage of such a broad scientific field, are another result and indicator of the special nature of international cooperation in nuclear energy.

The emergence of formal governmental action as the dominant element in spreading the knowledge and the benefits of the peaceful uses of nuclear energy has its origins in three interrelated facts: first, that programs for the development of peaceful uses were at the outset almost exclusively conducted by governments, or with heavy government financial support; second, that these programs were originally classified or drew heavily upon information which had been classified for national security reasons; and, finally, that these applications themselves, even though peaceful, involved the use of processes and materials which, unfortunately, can be applied to military purposes of awesome destructive force. It is not surprising that, under these circumstances, international cooperation in the peaceful use of nuclear energy began and has largely continued through intergovernmental arrangements, of both a bilateral and multilateral nature.

To conclude, however, that the international cooperation which has been created in this field was a natural and inevitable consequence of the auspices under which the peaceful uses of nuclear energy came into being would be to do a profound disservice to the statesmen and governments responsible for conceiving and implementing this unparalleled cooperative effort. The few nations which had undertaken large nuclear development programs had the alternative of seeking to retain their knowledge under secrecy indefinitely. As another alternative, diffusion of the knowledge and benefits of the peaceful applications could have been left to the workings of the more traditional channels of exchange, as these applications were gradually declassified or became known through independent efforts in additional nations. The adoption of this course of action would have both greatly reduced the rate at which other nations could realize the benefits of peaceful applications and greatly increase the risk that these applications would be turned to military purposes of grave potential danger.

Instead of these alternatives, the political leaders of a decade and a half ago chose another course -- that of deliberate and intensive efforts to share the peaceful benefits of the atom as rapidly as possible, under conditions which ensured insofar as possible that these benefits would be applied exclusively to peaceful purposes. Thus, they decided to accept the security risks which widespread possession of the knowledge and materials of nuclear energy entailed in order not to deny their benefits to the world at large, at the same time taking advantage of the world-wide appeal of these benefits to help establish conditions and understandings which would minimize the risk of improper use. This was a bold and imaginative decision and, in the opinion of the authors, one which time has shown to be a wise one.

It is the purpose of this paper to review and evaluate the programs which have evolved from this decision of the mid-1950's and to explore their future potential. In our nation, it has from time to time seemed to be fashionable to question the wisdom of the decision itself, as well as the achievement of the resulting programs -- and to ask "Whatever happened to Atoms for Peace?" The authors believe that a great deal has happened, of great world-wide benefit.

It is inevitable that in our review we shall deal largely with programs and viewpoints of the United States, since the essentially governmental nature of cooperation in this area makes it difficult to describe and evaluate the programs of others. We are well aware, however, of the broad international character of cooperation in the peaceful use of nuclear energy, as attested to by this Conference itself. The widespread willingness of other nations advanced in the peaceful use to join the United States in sharing these benefits was a goal of the U.S. program from the outset and has been most welcome to our Government.

PROGRAM DESCRIPTION

The fundamental concept of the United States program of international cooperation in the peaceful uses of nuclear energy has been that of providing access by other nations to the experience and assets of the large U.S. program devoted to the development of peaceful applications. These assets are of two principal kinds: first, the vast body of scientific information, technology, and know-how resulting from the expenditure to date of several billion dollars on the development of peaceful applications; and, second, the capacity to produce in large volume and at low cost the special materials -- such as heavy water and enriched uranium -- essential to many of the peaceful applications.

Economic and financial assistance, while employed to some extent, especially in the early years of the program, has been modest in comparison with that brought to bear in a number of other programs of national and international cooperation. Where employed, financial assistance has, from the outset of the U.S. program, been carefully tailored to stimulate local activity and investment, and not as a substitute for a genuine commitment on the part of the cooperating nations themselves to a meaningful national or regional peaceful nuclear energy program. For example, the program of research reactor grants, under which the United States undertook to contribute to the cost of research reactors in 26 countries between 1955 and 1960, was limited to providing up to one-half the cost, and in no event more than $350,000, of research reactor facilities constructed by cooperating countries. In nearly every case, the investment by the cooperating country in the research reactor facilities assisted under the program far exceeded the U.S. contribution of $350,000. In many cases, the funds committed by the other governments represented the first significant governmental investment in science which they had ever made. The importance of this result alone is obvious.

A similar approach of joint and equal participation was followed in the joint research and development program of the United States and Euratom, under which a total of $55,000,000 was devoted to improvement in light water reactor technology between 1959 and 1969.

Another feature of the U.S. program has been to encourage the formation in cooperating nations of governmental organizations which could serve as a focal point for undertaking a program in the peaceful application of nuclear energy. In many cases, this encouragement led to the formation of an atomic energy commission or comparable governmental body which, in many nations represented the first governmental organization ever devoted to fostering scientific research or development, or their applications. The beneficial side effects of introducing and legitimizing science and technology as an important concern of government in these nations may well exceed the direct benefits of the cooperation itself.

The United States cooperative program, as well as that of other advanced nuclear nations, has been a flexible one, designed to be of assistance to nations at any stage of nuclear development. It has ranged from furnishing materials or advice for relatively elementary radioisotope application to the supply of power reactors and fuel and the performance of joint experiments in high-energy physics or reactor technology. In all, active cooperation has been conducted with some 60 nations bilaterally, with many more nations benefitting through U.S. participation in the IAEA and other international forums, as well as through the intensive U.S. program of publication of the results of its research and development programs.

The participation in this Conference of 60 nations is eloquent testimony to the virtual universality of both interest and capability in the peaceful use of nuclear energy. No nation with which the United States has cooperated has lacked at least a small nucleus of genuinely talented scientists eager to apply their capabilities to the solution of urgent national problems. To deprive these outstanding individuals and their nations -- through emigration or stagnation -- of the opportunity to apply nuclear techniques to the solution of urgent national problems would be tragic indeed. The ability of nuclear energy programs to keep talented scientists in their native lands and constructively engaged in attacking scientific problems of local interest is one of the most important and gratifying results of international cooperation in the nuclear field.

Finally, the U.S. program has from the outset been reciprocal in nature. We believe, without apology, that cooperation from which all parties can derive direct benefit is fundamentally more effective, more stable, and more welcome to all parties concerned. Advanced countries cannot, of course, reasonably expect to receive scientific information of as much value as that which they provide to a less developed partner. Nevertheless, reciprocity of obligation has an important effect in strengthening the fabric of international contribution. Among nations of comparable level of development, reciprocity both of obligations and in practice is essential if cooperation is to survive.

The contributions which many less-developed countries are making, particularly to their less advanced neighbors, is one of the most encouraging aspects of international cooperation in the peaceful uses. Regional cooperation, often under the aegis of the IAEA, has been particularly effective on many occasions, and merits, in the authors' view, more widespread application.

With these general remarks, let us turn now to a more detailed description of individual elements of the international cooperative program.

TECHNICAL INFORMATION

A man's judgment is no better than his information. To this we might add that a nation's future is dependent in no small measure upon its ability and capacity to master and use information and knowledge. Unlike other natural or man-made resource, information can never be depleted nor destroyed through use.

The willingness of the nations advanced in the peaceful uses of atomic energy to share their knowledge with each other, and with others less advanced, has been an indispensable element to the world-wide progress in peaceful uses. The Geneva Conference of 1955, and to a lesser extent that of 1958, served a vital function in stimulating the declassification and publication of a vast amount of information which, until then, was classified. Since 1958, virtually all information dealing directly or predominantly with the peaceful uses of atomic energy has been treated as unclassified by the nations in which it has developed, and its publication has taken place in increasing volume on a regular basis. The International Atomic Energy Agency's vigorous program of topical conferences, symposia, and panel meetings has been a major element in providing a continuing stimulus for the publication of nuclear energy information, and the Agency's own publications have achieved world-wide status as a valuable source of information on the peaceful uses.

The United States Atomic Energy Commission, including its laboratories and contractors, has been the principal producer of peaceful uses literature. The total number of literature items published in the United States increased from 4,800 in 1955 to 24,000 in 1970. All U.S. literature, including the USAEC report literature, is available throughout the world and this report literature is sold for nominal charges reflecting reproduction costs through the International Atomic Energy Agency, National Lending Library (United Kingdom), and the National Technical Information Service (United States).

The literature output of other nations in the field of peaceful uses has also increased dramatically. Using Nuclear Science Abstracts (NSA) as a base, the world collectively published 8,020 items in 1955, compared to 53,080 items in 1970. Countries which contributed more than one percent of the total to 1970 NSA base were: USA - 45.5%; USSR - 11.1%; U.K. - 6.5%; Germany, F.R.- 6.1%; France - 5.4%; Japan - 4.8%; Italy - 2.9%; Canada - 2.4%; India - 1.8%; Australia - 1.3%; and Switzerland - 1.1%.

Clearly, despite this large volume, not all information and know-how in the field of peaceful uses is reduced to written form in generally available publications. To do so would be neither practical nor desirable for a variety of reasons.

Increasingly, nuclear energy information, especially in the key field of nuclear power, has attained the status of immediate commercial importance. At this stage, much of the information may be developed privately and is not available to national atomic energy authorities for distribution. Other information, even though developed in national programs, may be regarded as being of too great and immediate commercial interest to justify its publication without compensation commensurate with the assumed value of the information. Finally, at the advanced developmental stage, the sheer volume and detail of information may preclude its complete publication, regardless of any policy considerations. By the same token, the assimilation of such detailed and voluminous information becomes extremely difficult and essentially useless except to those who might be engaged in an almost parallel development program.

The United States has long favored the reciprocal exchange of detailed information with cooperating nations with comparable interests, conducting programs of comparable scope and scale. Such cooperation not only saves all parties effort and money, but, by providing a larger and more assured base of common knowledge, results in more rapid achievement of the developmental goals. The United States recognizes the importance of commercial incentives in contributing to the achievement of the most efficient results in any particular field of technology. At an appropriate stage in the development of an evolving technology, giving effect to these incentives may result in more rapid overall progress.

It is probable that there is general agreement on the principle of full exchange of basic knowledge, with gradually increasing application of proprietary considerations as the stage of commercial application is approached. There are, however, understandable differences in the application of this principle. From the United States' point of view, it appears that restrictions on the exchange of information have sometimes been imposed prematurely in the developmental process, with the result that the common goal of rapid progress may not be well served.

There are two fields related to the peaceful uses of nuclear energy in which exchange of information continues to be restricted in the United States and elsewhere by national security considerations. These are the fields of uranium enrichment and the peaceful applications of nuclear explosions. In the field of uranium enrichment, cooperation is now taking place among several countries on a classified basis, and this trend may be accelerated. However, declassification and general publication of uranium enrichment technology, in the authors' view, would not be in the overall international interest.

In the field of peaceful nuclear explosives, information concerning the design of devices will undoubtedly remain classified for the indefinite future, but there are essentially no classification restrictions imposed in the United States on information concerning the application of explosive devices and their results. The Soviet Union has also released extensive information on its peaceful nuclear explosives program to the IAEA and its Member States, and fruitful exchanges have taken place between the U.S. and the Soviet Union in this field.

The decade of the sixties witnessed great changes in information-handling techniques. Most of these changes flow from computer technology which provides practical means of storing, manipulating, and retrieving incredibly large banks of alpha-numeric data. In the seventies, third and fourth generation computers tied to rapidly accessible trillion-bit mass storage devices will be directly linked to individual users in laboratories, offices, and schoolrooms through world-wide data communication networks.

The treasury of man's knowledge which has, in the past, been available only to a fortunate few, and to them only after mountainous labor, will, in the not-too-distant future, become available to many, irrespective of geographic location. The United States has utilized the opportunity of this conference to demonstrate the feasibility of a user in Geneva, Switzerland, manipulating large data bases stored in a computer in Oak Ridge, Tennessee, the two linked together by a satellite communication network.

If these experimental information systems of today are to serve responsively and responsibly the changing needs of all segments of the world's societies tomorrow, we believe that orderly development can best be achieved through international cooperation. This is why we view the International Atomic Energy Agency's International Nuclear Information System (INIS) as a long step in the right direction. No other cooperative international information system is so far along operationally; no other has brought together the immensely varied interests of all nations, advanced as well as those not so advanced, and none yet proposed share the same degree of governmental support both at technical and political levels. The IAEA's INIS role of establishing standards, regulating the system, merging national inputs, providing forums for experts to improve the system so that users everywhere have what they want, when they want it, and in the form they want it, will require a continuing high degree of technical expertise and cooperative attitude on the part of both the Agency and participating nations.

We are only now at the threshold of understanding the application of computers and associated network hardware to the handling of information and knowledge resources. As systems move from developmental to operational status, and then to improved generations, their impact on the enormous range of ever-changing problems -- educational, security, economic, and political -- must be immense.

EDUCATION AND TRAINING

In the earlier years of international cooperation in the peaceful uses, a critical need existed for programs of education and training. The requirements, particularly for training at the specialized professional levels, extended far beyond the developing countries, and included advanced nations ordinarily self-sufficient in providing educational opportunities. The problem was compounded by the fact that, even in the most advanced nuclear nations, adequate facilities and programs for advanced nuclear training did not yet exist in the established educational institutions. To meet this need, the United States Atomic Energy Commission organized the International School of Nuclear Science and Engineering in 1955. In 1960, since colleges and universities were by then offering basic nuclear courses, the School was reestablished as the International Institute of Nuclear Science and Engineering, which conducted graduate level programs in several fields of nuclear science and engineering. This program was located at two universities (Pennsylvania State University and North Carolina State) and at the Argonne National Laboratory. This program was later supplemented by specialized courses open to students from abroad at the Oak Ridge School of Reactor Technology (ORSORT). Between 1955 and 1965, more than 820 students from abroad representing 56 countries, were trained at the International School and Institute, or at ORSORT, most with full or partial financial support from the United States Government.

The Oak Ridge Associated Universities has also played a major role in developing specialized personnel for the nuclear age. From 1948 to 1970 more than 660 overseas specialists, many of them physicians, were trained in the use of radioisotopes in their fields of interest.

Concurrently with this broad educational and training program, the United States Atomic Energy Commission was undertaking a vigorous program for improving the capabilities of established U.S. educational institutions in the nuclear field. This program, combined with decreasing demand for formal training from abroad, led to the termination of the International Institute program in 1965. Today, more than 70 colleges and universities in the U.S. offer degree courses in nuclear energy. All of these institutions accept properly qualified students from abroad.

Of particular interest and importance is the Puerto Rico Nuclear Center, located at the University of Puerto Rico, and financially supported by the USAEC. This institution is especially well qualified to offer graduate level training in a number of fields to students preferring Spanish language training, as well as to those interested in the specialized application of nuclear energy to problems of tropical agriculture and medicine.

Several other nations established, at a relatively early date, government training institutions in the nuclear sciences similar to the U.S. institutions just described. In these other nations, responsibility for nuclear training has generally been transferred to established educational institutions.

Today, from the world-wide point of view, there is clearly no shortage of educational and training opportunities in various branches of nuclear science for all qualified students. Financial support, often the crucial factor, is available from the IAEA, the OAS, and from various other governmental and private organizations which make scholarships and fellowships available to foreign students. The IAEA has the capability of awarding approximately 300 fellowships annually, including about 50 contributed "in-kind" by the United States Government.

A need continues to exist, and undoubtedly will continue, for post-graduate training opportunities -- "on-the-job training" -- in highly specialized fields of nuclear energy. The USAEC continues to offer these opportunities at its laboratories and research centers. On the average, approximately 1,500 overseas guest scientists are assigned to AEC laboratories, usually for periods of a year or more. Under some circumstances, exceptionally well qualified young scientists may be employed by the laboratories during their assignments. Others, if properly qualified, are accepted without charge, and may obtain financial support for living expenses from any of the sources noted earlier.

An important new type of requirement has arisen recently. This is for training in the "regulatory" aspects of nuclear power -- the process of determining the acceptability of proposed nuclear facilities from the standpoint of health, safety, and environmental considerations. The United States considers it inappropriate, as a matter of policy, to undertake the safety review of power reactors or other safety facilities built abroad. Indeed, this is a responsibility which no nation prepared to install a nuclear power plant should delegate to others, even though it may appropriately seek outside advice and assistance. Within the severe limits of its capability, however, the USAEC is prepared to assist other nations in establishing or improving their own capability to undertake regulatory programs by providing information and training on U.S. practices in this field. One regulatory training course was conducted in 1969, and the course may be repeated from time to time, if a sufficient demand exists.

The training of reactor-operating and supervisory personnel is an extremely important matter for any nation considering the installation of nuclear power plants. It is highly desirable that at least a few people trained in power reactor operation and supervision be available in any country during the study, bidding, and bid evaluation phases of any proposed nuclear power project. As soon as a specific reactor is selected, the training of people in the operation of that reactor is essential. A training program should be required as an integral feature of the reactor proposals, and the quality of the training program, including its "on-the-job" aspects, should be given considerable weight in the bid evaluation.

EQUIPMENT AND FACILITIES

As already mentioned, the U.S. provided financial support in the earlier years of the international cooperation program for the research reactors located abroad. Despite criticism that some of these grants were premature, we believe that they have proven their worth in virtually every instance, and have served as the indispensable nucleus for the nuclear programs of most of the nations in which they are located.

This reactor grant program was supplemented for several years by a program of equipment grants, under which 26 grants of nuclear laboratory equipment were provided. Today, the U.S. makes available each year to the IAEA a limited fund which may be applied in part to the acquisition of nuclear laboratory equipment to IAEA members. More than 100 grants, totaling over $1,000,000 have been made since the inception of this program through 1970. The IAEA also has available to it other sources of funds for equipment grants to Member States, including voluntary cash contributions from the U.S. and many other Member States, as well as the United Nations Development Program. The IAEA is, therefore, now the principal source of financial assistance for the acquisition of nuclear equipment.

Financial assistance for the purchase of nuclear power plants is a specialized matter, covered elsewhere in this paper. The United States view, which we believe is shared by other reactor suppliers, is that the financing of nuclear power plants should be considered on its economic merits within the framework of the various programs for development assistance or export financing.

MATERIALS

Cooperation in the supply of nuclear materials has been a cornerstone of the U.S. program of international cooperation since its beginning. Since local means for producing the principal nuclear materials were generally not available, an outside source of supply of these materials was an essential element in enabling development programs, especially in the field of nuclear power, to go forward in many countries.

The importance of the U.S. role in supplying enriched uranium has been generally recognized. U.S. enriched uranium has been and is being employed in research and materials test reactors, in reactor experiments, demonstration and prototype reactors and commercial nuclear power plants of most of the nations having a need for this material. It is perhaps less generally recognized that heavy water supplied by the United States was equally essential in enabling those nations interested in heavy water reactor concepts to undertake the necessary development programs. Similarly, U.S.-supplied plutonium has substantially accelerated fast-reactor development programs in a number of countries. The international supply of nuclear materials has been a factor at least as influential as that of sharing technology in enabling many nations to participate in the development of peaceful uses and to share in their benefits.

As the principal supplier of enriched uranium, the U.S. at an early date formulated policies which would ensure users abroad of access to this vital energy source on an assured, long-term, and stable basis. AEC supply policies have, therefore, been based on two fundamental principles: long-term assurances of supply, and nondiscriminatory terms and conditions, including prices identical to those charged domestic customers.

Since 1969, enriched uranium supply has generally been accomplished through means of "toll-enrichment" arrangements which allow customers to deliver their own feed material for enrichment in U.S. facilities. This unusual arrangement not only makes it possible for overseas consumers of enriched uranium to make use of their own natural uranium or to procure it from the source of their choice, but has also opened up a major world market for natural uranium.

The U.S. capability for the supply of enriched uranium is based on the availability of three large diffusion plants with a total capacity of 17,000 metric tons per year of separative capability — enough to meet the continuing enrichment requirement of much more than 100,000 megawatts of nuclear electric generating capacity. Because of their large size, the efficient process which they employ, and the low-cost electric power available to them, these plants are capable of accomplishing enriching services at unusually favorable costs. This factor, coupled with the USAEC policy of basing its enriching charges on costs, has made it possible for customers abroad to enjoy exceptionally attractive nuclear fuel costs. Despite recent unavoidable cost increases, U.S. enrichment charges of $32 per kilogram of separative work are 33% lower than those first announced by the USAEC in 1956. In a typical light-water reactor nuclear fuel cycle, these charges correspond to approximately 0.6 mills per kilowatt hour or less than 10% of the total generating cost for such a reactor.

A question of world-wide interest in the field of nuclear power is that of the adequacy of enrichment capacity to meet the rapidly growing requirements. The nuclear power industry has been fortunate in having available throughout its formative years a capacity for enriched uranium production far in excess of current requirements. As the nuclear power industry grows and absorbs this surplus enrichment capacity, the normal commercial situation of additional capacity being built as needed will prevail. When this point is reached in the late 1970's, the established nature of the nuclear power industry will ensure, as is the case in other industries, a normal balance between the supply and demand for enriching services. The vital subject of uranium enrichment is treated in greater detail in another U.S. paper.

Although the USAEC has not established a program to meet world requirements for heavy water, it has been prepared to sell heavy water (surplus to its own needs) on a first-come, first-served basis to domestic and overseas customers. As already noted, this heavy water supply has constituted almost the sole source of heavy water in the world market so far, and its availability has allowed those nations interested in heavy water concepts to pursue their objectives. It is of interest that the nuclear material of greatest scarcity to date has not been enriched uranium, but heavy water. Nuclear power projects, based on the use of natural uranium, heavy-water concepts in order to achieve independence of overseas sources of fuel supply, should take into consideration the availability of heavy water both for initial needs and routine or emergency replacement.

Most of the plutonium now employed in the crucial fast-breeder reactor development programs has been derived from reactors producing plutonium for defense requirements. The availability of this material has undoubtedly advanced by years the fast-reactor programs of countries not possessing their own sources of plutonium. With the availability of plutonium as a byproduct of the operation of nuclear power reactors, plutonium supply should place no limitation on breeder-reactor development work. Indeed, this material is now becoming available in quantities which create strong incentives for its use as a supplementary fuel in light-water or other enriched reactor systems. With many different sources of supply and potential customers, it should be possible to establish a free market in plutonium subject, of course, to necessary restrictions limiting its use to peaceful purposes.

There are many other materials of particular importance to the field of nuclear energy or which are produced as byproducts of nuclear operations. These include many radioisotopes of unique and exciting properties. One such example is plutonium-238 which has provided the thermal energy source now powering experiments placed on the moon by the Apollo astronauts. Production of these materials can ultimately represent a source of incremental revenue for nuclear power programs. Cobalt 60 is already being produced commercially in several nuclear power reactors. In general, the supply of these other nuclear materials has imposed new limits on the nuclear industries, and world-wide markets have been established for several of them.

SAFEGUARDS

An unusual feature of international cooperation in the peaceful uses of nuclear energy has been the development of the measures known as "safeguards." As a result of the awesome military potential of the atom, the framers of the Atoms for Peace Program in the United States and elsewhere felt that it was essential that international cooperation in this field take place under arrangements which assure that programs and materials devoted to peaceful purposes would not be turned to destructive uses.

Out of this conviction grew the concept of safeguards -- a series of measures, including on-site inspection, designed to provide assurance both to the cooperating parties and to the world at large that nuclear activities conducted under a peaceful designation were not employed for any military use.

The international verification of the obligation to employ nuclear materials only for peaceful purposes represents, in the authors' view, a development in international relations of an importance which far transcends its immediate field of application. The International Atomic Energy Agency is playing a key role in the development and application of these safeguards and has been assigned major responsibility in this area by the Non-Proliferation Treaty. The importance of this subject is such that it is treated in detail as a separate topic of this conference, but its crucial role in making possible broad and effective international cooperation must be acknowledged in this review. The existence of effective assurances that the United States' materials and equipment supplied for peaceful uses of atomic energy are not being used for unauthorized purposes has been an indispensable pre-condition of the broad program of cooperation in peaceful uses outlined in this paper.

INTERNATIONAL INSTITUTIONS

Cooperation in the peaceful use of nuclear energy has been a fertile field for the creation of multi-national arrangements of both a regional and world-wide nature. The high cost of nuclear development and applications has made it essential that nations work together to avoid duplication of effort and to achieve maximum progress in furthering peaceful developments. Moreover, the hazards of nuclear energy, unlikely as they are to materialize, would know no limits of national frontiers. Regulation of nuclear activities and materials to ensure safety is thus of international concern. The International Atomic Energy Agency is the foremost world-wide institution in furthering peaceful use of nuclear energy and in promoting cooperative efforts toward this end. In its 14 years of existence, the IAEA has clearly established itself as a major and effective force in the promotion and regulation for peaceful uses of nuclear energy.

On a regional basis many other organizations are playing important roles. These include the European Atomic Energy Community, the European Nuclear Energy Agency, the Joint Institute for Nuclear Research, and the Inter-American Nuclear Energy Commission. Regional arrangements of a more specialized nature, often under the auspices of the International Atomic Energy Agency, have also proven of value in fostering progress in the specialized problems of a particular geographic area. For example, the IAEA is coordinating a program of cooperation among several Asian nations to increase the practical application of neutron activation in medicine, agriculture and industry of the area. The IAEA also holds each year several regional and inter-regional training courses in various peaceful nuclear energy applications.

NUCLEAR-POWER FINANCING

With only a few exceptions, external financing of nuclear power projects has been undertaken by the national export financing institutions of the principal supplier nations. In the United States, this role is played by a Government institution, the Export-Import Bank, which expressed its confidence in nuclear power at an early date and consequently has played a crucial role in the introduction of nuclear power in many nations. At the time of the Third Geneva Conference in 1964, the Export-Import Bank had extended five loans to finance nuclear power projects outside the United States. This number has now grown to 20 major nuclear plants. The total value of Eximbank-supported nuclear-type exports from the U.S., including fuel for initial and reload cores, test reactors and other associated equipment and services, amounts to $1.1 billion. In addition, the Bank has made preliminary commitments to support seven other projects in six nations with a total U.S. export value of $800 million.

The Export-Import Bank's interest rates are competitive with those of the world capital market. Its loans are made in combination with financing provided by other U.S. and non-U.S. lending institutions, the degree to which Eximbank's own funds are used determined on a case-by-case basis. Where desired, Eximbank will also guarantee the loans made by the other institutions which are helping to finance nuclear power plant purchases from the U.S.

The Bank's general policy is to make these loans available for viable projects in countries which can reasonably demonstrate an ability to meet the payment schedule for such a project, along with their other international obligations.

While Eximbank financing is limited to the U.S. goods and services involved in each particular project, the Bank participates in projects where part of the financing is done outside the U.S. In practice, therefore, the projects typically involve procurement from several sources of supply, both to take advantage of lowest world prices for particular components as well as to reserve scarce foreign exchange through local procurement wherever possible.

Eximbank loans on reactors, related equipment and services customarily are for a period of 15 years, with repayments starting six months after construction is completed. Loans for the initial nuclear fuel inventory are made on 5-year terms, plus the same grace period as for reactors. Purchasers of U.S.-manufactured nuclear power equipment are assured of Eximbank financing for replacement fuel units. The Bank also is prepared to participate in the financing of U.S.-processed fuel sold separately from nuclear reactors, including replacement fuel inventories.

Where conditions require it, Eximbank also may assist in financing local costs, in the host country, incident to the completion of a nuclear power project. This assistance normally takes the form of guarantees of loans made by non-U.S. financial institutions to cover local costs. The guarantee may cover an amount equal to 15 percent of the costs of U.S. equipment and services used in the project.

In summary, through Eximbank and similar export financing institutions, there is adequate support for all feasible nuclear power projects. The essential requirement is that national authorities be able to justify the economic and technological validity of such projects, and be willing to give them sufficiently high priority.

Proposals have been made from time to time for the establishment of special international funds earmarked for the financing of nuclear power projects. These proposals are based on the understandable and generally commendable principle that there are incentives for the introduction of nuclear power into developing countries beyond the narrow economic merits of a particular project. This is a principle to which the authors take no exception. Nevertheless, it would appear that the most important step to be taken, if nuclear power is to be given the maximum encouragement, is for national authorities themselves to give nuclear power projects priorities which they consider appropriate, taking into account both tangible economic benefits and intangible technological factors. In general, projects which are given sufficiently high priority by national governments are being financed through existing means.

CONCLUSION

International cooperation in the peaceful uses of nuclear energy has been extraordinarily intensive and successful. Through it, the knowledge and benefits of an entire new field of science and technology have been transferred from a handful of countries to all interested nations in the space of less than two decades. The predominant influence in the creation and implementation of this broad program of international cooperation has been at the governmental level, especially on the part of the initially advanced nuclear nations. The International Atomic Energy Agency was created at their initiative and has become in itself a major positive force for international cooperations.

International cooperation in the peaceful uses of nuclear energy will continue to play a major role in the future, although a somewhat modified one. As particular activities, especially nuclear power, reach the stage of commercial feasibility, international cooperation will tend increasingly to be conducted through commercial and other non-governmental channels. Even here, however, the role of governments in establishing a favorable climate for international cooperation will be crucial for many years to come. In the areas of fuel supply and reactor exports, particularly, it can be expected that governmental approvals and participation will be required for an indefinite period.

In areas of less immediate commercial significance, governmentally sponsored international cooperation will continue to be the major factor in promoting the peaceful uses of nuclear energy. Among these fields are nuclear desalting, the peaceful use of nuclear explosives, and controlled fusion. The great promise which all of these fields hold for the future can be substantially advanced through the determination on the part of governments to continue the practices of the past in embracing the concept of international cooperation in the peaceful uses of atomic energy.

THE NPY-COOPERATION IN REACTOR PHYSICS
Final summary report*

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Abstract–Résumé–Аннотация–Resumen

THE NPY-COOPERATION IN REACTOR PHYSICS· FINAL SUMMARY REPORT.

The main organizational concepts are described concerning the cooperation in reactor physics among Norway, Poland, Yugoslavia and IAEA, called the NPY-Project, which was established in 1963 and concluded this year. Then the scientific objectives, which were the goals of this 7-year cooperation, are discussed in a more detailed way. On the basis of the output of this cooperation, the highlights of the scientific, technical and organizational achievements are presented. The merits of three International Advanced Summer Schools and many Seminars organized within the framework of this cooperation are discussed. Physical problems of particular interest for the three cooperating parties and for the rest of the scientific community of IAEA Member States, which were attacked and solved within the framework of the NPY-Project, are discussed. Finally there is an attempt to formulate conclusions for the cooperating parties and the IAEA, and for possible activities which could emerge out of this Project.

LA COOPERATION EN MATIERE DE PHYSIQUE DES REACTEURS DANS LE CADRE DU PROJET NPY: RAPPORT RECAPITULATIF FINAL.

Le mémoire décrit les principaux aspects de l'organisation de la coopération entre la Norvège, la Pologne, la Yougoslavie et l'AIEA dans le domaine de la physique des réacteurs, coopération qui a pour cadre le Projet NPY établi en 1963 et mené à terme au cours de l'année courante. Le mémoire présente également une discussion détaillée des objectifs scientifiques de cette coopération de 7 années. Il énumère les résultats les plus importants obtenus grâce à cette coopération dans les domaines de la science, de la technique et de l'organisation et discute les mérites de trois cours universitaires internationaux d'été et d'un assez grand nombre de journées d'étude, organisés dans le cadre de cette coopération. En outre, il met en lumière, en les formulant clairement, des problèmes de physique présentant un intérêt particulier pour les trois parties coopérantes ainsi que pour les autres membres de la communauté scientifique de l'AIEA, et à la résolution desquels on s'est attaché avec succès dans le cadre du Projet NPY. Enfin on tente de tirer, pour les parties coopérantes et l'AIEA, des conclusions concernant les activités susceptibles de découler de ce Projet.

СОТРУДНИЧЕСТВО НПЮ В ОБЛАСТИ ФИЗИКИ РЕАКТОРОВ.

В докладе представлены основные организационные концепции сотрудничества в области физики реакторов между Норвегией, Польшей, Югославией и МАГАТЭ, называемого сокращенно Проект НПЮ, который был учрежден в 1963 году и завершен в текущем году. Более подробно рассматриваются научные задачи семилетнего сотрудничества НПЮ. На основе достигнутых результатов представлены главные научные, технические и организационные достижения, в частности, проведенные в рамках Проекта НПЮ три Международные Летние Школы и ряд семинаров. Рассматриваются физические проблемы, имеющие особое значение для стран НПЮ и других стран-членов МАГАТЭ, сформулированные и решенные в рамках Проекта НПЮ. В заключение автор пытается сделать выводы относительно сотрудничества стран-участниц Проекта и МАГАТЭ, а также последующей деятельности, вытекающей из осуществления этого Проекта.

LA COOPERACION EN MATERIA DE FISICA DE REACTORES DENTRO DEL MARCO DEL PROYECTO NPY· VERSION FINAL DEL INFORME RESUMIDO.

Se describen los principales aspectos de la organización para la colaboración en materia de física de reactores entre Noruega, Polonia, Yugoslavia y el OIEA, llamada «Proyecto NPY», establecida en 1963 y llevada a término el presente año. Se exponen a continuación, de modo más detallado, los objetivos

* Prepared under the recommendation of and approved by the NPY Joint Committee.

científicos que han constituido las metas de la cooperación durante estos siete años. Fundándose en los resultados de esta cooperación, se presentan los logros científicos, técnicos y de organización más destacados. Entre ellos se estudian los obtenidos en tres Escuelas de Verano Superiores Internacionales y diversos Seminarios organizados dentro del marco de dicha cooperación. Se formulan y exponen problemas físicos de particular interés para las tres partes cooperantes y para el resto de la comunidad científica de los Estados Miembros del OIEA, problemas que fueron abordados y resueltos dentro del proyecto NPY. Finalmente, se formulan conclusiones relativas a las partes cooperantes y el OIEA y a posibles actividades que pudieran surgir de este proyecto.

INTRODUCTION

The cooperative research program in reactor physics between Norway, Poland, Yugoslavia and the IAEA was signed in 1963. The main motivation was the fact that national programs in reactor physics in each of these countries contained much in common on the one hand and, on the other were so complementary to each other that the parties could benefit from a cooperative effort and achieve greater progress in their respective reactor development programs. A practical motivation for the NPY-Project was the fact that the parties would have access to a larger pool of equipment than would be available to one country working independently. This includes a larger variety of critical and subcritical assemblies, larger computing facilities together with computer programs, and special laboratory instrumentation. Furthermore, a permanent exchange of information, technical discussions and critical considerations of the work done, exchange of staff, common performance and interpretation of experiments, and cross-checking of calculations of various chosen examples make the solution of particular problems more thorough and much faster. The main objectives of the cooperative Program were the development and testing of theoretical models and calculation methods used in the analysis of reactor experiments and interpretation of experimental data, the development of experimental techniques and the testing of their applicability in various fields of reactor physics.

The program was conducted in the national laboratories of the co-operating countries: the Institutt för Atomenergi, Kjeller, Norway; the Institute of Nuclear Research, Swierk, Poland and the Institute of Nuclear Sciences, Vinca, Yugoslavia. The International Atomic Energy Agency played a very important role as a catalyser and an active party of the Project during the preparatory period of establishing the Project and during its activity. On the other hand it seems that the activity of the Project helped the IAEA to some extent in performing its constitutional duties by organizing Summer Schools and Seminars attended by participants from many Member States and assisting in a Fellowship Program.

The objectives of the NPY-Project were implemented under the scientific guidance of the Joint Committee of the Project, which formulated tasks from a list of selected topics, recommended definite jobs to be undertaken, discussed staff problems and the exchange of information, and considered, at the Technical Seminars, the progress made in the host country to the actual meeting of the Joint Committee.

The tasks were initially formulated as follows:

Establishment of a consistent set of nuclear data
Calculation of the thermal neutron distribution and reaction rate

in reactor cells and comparison with experiments
Resonance absorption effects
Buckling measurements and interpretation
Void effects
Neutron thermalization and slowing-down problems
Pulsed neutron technique
Reactor kinetics
Development of nuclear design codes

In 1967 the list of tasks was reformulated as follows:

Thermalization and thermal neutron distribution
Slowing-down and resonance absorption effects
Buckling measurements and interpretation
Reactor kinetics
Development of nuclear design codes
On-line digital control of reactors
Burnup calculations and experiments

For the implementation of the cooperative program the following main experimental and computational facilities were at the disposal in the cooperating countries:

In Norway:	NORA reactor, CDC-3600 digital computer
In Poland:	ANNA and MARYLA critical assemblies, HELENA subcritical assembly, GIER digital computer, RA and RB critical assemblies, ZUSE Z-23V and CDC-3600
In Yugoslavia:	Digital computers.

Let us review now the progress made on the initially formulated tasks.

1. ESTABLISHMENT OF A CONSISTENT SET OF NUCLEAR DATA

Norway made available to the other parties the IFA Reactor Physics Handbook [NPY-N-17][1], a valuable compilation of nuclear data. In accordance with the recommendation of the NPY-Joint Committee, this set was accepted as a common basis for reactor calculations and interpretation of experiments related to the cooperative programs.

2. THERMALIZATION AND THERMAL NEUTRON DISTRIBUTION

One of the most important results was obtained in a common undertaking devoted to measurements and interpretation of intracell flux distribution in the critical assemblies of the NPY countries, using different methods and techniques. The critical assemblies include: Norwegian

[1] A complete List of NPY Reports is given at the end of this paper. Some of these Reports are referred to in the text. The letters NPY-N, NPY-P and NPY-Y refer to Norwegian, Polish and Yugoslavian reports, respectively.

NORA, Polish ANNA and Yugoslavian RB. Intracell neutron flux distributions in all three assemblies were measured by the representatives of the three NPY countries and calculated by various theoretical methods.

The summarized results of these efforts are presented in the Joint Report on Neutron Thermalization prepared by R. J. J. Stamm'ler from Norway, Z. Weiss from Poland and S. Takac from Yugoslavia and published in the IAEA Technical Report Series No. 68, 1966.

One of the major results was that the thermalization code K7-Thermos, developed at IFA, Kjeller gave good agreement with experimentally observed neutron density distributions for water-moderated lattices. This code was then adapted and developed as S-II-Thermos and S-III-Thermos at INR, Swierk. The changes and innovations introduced will be discussed under task No. 9. Definite progress was achieved in the experimental methods used for the determination of the thermal neutron density distribution in reactor cells. The aim was to minimize or to evaluate as correctly as possible the perturbing effect of the experimental devices on the thermal neutron distribution. This effort resulted in the improvement of the existing techniques or in the development of new experimental techniques. The rolled wire and pin detector technique was extensively used in Norway. The spiral technique with theoretical evaluation of the perturbing effects was developed in Poland [NPY-P-49]. In Yugoslavia it was decided to eliminate the perturbing effects by extrapolation of the results to a zero amount of foreign materials (detectors) [NPY-Y-27, 28, 29].

Extensive studies devoted to thermalization effects were performed in Poland using the eigenfunction expansion method [NPY-P-2, 20] or the Wiener-Hopf technique [NPY-P-54].

In Yugoslavia an analytical method for neutron thermalization calculations was developed based on the use of energy-dependent boundary conditions combined with the Laguerre polynomial expansions in the moderator and the collision probability technique in the fuel [NPY-Y-13]. In addition, multigroup P_3 calculations were carried out for the neutron flux distribution in D_2O and H_2O reactor cells [NPY-Y-37]. Then the emphasis was put on the development of the discrete energy-points method for the determination of the thermal neutron spectrum [NPY-Y-38]. A new scheme for point-to-point scattering matrix calculations based on the Lagrange interpretation was proposed. The discrete energy method was also combined with a P_3 approximation and the multipoint and multigroup procedures were compared in a number of different cases [NPY-Y-46].

Analogous studies on the application of the energy-point method for thermalization calculations were performed in Norway. A special point-energy version of the K-7 Thermos and DATAPREP was proposed. Special attention was given in both countries to the investigation of an exposed uranium fuel with plutonium isotopes present; low-energy resonances of ^{240}Pu were included in the thermal region. Comparison with conventional multigroup calculations was very promising.

The theory of time-dependent neutron thermalization was developed in Poland. The spectral properties of the Boltzmann operator were extensively studied and, on the basis of these studies, the effective solution to the initial value problem for neutron thermalization was formulated [NPY-P-85] and the numerical code TEINTRA calculating fundamental decay constants in moderators was developed. In attempting to resolve the discrepancies between theoretical predictions and experiments for small samples, where, in contrast to the theory, the exponential decay is still observed, the investigations of neutron thermalization were extended from the usual space of functions which are square summable over a finite region to infinite regions [NPY-P-86] and to a space of bounded measures. This approach was also applied to study the wave phenomena in neutron transport theory [NPY-P-127]. At the Symposium on Application of Transport Theory held at Oxford in September 1970 a paper on fundamental time and critical eigenvalues of the linearized Boltzmann equation was presented.

The experimental investigations of thermal neutron flux distributions, thermal utilization factors, disadvantage factors, and Lu : Dy spectrum index distributions were continued on the ANNA and MARYLA reactors. In the latter case a broad range of lattices with a variable uranium/water ratio was studied. Measurements were performed in clean cores and in the vicinity of "irregularities" such as control rods, water channels or the reflector boundary [NPY-P-78, 79]. An extensive series of such experiments was also performed in the NORA-reactor [NPY-N-82]. A special set of experimental techniques designed for use in complex multitube fuel elements was developed [NPY-P-91, 128]. Using a fast chopper as a pulsed neutron source, a series of measurements of the neutron decay constant in the small beryllium and graphite blocks at -80°C and at room temperature was performed. Attempts were made to interpret the results, which exhibited an exponential decay for blocks smaller than critical ones [NPY-P-84, 89].

3. SLOWING-DOWN AND RESONANCE – ABSORPTION EFFECTS

The main contribution was the development of a chemical separation technique for the isolation of ^{239}Np, used in measurements of resonance absorption of ^{238}U. This technique was developed in Norway [NPY-N-9] and broadly applied in Poland for ρ^{28} measurements on the ANNA and MARYLA reactors [NPY-P-29, 55, 56]. Measurements included also δ_{25} measurements and resonance escape probability calculations. Close cooperation was established between Poland and Yugoslavia in measurements of the resonance integrals, using a pile oscillator technique, and resulted in joint measurements or detailed intercomparison of independent measurements. Various substances like silver, zirconium, Zircaloy, tantalum, uranium were measured and compared with calculated values (NR-IM approximation and Levine's formula for escape probability) [NPY-P-97, NPY-Y-35, 45]. Results were presented at the 5th Conference on Physics and Engineering of Research Reactors, Dec. 1968, Warsaw.

The neutron slowing-down equation for an infinite homogeneous monoatomic medium was solved exactly, assuming cross-sections to be energy dependent. The solution is given in an analytical form as a sum of probabilities, which are given by Green's functions [NPY-Y-50]. At Swierk experiments were performed using pulsed neutron sources of the FLASH and GUN type with an efficiency of about 10^8 neutrons per 2 μsec pulse. The slowing-down parameters were investigated in light-water and graphite assemblies. The theoretical interpretation was based on a specially defined slowing-down probability in the diffusion approximation [NPY-P-112].

4. BUCKLING MEASUREMENTS AND INTERPRETATION

Within the framework of this task several buckling measurements and theoretical interpretations of critical experiments were made in the three countries. Some attempts to synthetize the results obtained in order to select the reliable experimental techniques and theoretical models for interpretations failed because it was not possible to perform such an ambitious job without additional experimental and theoretical efforts, which were not in the national programs of the cooperative countries.

A selection of experimental results of buckling measurements in the mixture of heavy- and light-water lattices have been reported by Norway in [NPY-N-6, 7, 72].

The measurements on the Polish ANNA (graphite-moderated, light-water-cooled) and MARYLA(light-water) reactors have been reported in the papers [NPY-P-5, 6, 9, 19, 23, 31, 36, 41, 67, 68, 93, 105, 106, 118, 121].

Heavy-water lattices with tubular 2%-enriched fuel were studied in Yugoslavia and described in [NPY-Y-3, 11, 14, 15, 23].

A series of mixed lattices using natural and 2% - enriched uranium fuel was investigated both experimentally and theoretically in order to establish the relation between the buckling of a compound core and the bucklings of each individual fuel lattice. There are indications of a linear relation between those bucklings [NPY-Y-41]. It was shown that the integral transformation method and the spatial spherical harmonics approximation are completely equivalent [NPY-P-87]. It was proven that the algorithm of the critical transport calculation based on the integral equation is convergent to the unique, non-negative solution corresponding to a positive value of the effective neutron multiplication factor [NPY-P-120].

The Norwegian interpretation of buckling and macrodistribution measurements are based on the following publications: [NPY-N-8, 10, 12, 15, 18, 21, 22, 23, 25, 30, 52, 53, 55] related to K-7 THERMOS, BIGG-II, DATA PREP-II, and TWENTY GRAND SPORT codes.

Polish interpretations are based on the following publications: [NPY-P-7, 12, 48, 69, 70, 111, 117, 126] related to PROGONKA, DIFIGREC, DIFIGREC-TAPE, EWA-I, EWA-II, S-II-THERMOS, BIGG-II, HELENA and other codes.

5. VOID EFFECTS

Under this task the experimental work was done in Norway only. Void effects were measured in the NORA reactor [NPY-N-19] and interpreted satisfactorily.

6. REACTOR KINETICS

In this task many interesting results were obtained which are summarized in the Joint NPY Report on Reactor Kinetics (submitted for publication in the IAEA Technical Reports Series). It contains contributions of all parties and common efforts on the following subjects:

Theory of zero-power reactor kinetics
Reactivity measurements
Pulsed neutron technique
Neutron statistics analysis
Ion-chamber current fluctuations analysis

The main theoretical contributions are connected with the transport theoretical treatment of time-dependent problems with delayed neutrons. The multigroup approach was the first step, initiated in Poland in collaboration with Yugoslavian colleagues [NPY-Y-36]; the extension of the method for the case of continuous energy dependence is the basis of a Ph. D. dissertation on the transport theoretical calculations of the reactor period, in preparation at Swierk, Poland. The multigroup approach was studied more extensively in Yugoslavia in the diffusion or P_1 approximation. First the spectral properties of the appropriate operators were studied, then the Bubnov and Galerkin methods were applied to a multiregion thermal nuclear reactor (as a by-product, the corresponding stationary problem was investigated) [NPY-Y-34, 53, 54]. Interesting results were obtained in the formulation of reactor kinetic equations on the basis of the Feinberg-Gałanin heterogeneous reactor theory. The solutions were found for a step change of reactivity as well as for a pulsed neutron source. In the same way the zero-power transfer function was derived [NPY-Y-49].

Experimental activity was mostly connected with items (a) and (b) below.

(a) Further evaluation of reactivity: improvements of measuring methods

Some techniques were investigated from the point of view of their application to the reactivity measurements. The oscillation method for water level reactivity coefficient measurements was applied in Norway [NPY-N-57], where the pulsed neutron source technique was also applied for measurement of negative reactivities [NPY-N-59, 70, 71, 78, 79]. Low reactivity measurements using a reactor oscillator were performed also in Yugoslavia [NPY-Y-16, 21, 22]. Some techniques were studied in Poland: source jerk methods, various noise techniques, and the periodic reactivity coefficient of the moderator (it was found that this method can be successfully used to evaluate the reactivity built into the reactor as well as to calibrate the control rods). The new method of reactivity measurements, which is the modified rod drop technique, was proposed in Poland. The improvement takes into account the real change of reactivity (formerly approximated by a step function) [NPY-P-126].

(b) Reactor noise analysis: elaboration of new techniques

Reactor noise analysis was one of the most fruitful domains of cooperation. There was a relatively active exchange of staff and ideas, and the IAEA Fellows from Poland and Yugoslavia took an active part in the research program on the NORA reactor and contributed by their research activities in their own countries. Rossi-α measurements and the power spectral density method was used in Norway [NPY-N-36, 37, 38, 56, 63]. A new theory for interpretation of Rossi-α measurements was developed in Norway for measurements using the time analyser technique

[NPY-N-47]. This theoretical work is considered very important in the field and seems to resolve the long-standing discrepancy between experimental results and the existing theories. The theory of interval distribution measurements [NPY-N-46] was used to interpret the count-to-count interval distribution experiments.

In Yugoslavia the auto-correlation and power spectral density methods were used for the measurements of the zero-power reactor parameters and for the search of sources affecting reactor stability [NPY-Y-31, 47]. Experiments were performed with the use of a data acquisition system and a PSD spectrometer.

In Poland reactor noise research covered various techniques. Attention was mainly paid to measurements (and their suitable interpretation) based on the conditional probabilities. Two new techniques were proposed in this field: the analogue flash start and the drop start, with their theoretical interpretations [NPY-P-74, 77, 81, 96]. The interpretation of the digital flash-start technique proposed by N. Pacilio was also given [NPY-P-99, 115], as well as the proposal for the modification of the dead-time-alpha method [NPY-P-100].

Studies of reactor noise experiments were performed using numerical Monte Carlo techniques for simulation of reactor noise. The main assumptions were the one-point reactor model and no delayed neutrons. Numerical programs can simulate different measuring devices, make possible comparisons of experiments and allow the determination of the best experimental conditions [NPY-P-114, 134].

The analogue computer has been directly applied to measure the autocorrelation function of the signal coming on line from a neutron detector [NPY-P-82].

The fast data-acquisition system for the analysis of kinetic processes has been put into operation in Poland. The system is based on analogue to digital conversion, magnetic tape registration and digital data processing. This system permits measurement of the autocorrelation function and the mean frequency of zero crossing, as well as the investigation of the utility of noise methods for absolute reactor power calibration [NPY-P-96].

The applicability of the reactivity concept for a description of reactor kinetics was investigated. The derived criterion of its applicability was used in the analysis of various methods of reactivity measurements. An especially informative idea was to correlate the stable reactor period and the prompt neutron time constant [NPY-P-90, 98, 101].

7. DEVELOPMENT OF NUCLEAR DESIGN CODES

This task was formulated in 1965 in order to co-ordinate efforts in the three countries on power reactor calculations.

The implementation of this task met various difficulties caused mostly by the different computers with different languages in each of the three countries.

Because of the fact that Norway has a large CD-3600 computer, with the greatest possibilities of all three parties (Yugoslavia acquired a CD-3600 computer in 1970) it was agreed that cooperative efforts be oriented towards developing codes for this computer and to use some of the blocks, after appropriate adaptation in other countries.

As a result of the cooperative efforts, modified versions of the two-dimensional diffusion code TWENTY GRAND SPORT [NPY-N-55, 67] was completed, as well as a new method for solving two group diffusion equations in a square cell [NPY-N-28].

A new code, PIGG, a one-dimensional multigroup P-1 code using the Greuling-Goertzel slowing-down model in 40 epithermal groups and a full scattering matrix in 6 thermal groups was programmed [NPY-N-80].

Polish researchers participated in the investigations on the rate of convergence of various iterative schemes applied in reactor diffusion codes and developed a two-dimensional diffusion code [NPY-N-81].

During the reported period the following reactor design codes have been developed or adapted and included into the Swierk Nuclear Codes Library:

1. MINIGASKET: special version of a GASKET code, with changed integration procedure, based on calculating the scattering law for crystalline moderators [NPY-P-125].
2. FLANGE-AL4: an Algol, slightly modified version of the General Atomics FLANGE code computing the thermal neutron cross-sections and scattering kernel for inelastic scattering from the scattering law [e. g. MINIGASKET output-tape].
3. HEXSCAT-S: an Algol-4 version of the HEXSCAT code computing the elastic part of the thermal neutron scattering cross-section.
4. S-III-THERMOS: a replacement for the former S-II-THERMOS code. The innovations include:
    a. Use of scattering matrix stored on the magnetic tape (e. g. FLANGE-AL4 output tape)
    b. Addition of pseudonuclide Fissium to the library
    c. Any combination of materials in separate zones
    d. FLURIG technique for transport matrix calculations
    e. Other organizational improvements (report in preparation).
5. MIXER: a data preparation code which calculates the effective 26-group cross-sections from the ABBN library for a given material composition. It takes into account self- and mutual-resonance shielding and can handle up to 15 nuclides [NPY-P-116].
6. BIGG-II: an Algol version of the IFA, Kjeller code [NPY-P-126].
7. BIGG-S: a modified version of the BIGG-II code that guarantees the positivity of solutions to the B-1 Greuling-Goertzel equations. This code also uses a slightly modified library (report in preparation).
8. EWA-TAPE: an enlarged version of the one-dimensional code EWA-I. It can deal with up to 40 energy groups.
9. EWA-ADJOINT: algorithm of EWA-I used for adjoint flux.
10. EWA-III: algorithm of EWA-I supplemented with logarithmic boundary condition.
11. EWA-II: two-dimensional diffusion code with a new, very fast iteration scheme. Its present version can deal with up to 1900 space points. This algorithm is very promising. Work on its theoretical basis is in progress.
12. DIFIGREC-JAP: an accelerated version of the previous DIFIGREC-2D, few-group diffusion code and based on the line overrelaxation scheme. The anisotropy of the diffusion has also been introduced.

Besides these, some minor calculational subroutines were developed:

DOVER:	a Kushneriuk method for logarithmic boundary condition calculation for a cylinder (unpublished).
GAP:	a few-group subroutine for the effective boundary condition calculations in cylindrical geometry.
BUCKLING-EWA:	a fitting procedure for finding the value of the axial buckling from a given set of data (unpublished).

In Yugoslavia the following reactor physics codes have been developed or adapted:

(1) ANTER: calculates the thermal disadvantage factor by the analytical method using the energy-dependent boundary conditions [NPY-Y-13].
(2) SIGMA: calculates the group values of cross-sections, scattering matrix and outer sources of neutrons using the Brown St. John scattering model [IBK-449].
(3) MULTI: a multigroup or multipoint P_3 program for calculating thermal neutron spectra in a reactor cell [NPY-Y-37].
(4) CAMP: calculates the multipoint data for thermal neutron spectra determination using the Lagrange interpolation scheme [IBK-714].
(5) VESTERN: a one-group program for thermal disadvantage factor calculation using the collision probability method [IBK-653].
(6) PRIMAX: calculates the optimal fuel distribution in a high-flux research reactor according to the Pontryagin maximum principle [NPY-Y-51].
(7) PEZEPEF-CP-1: solves the eigenvalue problem for the stationary diffusion operator [NPY-Y-53].
(8) PEZEPEF-BZN: solves the eigenvalue problem for the diffusion operator without delayed neutrons [NPY-Y-53].
(9) HETERO: a two-dimensional criticality code based on Feinberg-Galanin heterogeneous theory. Solves K_{eff} and flux distribution for a square and hexagonal lattice.
(10) RESON: determines the slowing-down spectra of neutrons in a reactor lattice cell (resonance absorption effects).
(11) MARIA: a two-dimensional diffusion calculation of thermal neutron flux distribution in a perturbed three-region reactor cell.
(12) PEZEPEF-SZN: a group of programs for the solution of the eigenvalue problem for a diffusion operator with delayed neutrons [NPY-Y-53].

8. ON-LINE DIGITAL COMPUTER CONTROL OF REACTORS

A detailed program of cooperation in this task was formulated with the emphasis on:

The development of adaptive control with on-line identification of parameters changes;
The reduction of dimensionality of the model by simplification of the control strategy;
The estimation of flux and power distribution;
The development of methods for prediction of an accidental situation.

As the first step in the cooperation, the formulation of the mathematical model of a large nuclear reactor was considered. According to this decision the Polish group developed its first version [NPY-P-110]. Later this version was slightly modified by the Norwegian group by introducing common pressure feedback, necessary in a BWR reactor. This group also elaborated the model in more detail, introducing coefficients and their numerical values. It was agreed that this model be used in further cooperation calculations of optimal strategy [NPY-P-129].

One of the ideas of the simplification of the control strategy was the splitting of a system into small, weakly interacting subsystems. In [NPY-N-84] a partitioning of the system into five smaller subsystems was investigated with compensation for the interaction effects by cross-coupling controllers. In [NPY-N-85] the optimum control law was calculated based on a much-reduced, one-point model, giving satisfactory results for short-term transients.

Two methods were investigated for treating the optimal control of distributed parameter systems:

(a) A modal expansion of the dynamics equations, leading to a very simple control design [NPY-N-87] (second order Ricatti Eqs)

(b) The usual dynamics programming approach for finite systems, generalized to distributed systems. The system is described by the Green' s function, which can be measured experimentally [NPY-N-88]. Two computer programs were completed for process identification from experimental data. One code works on the basis of differential equations, the other builds up a linear time discrete representation.

In Poland the influence of the time delay of temperature feedback on the linear dynamics of the coupled core reactors was investigated. It was found that instability occurs for some values of the above time delay.

Non-linear power reactor dynamics was considered in the example of a one-point non-linear model with two temperature reactivity feedback. The stability of this non-linear model was investigated by means of the Volterra functional approach and the Runge-Kutta method [NPY-P-132, 133]. In Yugoslavia, work is near completion on the identification of the linear dynamic systems. The same situation occurs in the synthesis of the optimal feedback regulator using the maximizing principle of Pontryagin.

Specific results for the problem of constraints were obtained in three ways:

(i) Using Lagrangian multipliers for constraints on input variables
(ii) Formulating the suboptimal regulator (constraints on state variables)
(iii) Using "physical amplitude" restrictions of control signals.

These approaches should be compared and, if possible, combined. The results discussed refer mostly to the first two items in the list of chosen problems to be solved under this task. There are plans to continue this cooperation in another form, as will be discussed later on.

9. BURNUP CALCULATIONS AND EXPERIMENTS

The activities of the Norwegians concentrated on the development and testing of three codes for analysis of boiling-water reactors (BWR).

RECORD is a code for burnup analysis of BWR fuel elements. A multigroup model is used to represent the epithermal range. The thermal energy range extends up to 1.84 eV to handle the ^{240}Pu low-energy resonances. The point-energy method is used for thermalization calculations. Flux distributions within the elements are calculated by 5-group diffusion theory.

PRESTO is a three-dimensional BWR simulator belonging to the class of codes coming from the American FLARE code. BWR life histories may be simulated, on a macroscopic scale, taking into account the interaction between nuclear power and thermal hydraulic conditions. Fuel elements and control rods are individually represented. Power distributions in three dimensions are calculated optionally by diffusion theory or the nodal coupling method. The diffusion scheme is based on coarse mesh representation and requires a modest computer memory. Nuclear data are represented by polynomials generated by separate runs of RECORD or a similar code. FSC-II is a code designed for fuel management studies in a BWR. Using simplified physical models combined with iterative methods, various refuelling parameters may be determined so as to optimize fuel cycle economy under given constraints.

In Poland, owing to limited computer possibilities, the work until now was limited in scale. The one-point burnup and fission products code TIDEC, based on the CINDER [WAPD-TM-334] approach for fission products chains, was completed with three auxiliary libraries for fission products.

Polish Fellows cooperated with Norwegian colleagues in elaboration of the fast, two-dimensional diffusion code FROST [NPY-N-81], calculating the neutron flux distribution in a BWR fuel assembly.

The Yugoslavians developed the TER code (a burnup code based on the Swedish BOB and REBUS) in three versions and the REDIR code giving the axial and radial reactor macroparameters as a function of burnup [NPY-Y-32, 33].

As a part of the scientific activity of the NPY-Project, a series of Seminars and Summer Schools was organized which were devoted to the discussion of chosen problems important for the cooperative program. The main objectives of these Seminars and Summer Schools were twofold:

To review the progress in various branches of reactor physics, with the outline of their foreseeable future trends as the basis for the NPY-Joint Committee recommendations.

To increase the scientific level of the NPY staff, to organize the exchange of ideas and experience among NPY specialists, and to use these occasions for other countries (Member States of the IAEA) to train their staff.

All these Seminars and Summer Schools were partially financed by the IAEA and partially by the host country. The assistance of the IAEA in providing lecturers and Fellowships for NPY and non-NPY Fellows is gratefully acknowledged.

The list of the NPY-Seminars organized during the existence of the Project is as follows:

1. Seminar on Resonance Absorption Effects, Belgrade, Yugoslavia, January 1964; invited lecturer: R. Hellens, Brookhaven National Laboratory, USA.
2. Seminar on Reactor Kinetics and Related Topics, Kjeller, Norway, May 1964; invited lecturers: H. Smets, ENEA, Paris, A. T. Eurola, Halden Project, N. G. Sjöstrand, Chalmers Technical University, Gothenburg.
3. Seminar on Neutron Thermalization, Warsaw, Poland, December 1965; invited lecturer: P. Michael, Brookhaven National Laboratory, USA.
4. Seminar on Reactor Noise Analysis, Kjeller, Norway, March 1966; invited lecturers: P. Stegemann, Kernforschungszentrum, Karlsruhe, W. Matthes, Euratom, Ispra.
5. Seminar on Numerical Solution of Multidimensional Diffusion Equations, Warsaw, Poland, March 1969; invited lecturers: K. Lathrop, General Atomics, USA, R. Coveyou, IAEA.

Each of these Seminars was attended by about 25-30 participants from many IAEA Member States, who usually took a very active part in the discussions and presented their own contributions. Chosen problems for the topics of NPY-Seminars were usually directly correlated with the definite tasks of the NPY-Project and were intended to resolve certain difficulties or to summarize the output of the cooperative efforts.

Besides these seminars, at each NPY Joint Committee Meeting the host country to the Meeting presented a Technical Seminar which was a review of results achieved during the $1\frac{1}{2}$ year period since the last Joint Committee Meeting in that country. The Seminars, together with visits to laboratories, helped the Joint Committee to keep in touch with the actual situation in the implementation of the NPY tasks in all three countries and helped it to make its organizational and scientific decisions. These activities are considered a very important part of the organizational experience gained during the activity of the Project and are highly recommended for similar projects.

The following International Advanced Summer Schools in Reactor Physics took place:

1. 13-28 September 1964, Zakopane, Poland. The scientific program covered various subjects of theoretical and experimental reactor physics and was given by nine invited lecturers from different countries. Also, informal seminars were held in order to discuss the topics covered by the program. There were about 30 papers contributed by 67 participants and 19 observers from 28 countries from all over the world. Lecture notes were published by the IAEA in 1966.
2. 22 August - 2 September 1966, Sandefjord, Norway. The scientific program covered the interpretation, analysis and utilization of reactor physics experiments in thermal critical and subcritical assemblies. Seminars and discussions were organized after each lecture, including a number of original presentations by the participants. Eight invited lecturers delivered 10 lectures, published afterwards by IFA, Norway in 1967. The school was attended by about 90 participants.

3. 31 August - 10 September 1970, Hercegnovi, Yugoslavia. The scientific program covered physical problems on thermal neutrons of nuclear power reactors. Nine lectures were delivered by seven invited lecturers. The school was attended by 92 participants from 24 countries. Lectures were followed by discussions and seminars. The school was concluded by two panels devoted to the following subjects:

   (a) The problems in reactor physics of interest to the countries importing power reactors
   (b) Outstanding problems in power reactor physics.

   The lectures are to be published by the IAEA.

It is considered that these Schools served the NPY-countries as well as the scientific community of IAEA Member States working in the field of reactor physics. It is most desirable to keep the tradition of organizing such Summer Schools by the IAEA. If this happens, all active participants of the NPY-Project will consider these Schools as the best tribute to the existence of NPY-Project and the spirit of the scientific cooperation and friendship which was successfully generated during the seven years of its activity. This opinion was expressed by all lecturers and participants of the 3rd NPY International Summer School in Hercegnovi.

Looking back on the output of the NPY-Project we can distinguish problems of rather limited scope, which were closely connected with the national programs of the cooperating parties. Tasks and problems of a more general character, interesting to a wider circle of physicists working in reactor development, were also formulated. Some of the tasks have been carried out. Some of those which are not yet finished merit further research because of their general importance. The IAEA has considered substituting the NPY-Project by a series of scientific co-operations on a larger scale with greater scientific potentialities, trying to build up a series of coordinated research programs. These programs are to include more scientific institutions working in reactor physics and interested in cooperative efforts of the type of the NPY-Project.

It is contemplated that three co-ordinated research programs be formed which are devoted to the following topics, recommended by NPY-Joint Committee and many scientific panels organized by the IAEA and other scientific organizations:

(1) Fuel burnup calculations and experiments

There exists a need to improve existing possibilities in optimization of fuel management problems. This improvement requires a specific progress in theoretical and calculational methods and comparison of these methods with properly programmed experiments. A very important part of these activities should be problems related to the re-evaluation of existing nuclear data, especially for fission products.

(2) Dynamics and digital control of power reactors

The contemporary nuclear power reactors require an optimal control to meet imposed conditions of safe and economic operation. It is considered that this problem can be best solved with the use of on-line digital control. On the other hand, this imposes a number of problems related to reactor dynamics, control theory and instrumentation.

(3) New methods in linear transport theory

It has been recognized recently that many aspects and techniques of reactor theory and calculations should be re-evaluated and/or reformulated on sounder physical and mathematical foundations. These requirements are due to new reactor concepts and operational demands and the rapid development of computer technology. The only rational way to meet these new conditions is the development of advanced transport theory methods in practical calculations. Studies of the mathematical properties of transport equations should be oriented towards greater efforts to apply their results to the further development of numerical methods of neutron transport theory.

If these Coordinated Research Programs attract a larger number of scientific institutions and stimulate cooperative research in Europe, those who took an active part in the establishment and activity of the NPY-Project will consider their efforts as successful not only from the point of view of their national goals but also from that of their contribution to the IAEA activities and those of the scientific community of reactor physicists.

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It seems very appropriate to take this opportunity to express, on behalf of the entire community of NPY scientists, sincere thanks to Prof. S. Andrzejewski, Dr. V.O. Eriksen, Mr. Vojen R. Guyina and Dr. S. Eklund for their personal interest in the NPY-Project activities and the invaluable assistance and support of the Governments of Poland, Norway and Yugoslavia, and of the IAEA, which should be considered the crucial contribution to the final success of the Project.

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AN APPROACH TO REGIONAL COOPERATION IN NUCLEAR ENERGY: THE NORDIC COLLABORATION

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Abstract–Résumé–Аннотация–Resumen

AN APPROACH TO REGIONAL COOPERATION IN NUCLEAR ENERGY· THE NORDIC COLLABORATION.

Work in nuclear energy in Denmark, Finland, Norway, and Sweden has been organized in quite different ways to suit the individual needs of each country. The national nuclear energy institutes and their programs in relation to the nuclear power schedules are briefly described in the paper. In 1957 a permanent liaison group was created by the governments to follow development and promote cooperation. According to a recommendation from this group, collaboration was intensified in 1968 through the foundation of the Nordic Co-ordination Committee for Atomic Energy. This committee caters to permanent exchange of relevant information and knowledge between the national institutes and initiates common ventures. The committee members act through their normal positions as directors of the institutes, and each institute remains independent and continuously adapts its programs to national needs. One additional committee member acts as an official exclusively devoted to Nordic cooperation in this field. Whenever a scheme for practical collaboration between two or more institutes has been worked out, the committee proposes the conclusion of an agreement on this particular item between the institutes involved. In this manner important joint ventures have been carried through, mainly in areas related to reactor technology. These are enumerated and described in the paper. Some of them are discussed in other contributions to this conference. Schemes for Nordic cooperation in related fields are also mentioned, such as Nordel (the electricity producers' organization), and the collaboration organized around the large-size Swedish nuclear power station Ringhals. Finally, an official collaboration scheme between the four countries has been set up in reactor safety. Its initial aim is to make recommendations for uniform rules concerning reactor licence applications, and to promote, as far as possible, the harmonization of safety criteria.

REALISATION D'UNE COOPERATION REGIONALE DANS LE DOMAINE DE L'ENERGIE NUCLEAIRE· COLLABORATION ENTRE LES PAYS NORDIQUES.

Les activités dans le domaine de l'énergie nucléaire au Danemark, en Finlande, en Norvège et en Suède ont été organisées de façons assez différentes afin de répondre aux besoins propres à chaque pays. Les centres nationaux d'énergie nucléaire et leurs programmes de travail en matière d'installation de centrales nucléaires sont brièvement décrits. En 1957 les gouvernements ont créé un groupe de liaison permanent pour suivre le développement et pour encourager la coopération. Conformément à une recommandation de ce groupe, la collaboration a été intensifiée en 1968 par la création du Comité nordique de coordination nucléaire. Ce comité s'occupe de l'échange permanent d'informations et de connaissances entre les centres nationaux, et il prend l'initiative d'entreprises communes. Les membres du comité agissent en tant que directeurs des centres, et chaque centre reste indépendant et adapte ses programmes aux besoins nationaux. Un autre membre du comité remplit les fonctions de fonctionnaire nordique commun, entièrement voué à la coopération nordique dans ce domaine. Lorsqu'un projet de collaboration pratique entre deux ou plusieurs centres a été élaboré, le comité propose la conclusion d'un accord sur ce sujet particulier entre les centres intéressés. De cette manière, des travaux communs importants ont été réalisés, principalement dans les domaines se rapportant à la technologie des réacteurs. Ces travaux sont énumérés et décrits en détail dans le mémoire. Certains des projets communs sont examinés dans d'autres communications présentées à cette conférence En outre, des programmes de coopération nordique dans des domaines voisins sont mentionnés, par exemple le Nordel (organisation des producteurs d'électricité) et la collaboration organisée dans la grande centrale nucléaire de Ringhals en Suède. Finalement, dans le domaine de la sécurité des réacteurs, un plan officiel de collaboration entre les quatre pays a été élaboré, dont l'objectif initial est de recommander des règles uniformes concernant les demandes d'autorisation pour les réacteurs, et de contribuer autant que possible à l'harmonisation des critères de sécurité.

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РЕГИОНАЛЬНОЕ СОТРУДНИЧЕСТВО СКАНДИНАВСКИХ СТРАН В ОБЛАСТИ ЯДЕРНОЙ ЭНЕРГИИ: НОРДИК.

Деятельность в области ядерной энергии в Дании, Финляндии, Норвегии и Швеции организована по-разному и направлена на удовлетворение индивидуальных потребностей каждой страны. В докладе кратко излагается деятельность национальных учреждений по ядерной энергии и реализация их программ, касающихся планов развития ядерной энергетики. В 1957 году правительствами была создана постоянная группа связи в целях содействия развитию и сотрудничеству. В соответствии с рекомендацией этой группы в 1968 году был создан Координационный комитет скандинавских стран по атомной энергии, который значительно расширил сотрудничество в этой области. Этот Комитет осуществляет постоянный обмен соответствующей информацией между национальными институтами и содействует осуществлению совместных проектов. Члены комитета действуют в соответствии с их обычными занимаемыми должностями как директора институтов; каждый институт остается независимым и постоянно разрабатывает программы применительно к своим национальным нуждам. Один дополнительный член комитета выступает в качестве чиновника от всех скандинавских стран и занимается сотрудничеством в этой области. Всякий раз, когда разрабатывается программа практического сотрудничества между двумя или более институтами, Комитет предлагает заключить соглашение по данному вопросу между соответствующими институтами. Таким образом, проводятся важные совместные работы, главным образом в области реакторной техники. В докладе перечисляются и рассматриваются указанные работы. Некоторые из них освещаются в других докладах, представленных на эту конференцию. Рассматриваются также проекты сотрудничества скандинавских стран (НОРДИК) в соответствующих областях, как например, НОРДЕЛЬ (организация производителей электроэнергии) и сотрудничество по строительству крупной атомной электростанции Рингалс в Швеции. Наконец, утверждена программа сотрудничества между четырьмя странами в области безопасности реакторов. Первоначальной целью этой программы является разработка рекомендаций по единым правилам применения лицензий к реакторам и содействие, в пределах возможного, разработке единой системы норм безопасности.

LA COOPERACION REGIONAL EN EL CAMPO DE LA ENERGIA NUCLEAR: COLABORACION ENTRE LOS PAISES NORDICOS.

Las actividades en el campo de la energía nuclear en Dinamarca, Finlandia, Noruega y Suecia se han organizado de formas muy diferentes para ajustarlos a las necesidades individuales de cada país. Las instituciones nacionales de energía nuclear y sus programas en relación con los planes de energía nucleoeléctrica se describen brevemente en la memoria. En 1957 los Gobiernos crearon un grupo permanente de enlace para continuar el desarrollo y promover la cooperación. De acuerdo con una recomendación del grupo, en 1968 se intensificó la colaboración a través de la fundación del Comité Nórdico para la coordinación de la energía atómica. Este Comité procura un intercambio permanente de información y de conocimientos entre las instituciones nacionales y emprende trabajos comunes. Los miembros del Comité actúan desde sus puestos de directores de las instituciones, y cada instituto permanece independiente y adapta continuamente sus programas a las necesidades nacionales. Un miembro adicional del Comité se ocupa exclusivamente de la cooperación nórdica en este campo. Siempre que se elabora un plan de colaboración práctica entre dos o más instituciones, el Comité propone la conclusión de un acuerdo sobre el particular entre las instituciones de que se trate. De esta forma se han llevado a cabo importantes empresas conjuntas, principalmente en campos relacionados con la tecnología de los reactores. La memoria enumera y describe dichas empresas, algunas de las cuales se discuten en otras memorias presentadas en esta conferencia. Se mencionan también algunos planes de cooperación nórdica en campos afines, como el Nordel (Organización de productores de electricidad) y la colaboración organizada en la gran central nuclear sueca Ringhals. Se ha establecido un plan de colaboración oficial de los cuatro países en el campo de la seguridad de los reactores. Su propósito inicial consiste en hacer recomendaciones para uniformizar las normas en materia de solicitud de licencias para reactores, y en promover, en todo lo posible, la armonización de los criterios de seguridad.

1. BACKGROUND FOR COLLABORATION BETWEEN NUCLEAR ENERGY INSTITUTES

Few other areas have seen such an extensive collaboration across the borders as nuclear research. Close relations between nuclear energy laboratories or "institutes" have been favoured by their simultaneous development in many countries and, consequently, by a desire to benefit from experience gained elsewhere and to limit expenditure.

Schemes for collaboration between nuclear institutes must take into account similarities and differences between them so that cooperation efforts can be placed at an appropriate level. World-wide, regional and national schemes may each have their advantages depending on the topics involved.

The scope of a national nuclear research institute and its goals depend on the circumstances prevailing in the particular country. Of special influence is the state of advancement of nuclear power and its industrialization, the organization of research and development in related fields, the need for educational programs, and the expert knowledge required by authorities.

The original, general purpose of many nuclear research institutes is gradually turning into more specific goals as areas previously in the domain of research are taken over by industry, electricity producers and others. The change of policy which can at present be observed at many nuclear institutes is a proof of their efforts to make continually the best use of their resources and to meet new requirements. Nuclear research institutes, with their unique combination of expertise in many different disciplines, provide an excellent focal point for the solution of scientific and industrial problems in new areas and are particularly suited to stay in the forefront of development.

Today, the scope appears to be from purely scientific work to typical nuclear energy development, diversification into non-nuclear areas and commercialization of activities. In spite of such differences in goals, rewarding forms of collaboration between nuclear institutes can be found. In this paper a regional system is described where an attempt has been made to take advantage of cooperation without investing in extensive organizational measures. This regional system is complementary to participation in world-wide collaboration as organized through the IAEA and to other more specific schemes such as European nuclear collaboration sponsored by ENEA and bilateral agreements of collaboration with other countries.

2. NUCLEAR WORK IN DENMARK, FINLAND, NORWAY, AND SWEDEN[1]

2.1. The Nordic Collaboration

In the four Nordic countries in northern Europe there is a tradition for international collaboration. The close relation between these countries in cultural, natural and political setting, the comparable standards of living and education and the similar scientific levels all contribute to creating the basis for what has been termed the Nordic or Scandinavian Collaboration, which extends into hundreds of different fields.

It should be stressed that the four countries, with a total of approximately 20 million inhabitants, form neither a political nor an economic union. Any collaboration scheme is measured by its real merits and carried through only to the extent that it is useful for the participants.

[1] The fifth Nordic country, Iceland, is not further mentioned in this paper although it takes part in some of the cooperation schemes described.

2.2. The nuclear field

The form the Nordic Collaboration has taken in the nuclear field can be considered a consequence of (1) the different needs for nuclear power, (2) the varying industrial engagement in the nuclear field, and (3) the different organization of nuclear research and development work in each country.

(1) The need for nuclear power is by far the greatest in Sweden and Finland, whose hydro sources will soon be fully committed. The first Swedish commercial nuclear plant goes on line this year, and more than 7000 MW(e) are expected to be in operation in 1980. Finland's first nuclear plant is on order, and another two are to be completed by 1980 to give a total of 1500 MW(e). In Norway, one third of the hydro reserves are still unexploited, and the first nuclear station is now expected around 1980. Danish electricity producers feel confident that with the prevailing special conditions, conventional thermal power can also be produced economically in the years to come, and also here the first nuclear plant is expected only about 1980.

(2) The commitment of industry in the Nordic countries shows a similar spread. Sweden's half state-owned Asea-Atom is the only reactor vendor not just in Scandinavia but also the only one outside the "big" countries. Industrial firms specializing in various components for nuclear plants are already active in Finland also, while in Norway certain special components related to nuclear installations are being marketed.

(3) The work at the state-financed nuclear research institutes has long traditions going back to the Norwegian Jeep reactor which went critical in 1951. With the difference in timing for introduction of nuclear power, the original, more general research programs have developed in a characteristic direction in each of the four countries.

Denmark

The Risö research establishment operated by the Danish Atomic Energy Commission is located at Roskilde near Copenhagen. It has a staff of about 800 of whom 200 have an academic or similar degree. The net operating costs ($10 million in 1971) are provided in the budget of the AEC and form part of the Danish state budget.

Under the terms of reference of the Danish AEC, research and development at Risö have from the outset in 1955 been directed towards many different aspects of scientific and practical peaceful uses of atomic energy. The work today thus comprises not only reactor technology, but also basic and applied research in a number of fields where research reactors and other radiation sources are put to use. Solid state physics and radiation chemistry take up important positions in the basic research program.

Several senior members of the staff hold teaching posts at institutes of higher education, and a number of students as well as post-graduate students perform their research work at Riso. Similarly, the basic research at Risö is in close contact with University research in neighbouring fields.

In applied research, collaboration is found with enterprises in such areas as plant breeding and medico-technical application of radiation and isotopes. Industry also participates in work related to reactor technology, for example in fuel element manufacture, where the knowledge obtained is equally useful for fuel fabricators, electricity producers, and in safety evaluation. Together with the National Health Service, the Danish AEC is responsible for assessing the safety of nuclear power plants, and hence it is expected that Risö will be called upon to provide the technical expertise that will be needed for this task in the future.

Finland

Nuclear research and development work is not centralized in one single research institute. The major part of the work is carried out at the Otaniemi Reactor Laboratory of the State Institute for Technical Research. The latter, together with the Helsinki University of Technology, now form the important Otaniemi Polytechnical Research Center located just outside Helsinki. Another part of the work is carried out by various groups working at different research institutes.

All nuclear research and development work is co-ordinated by the Atomic Energy Commission, which has an advisory function to the Ministry of Commerce and Industry.

Owing to the decentralized organization, there is no clear definition of the total amount of governmental funds and of persons involved in Finnish nuclear research. They may be estimated at approximately $3 million in 1971 and 120 persons, of whom 70 have an academic or similar degree.

As the Finnish nuclear work was started relatively late and as there is an important nuclear power program, work is now mainly concentrated on functions that are essential in order to develop the knowledge needed for controlling the design, construction and operation of power plants. Specialist teams have been formed in such areas as materials, reactor dynamics, reactor codes, reliability, environment, reactor safety, etc. Direct contributions are also made by the Ministry to the development work carried out by the component industry, in particular the Finnatom Company created by eight industrial firms for the purpose of manufacturing components for the nuclear power industry.

Norway

Institutt for Atomenergi (IFA) located at Kjeller near Oslo is a foundation partly financed by the state ($4.5 million in 1971) with outside contributions amounting to about 50% of the state contribution. A total of 500 persons are employed (120 with academic or similar degrees). The Institute has an advisory function to the Ministry of Industry to which it also reports. The Council for Scientific and Industrial Research advises the Ministry on the scope of work of the Institute.

There is close cooperation with the major power producers and consumers, with whom assessment studies have been performed on problems related to the introduction of nuclear power. The particular problem of underground containment in solid rock has attracted much attention.

The Halden reactor, home site of the OECD Halden Reactor Project where ten countries and organizations are collaborating, is owned by the Institute. Development work in fuel technology, with emphasis on fuel performance and reliability studies, is part of the Halden reactor program.

Hot-cell facilities at Kjeller are offered on a commercial basis for post-irradiation investigations in this connection. Experience in fuel technology is made available to a Norwegian firm producing Zircaloy canning tubes.

Part of the nuclear work has found non-nuclear application: fuel reprocessing technology is applied in the separation of rare earths in collaboration with industry, and experience in reactor digital-control work has found widespread application in industrial process control. Production of isotopes for medical and industrial applications has taken place for more than fifteen years. The Institute has a close cooperation with hospitals in this matter.

The Netherlands-Norwegian reactor school at Kjeller, in operation for more than 10 years, organizes courses with a large international attendance. Student training is offered at the universities, particularly in physics and physical chemistry.

Sweden

AB Atomenergi is a wholly state-owned company with a program council composed of representatives from industry and power producers and advising the board on future activities. The company is mainly located at Studsvik and has a staff of 1000 (200 with academic or similar degrees). Another branch with 100 people is located at the uranium mill in Ranstad, now used for large-scale development work. State contributions of $12 million cover the operation of the company infrastructure and a base program mainly concentrated on light-water reactors and the uranium mill. Plutonium recycling and fast breeder work is also done, but the latter now receives lower priority on account of the late starting date for commercial breeder reactors expected in Sweden.

Results of state-funded research and development work in reactors and fuels are made available to Asea-Atom and other Swedish industries and utilities, while specific tasks are performed for payment. Such development work is a vital task, as a reactor vendor must have its concepts tested in facilities that are only available at a sizable nuclear institute, and AB Atomenergi has made a point of providing facilities tailored to the needs of water reactor development.

Another type of task performed for utilities and authorities is the investigation of safety aspects of nuclear plants and their location close to urban areas.

The facilities and services at Studsvik are also available on commercial terms to companies from abroad. Efforts are being made to increase diversification from purely nuclear work; one example is the measurement of pollution caused by car exhaust gases. Yearly contributions from paid tasks now amount to $6 million, mainly from nuclear work, and include revenues from isotope sales. There is thus a strong move towards commercialization. Modern planning and full-cost budgeting systems are used.

Long-range research is limited to what can be financed through outside funds, at present approximately $2 million annually. The main source is the Swedish Board for Technical Development which, through its distribution of funds, acts as a co-ordinating state agency for development work all over the country. Training of students, mainly in physics, takes place at the Studsvik reactors and other facilities. The Swedish Research Council has separate laboratories at Studsvik for its scientists.

2.3. A comparison of the four institutes

As will be seen from the foregoing, we have in these four countries a typical example of different approaches to nuclear energy work (see also Table I). Within the general framework of policy changes at nuclear research institutes we can compare the present role of the Nordic institutes and their relation to nuclear power and research work.

In Denmark the institute is maintaining its character as a specialized scientific nuclear research centre with links to research organizations all over the country. In Norway the move is towards industrial development both inside and outside the nuclear power field. In Sweden, where there is an ambitious nuclear industry, the work at the institute is concentrated on nuclear technology with a conscious effort towards commercial viability. In Finland, where there is no nuclear research institute as such, work is confined to the immediate problems in connection with the first nuclear plants and the component industry entering the nuclear market.

The cooperation between these four institutes is an example of possibilities and limits in international collaboration.

3. ORGANIZATION OF NORDIC COLLABORATION IN THE NUCLEAR FIELD

3.1. Governmental and research institute committees

In 1957 the governments of the Nordic countries decided to create a permanent Nordic Liaison Committee for Atomic Energy with the main task of following developments in the nuclear field. This Liaison Committee, composed of state officials from the five Nordic countries, meets twice a year to discuss policy matters in international affairs and initiatives for cooperation to be taken within the Nordic ountries. Customarily the four countries alternatively occupy one seat on the IAEA Board of Governors. Two groups with specific working areas, NAK and NARS, have been created by and report to the Liaison Committee.

NAK, the Nordic Co-ordination Committee for Atomic Energy, was created in 1968. NAK attempts to make the best possible use of the resources at the nuclear institutes and promotes co-ordination of their research and development programs. NAK has as its members the four managing directors from the institutes and one liaison officer. NAK does not act as an independent organization, but decisions reached in the committee are carried through at the institutes concerned by virtue of the committee members' executive positions. As no separate organization has been built up for NAK, all administrative work is referred to the institutes. The liaison officer, who is also a member of a working group handling the day-to-day problems of Nordic cooperation, supervises the practical application of the guidelines decided upon. Specialist groups are called upon when new schemes for collaboration are to be examined or proposed.

NARS, the Nordic Working Group on Reactor Safety, was created in 1969. Its purpose is to propose common guidelines for reactor safety assessment documents and to promote, as far as possible, the harmonization of safety criteria. These rules are intended to serve as a basis for the preparation of official guidelines in each of the countries.

TABLE I. NORDIC NUCLEAR ENERGY RESEARCH INSTITUTES

	Organizational form	Research centre	Direct state contribution in 1971 (million $)	Total budget in 1971 (million $)	Personnel (academic/ total)	Main working areas, 1971	Nuclear generating capacity expected in 1980 (MW(e))
Denmark	AEC, state-financed (under Minister of Education)	Risö	10	10	200/800	Basic and applied research	Possibly 600
Finland	Advisory AEC, work under State Institute for Technical Research (Ministry of Commerce and Industry)	At Otaniemi Polytechnical Research Centre	3	3	70/120	Work related to first power plants	1500
Norway	Independent foundation (under Ministry of Industry) partly state-financed	Kjeller and Halden	4.5	7	120/500	Use of knowledge for national industry	Possibly 800
Sweden	State-owned company (under Ministry of Industry) partly state-financed	Studsvik and Ranstad	12	20	200/1100	Commercial tasks and development for reactor industry	Above 7000

3.2. Other joint organizations

Parallel to the committees already mentioned, the electricity producers in the Nordic countries have created their own cooperation in the Nordel organization. Here questions of common interest are handled, such as the routine exchange of electricity between the countries and planning activities [1]. The latter include the distribution network, where Nordel has recommended important additional links between the Nordic countries. In certain cases, an organized sharing across borders of output from oversized nuclear plants will take place.

Another power producer's initiative is the Ringhals centre, where staff from the Nordel companies gain experience by taking part in the planning, construction and startup phases of what is so far the largest Swedish nuclear power station (2 × 800 MW).

Numerous other fields related to nuclear energy are the subject of Nordic collaboration. Examples are the implementation of ICRP recommendations, specifications for radioactive drugs for the Nordic Pharmacopea, and related quality requirements.

3.3. Stages of cooperation

The experience obtained from the schemes described shows that positive results can be obtained regardless of the extent of cooperation aimed at. From the work of NAK some general conclusions can now be drawn on the possible stages of cooperation between nuclear institutes with different scopes.

(1) An initial step is to organize an ample exchange of information, which must be carefully planned to make it efficient at all levels. This first stage may allow participants to benefit systematically from experiments and experience relevant to their own work.

(2) In the natural continuation of step (1), such information exchange may lead to discussions of future programs. As a result, programs planned at one institute may be modified so as to give results more directly useful to the work carried out at another institute. Such a scheme will obviously be succesful only if reciprocity is obtained.

(3) Where activities at other institutes are complementary to a program carried out at one laboratory, the next step is to arrange for participation by sending people from the other institutes to take part actively in the work at the laboratory in question. In this case, the management of the work remains entirely with the host laboratory but the practical experience is shared.

(4) A stage where activities are more evenly distributed is the cooperation scheme termed "joint project", carried through at one particular institute. In this scheme, the costs are shared by the parties who also send manpower and take an active part in the planning and project execution. The results obtained are common property.

(5) The most advanced stage of participation realized in the collaboration between the Scandinavian institutes is a project with distributed tasks where the work is divided between all the institutes involved, while a joint group evaluates the results and recommends further action. This arrangement is practical in central fields of common interest and reduces the necessity of placing staff at the other institutes.

3.4. Organizational experience

It has proved practical to make separate arrangements for each cooperative venture started according to schemes (3) through (5). Here, one institute assumes the role of host organization and takes care of all administrative matters. General guidelines have been worked out concerning agreements, principles of payment, right to obtained knowledge, patents, etc. Each project is operated by a project council with representatives from the institutes involved. NAK only influences the work of the groups when policy matters have to be settled.

As mentioned, a necessary condition for establishing cooperation between different institutes is an efficient flow of information at all levels. It is important that scientists and engineers should be convinced of the professional merits of a collaboration scheme in order that they give it their personal support. Preferably, initiatives for new ventures should come from persons directly involved in the work. Another principal point is to make use of the existing organizations without creating new bodies that might cause wasteful duplication of work.

Scientific work seems most suited for cooperation according to schemes (1) and (2), which are limited to information about present and future work. Only if equipment is needed which would not otherwise be available are more far-reaching schemes selected. In many cases, the international scientific contacts and traditional collaboration partners abroad attract scientific workers more than does the work done at other Scandinavian institutes.

The best results of Nordic cooperation have been obtained in technological areas. Other national or foreign commitments may, however, prevent institutes from taking part in new joint development projects. The closer the working field is to commercial application, the more restrictive are the participants and the more complicated the organization of a common venture will be.

4. PRACTICAL RESULTS FROM THE NORDIC COOPERATION

The co-ordination organized within the framework of NAK has helped to create a positive climate where specialist groups have been formed and joint projects run that have added to the experience and opened new perspectives for the participants. A total of forty different matters are or have been handled according to the collaboration schemes described in the preceding chapter. The corresponding expenditure (cash contributions and man-hours spent on joint projects) can be estimated at less than $5 million over three years and may appear modest when compared to the total yearly state expenditure at the institutes ($30 million in 1971 according to Table I). When considering this figure it should be remembered, however, that from the yearly budget of each institute only a minor part is available for new projects and that Nordic projects have also to compete on equal terms with national programs that cover a far larger field of activities.

4.1. Two-phase flow

One technological area that has proved to be well-suited for Nordic collaboration is related to two-phase flow in power reactor fuel elements. Calculation methods are today insufficiently developed to permit predictions to be made with the desired accuracy for normal and accident conditions in light-water reactors. Better knowledge would allow reactor designers to establish closer safety margins and reactor operators to improve their control routines and permit analysis of possible accidents.

Several joint projects have been run in this area. The first one comprised engineering tests with full-scale fuel models in the 6-MW "Frigg" test-loop at the Asea-Atom laboratory in Sweden, where a group of Nordic engineers and technicians took part in the experiment for several months.

The second project aims at producing a three-dimensional calculation code for the dynamic behaviour in reactor cores. The code combines neutron physics, heat transmission and hydraulics. This work is being done in Norway by a joint Scandinavian team, and the code will be tested in an operating Swedish power reactor.

A third project comprises research on the nature of flow patterns in subchannels in fuel elements; here work is done at each of the Institutes, Risö, Kjeller and Studsvik, on different element configurations, while a joint theory group located in Denmark develops the corresponding computer programs and acts as a central advisory body in the experimental work.

4.2. Concrete reactor vessels

Another area of technology which has been developed in a comprehensive Nordic project is that of the use of prestressed concrete reactor vessels in water reactors [2]. With the increasing unit size of nuclear plants and the transportation problems with large steel reactor vessels, and with the need for power production near urban areas, there seems to be an incentive for the development of the technology for concrete vessels on account of their safety characteristics and their convenient erection procedure on site, requiring a comparatively short building time. A detailed 1 : 3.5 scale model has been erected and tested at Studsvik as a joint project. It demonstrates the specific features for water reactor application, e.g. a rapidly removable lid and a novel removable insulation system. Complementary calculations with different programs have been performed at Risö, where concrete irradiation tests are also made. Another series of parallel tests with smaller models was run in Norway, while studies on concrete permeability took place in England.

Electricity producers as well as private industrial firms have actively participated in the project. Stress calculations and aspects of concrete technology were supervised by an advisory committee including university professors and consultants from industry. In a continuation of the experimental work another Nordic study group has evaluated the design and safety aspects of a prestressed concrete tank for a full-size (850-MW(e)) boiling-water reactor. Questions related to location of concrete reactor vessels in rocks and to actual construction of a full-size model tank are being evaluated.

4.3. Safety

The field of reactor safety seems destined for a broad regional collaboration. In each country the nuclear research institute has its specific tasks and role in safety matters in relation to the competent authorities. There is, however, a large number of parallel activities with a bearing on safety that takes place at each of the institutes. On their part, safety authorities in the Nordic countries do collaborate in a number of areas, and the NARS working group on reactor safety, described in Section 3, is an example of authority collaboration confirmed by a governmental agreement.

NARS has established a number of small groups composed of specialists mainly from the four Nordic nuclear institutes. Each group prepares part of the recommendations concerning the data to be presented in safety documents about such items as, for example, siting, plant equipment and its reliability, analysis of normal operation, incidents and accidents, etc. In the present phase, work on criteria has started with criteria for safety systems. International recommendations, safety evaluation report guides, and general design criteria from other countries are used as working documents, but the NARS document is intended to be more specific and adapted to the conditions in the Nordic countries.

Exchange of information has been organized on an ad hoc basis in a number of other areas related to safety, such as meteorological dispersion phenomena, criticality regulations for local work with fissile materials, retention of active gases and aerosols, etc. A joint group with participants from institutes and electricity producers evaluates the availability of calculation codes for accidental release of activity from the reactor core and its containment, and in this connection the need for results from large-scale containment experiments is examined with a view to making use of the Marviken installations in Sweden. Finally, more general areas of work such as metallurgy (fracture mechanics) and instrumentation in reactor control are examined to establish common goals in work related to safety.

4.4. Zirconium and hot cells

Even areas where industrial competition exists can lend themselves to cooperation, at least on the basic development side. One example is the nuclear application of Zircaloy. Development of novel zirconium alloys is organized so that identical material is tested at several institutes. Testing methods are distributed so that the best use is made of particular qualifications existing at each institute.

Similarly, in the field of post-irradiation examination of irradiated fuel in hot cells, experience on working methods and equipment is openly exchanged in spite of the competition for outside customers existing between the three Scandinavian hot-cell laboratories.

4.5. Administration

In order to facilitate the organization of cooperative ventures, action on several aspects has been taken on the administrative side. Recommendations for presentation of budgets and for uniform fees to be charged have been worked out. Joint ventures are basically financed according to the same scale as is used for the national contributions to the IAEA. However, host organizations for joint projects carry a relatively higher burden in exchange for the benefit of having the experimental facility at their institute and keeping their staff at their home site.

4.6. Documentation

In the documentation field the Nordic atomic libraries have formed their own joint secretariat. The four libraries act as one region in relation to the USAEC for the exchange of information for Nuclear Science Abstracts and also operate as a single region in the International Nuclear Information System of the IAEA. Co-ordination of key-wording and information retrieval is planned in order to rationalize the daily documentation work.

5. CONCLUDING REMARKS

In this paper an attempt has been made to describe how regional collaboration can be organized between national nuclear energy laboratories in spite of their different scopes and purposes. The advantages of the system described are flexibility, low cost, and the absence of an independent joint organization. The correct functioning of the system is supervised by one person who is jointly employed by the organizations involved and who is sufficiently familiar with the working areas to identify fields where new initiatives may be taken. Experience has confirmed the value of this sytem where exchange of information on all levels organized through the staff itself can lead to important joint ventures.

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LA STRUCTURE DU COMITE D'ETAT POUR L'ENERGIE NUCLEAIRE DE LA REPUBLIQUE SOCIALISTE DE ROUMANIE ET SES ACTIVITES EN MATIERE DE COOPERATION INTERNATIONALE

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Abstract–Résumé–Аннотация–Resumen

THE STATE COMMITTEE FOR NUCLEAR ENERGY IN ROMANIA AND ITS ACTIVITIES IN THE FIELD OF INTERNATIONAL COOPERATION.

The paper deals with the organization of the State Committee for Nuclear Energy and its main tasks in achieving a national nuclear program in Romania. Taking into account the catalytic role which the development of international cooperation plays in the present technical and scientific revolution, the paper underlines the importance of international cooperation for nuclear development in Romania. The paper then refers to Romania's experience in international cooperation for the peaceful uses of atomic energy, emphasizing the role of bilateral and multilateral international cooperation. Also emphasized is the significance of Articles IV and V of the Treaty on the Non-Proliferation of Nuclear Weapons, which stresses the necessity of international cooperation for development as a legal obligation of the States Parties. Also presented are certain concrete activities of cooperation within some international nuclear organizations to which Romania belongs such as the International Atomic Energy Agency, the Commission for Atomic Energy of the CMEA, JINR-Dubna, and others. The paper also discusses the role played by the IAEA in the development of international cooperation in the nuclear field and the tasks of the Agency in the context of the NPT. Particular importance is attached to international cooperation for the necessary training of staff. The last part of the paper suggests some forms and methods of international cooperation in peaceful uses of nuclear energy, which should be useful for the future.

LA STRUCTURE DU COMITE D'ETAT POUR L'ENERGIE NUCLEAIRE DE LA REPUBLIQUE SOCIALISTE DE ROUMANIE ET SES ACTIVITES EN MATIERE DE COOPERATION INTERNATIONALE.

Les auteurs décrivent la structure du Comité d'Etat pour l'énergie nucléaire et les principales attributions de celui-ci dans le cadre du programme nucléaire roumain. Vu le rôle catalyseur que joue la coopération internationale dans l'actuelle révolution technique et scientifique, ils soulignent l'importance de cette forme de coopération pour le développement nucléaire en Roumanie. Puis ils présentent l'expérience de la Roumanie en matière de coopération internationale dans le domaine des applications pacifiques de l'énergie nucléaire, en soulignant le rôle de la coopération internationale bilatérale et multilatérale. Ils relèvent la portée des articles IV et V du Traité sur la non-prolifération des armes nucléaires (TNP), qui font de la coopération internationale à des fins de développement une obligation juridique pour les Etats parties. Les auteurs mentionnent également certaines activités concrètes en matière de coopération qui se déroulent dans le cadre des organismes internationaux s'occupant du domaine nucléaire et dont la Roumanie fait partie, tels que l'Agence internationale de l'énergie atomique, la Commission pour l'énergie atomique du Conseil d'assistance économique mutuelle et l'Institut unifié de recherches nucléaires de Doubna. Les auteurs se réfèrent également au rôle joué par l'AIEA dans le développement de la coopération internationale conformément aux tâches que lui confère le TNP en matière de coopération nucléaire. Ils soulignent le rôle que doit jouer la coopération internationale dans la formation du personnel. Ils suggèrent enfin des formes et des méthodes de coopération internationale dans le domaine des applications pacifiques de l'énergie nucléaire qui pourront à l'avenir être utilement mises à profit.

ГОСУДАРСТВЕННЫЙ КОМИТЕТ ПО ЯДЕРНОЙ ЭНЕРГИИ СОЦИАЛИСТИЧЕСКОЙ РЕСПУБЛИКИ РУМЫНИИ И ЕГО ДЕЯТЕЛЬНОСТЬ В ОБЛАСТИ МЕЖДУНАРОДНОГО СОТРУДНИЧЕСТВА.

В докладе дается описание структуры Государственного комитета по ядерной энергии и его основных задач в рамках ядерной программы Румынии. Учитывая стимулирующую роль, которую играет международное сотрудничество в современной научно-технической революции, авторы подчеркивают важность этого вида сотрудничества для развития применения ядерной энергии в Румынии. Далее говорится об опыте Румынии в области международного сотрудничества по мирному использованию ядерной энергии. Подчеркивается значение статей IV и V Договора о нераспространении ядерного оружия, в котором необходимость международного сотрудничества рассматривается как юридическое обязательство государств – участников Договора. Авторы дают также описание некоторых конкретных видов деятельности в этой области в рамках международных организаций, занимающихся вопросами применения ядерной энергии и участником которых является Румыния,– таких,как Международное агентство по атомной энергии, Комиссия по атомной энергии Совета Экономической Взаимопомощи, Объединенный институт ядерных исследований в Дубне и др. Авторы рассматривают роль, которую играет МАГАТЭ в развитии международного сотрудничества в области атомной энергии, а также задачи Агентства в связи с Договором о нераспространении. Подчеркивается роль международного сотрудничества в подготовке специалистов. В заключительной части доклада предлагаются некоторые формы и методы международного сотрудничества в области мирного применения ядерной энергии, которые могут эффективно использоваться в будущем.

EL COMITE ESTATAL PARA LA ENERGIA NUCLEAR EN LA REPUBLICA SOCIALISTA DE RUMANIA Y SUS ACTIVIDADES EN MATERIA DE COOPERACION INTERNACIONAL.

Los autores describen la estructura del Comité Estatal para la Energía Nuclear y sus cometidos principales dentro del programa nuclear rumano. Subrayan luego algunos problemas relacionados con la importancia que tiene la cooperación internacional para el desarrollo de la energía nuclear en Rumania, teniendo en cuenta que esa cooperación actúa de catalizador de la revolución científica y técnica actual. Más adelante explican la experiencia de Rumania en la cooperación internacional para los usos pacíficos de la energía atómica, haciendo resaltar el papel de la cooperación internacional bilateral y multilateral. Insisten también en la importancia de los artículos IV y V del Tratado sobre la no proliferación de las armas nucleares, que señalan la necesidad de la cooperación internacional con fines de desarrollo, al considerarla como obligación jurídica de los Estados signatarios. Los autores señalan actividades concretas en la cooperación dentro de algunas organizaciones internacionales nucleares a las que pertenece Rumania, como por ejemplo el Organismo Internacional de Energía Atómica, la Comisión de Energía Atómica del COMECON y el Instituto central de investigaciones nucleares de Dubna. También se refieren al papel del OIEA en el desarrollo de la cooperación internacional y a los objetivos que le señala el TNP en el campo nuclear. Se presta atención particular al papel de la cooperación internacional en el adiestramiento del personal. La última parte expresa algunos puntos de vista que se refieren a los métodos de cooperación internacional para los usos pacíficos de la energía nuclear que podrían aplicarse en lo futuro.

1. GENERALITES

Au cours du dernier quart de siècle, l'un des traits fondamentaux de la vie économique et sociale de la Roumanie a été l'accroissement continuel et rapide des indices de développement dans tous les domaines d'activité. La Roumanie socialiste, en poursuivant une politique d'industrialisation rationnelle, s'est élevée au rang des Etats bénéficiant du développement économique et social le plus dynamique. Le rythme d'accroissement de la production industrielle globale, qui atteindra 12% entre les années 1971 et 1976, le confirme. Un résultat particulièrement favorable a été atteint dans le cadre du plan quinquennal pour la période 1966-1970, au cours de laquelle la production industrielle a été presque égale à celle des trois plans quinquennaux précédents.

Etant donné que ce développement rapide a des effets considérables sur toute la vie sociale, il a imposé un développement correspondant de la science et de la technique en Roumanie. Un intérêt particulier est accordé à la physique, et surtout à la physique nucléaire, qui est un des domaines les plus avancés de la science moderne et qui offre la possibilité de nombreuses applications sans lesquelles le progrès rapide d'une société est aujourd'hui inconcevable.

Dans un discours prononcé devant la Quatorzième session de la Conférence générale de l'AIEA, le Président du Conseil d'Etat de la République socialiste de Roumanie, Son Excellence Monsieur Nicolae Ceauşescu, déclarait: «La Roumanie, consciente de l'importance décisive de la physique atomique dans la vie de la société contemporaine, fait des efforts considérables pour développer la recherche nucléaire et pour utiliser l'énergie d'origine atomique dans différents domaines de la production et de la vie sociale — parmi lesquels je mentionnerai spécialement la construction de certaines centrales nucléaires — pour l'utilisation de cette immense force dans la vaste œuvre qu'elle réalise: l'édification d'une nouvelle société.»

L'évolution rapide de l'industrie et d'autres activités économiques et sociales a exigé une augmentation rapide de la puissance installée des centrales électriques. En Roumanie, la puissance installée s'élevait à la fin de l'année 1970 à 7000 MW(e) environ, la production totale brute d'énergie électrique dépassant 35 TWh. Le temps de doublement de la production d'énergie a été de cinq ans pendant la dernière décennie; pour les années 1970-1980, on prévoit un doublement tous les six ans environ.

La Roumanie possède des réserves énergétiques fossiles (pétrole, gaz naturel, charbon). Cependant, quelque grandes que soient ces réserves, elles sont toutefois limitées et, dans l'avenir, même avec le complément que leur apportera la mise en valeur de la plus grande partie du potentiel hydraulique qu'il est techniquement possible d'aménager, elles ne suffiront pas au développement de la production énergétique au rythme exigé par les décennies futures.

D'ailleurs il ne faut pas perdre de vue le fait que les réserves de pétrole roumain, d'une qualité supérieure, ainsi que celles de gaz naturel, sont normalement utilisées avant tout par l'industrie pétrochimique, qui est la mieux à même d'en assurer la mise en valeur. Dès lors, la Roumanie essaie de résoudre le problème de la «faim d'énergie» par d'autres moyens: l'importation de pétrole, l'exploitation aussi intensive que possible des ressources hydrauliques et l'«industrialisation» de l'énergie nucléaire sont, pour le moment, les uniques solutions, la solution d'avenir étant l'utilisation des réserves d'uranium et de thorium pour la production d'énergie dans des centrales nucléaires de grande puissance.

Ces raisons ont amené le Gouvernement roumain à décider d'introduire l'énergie d'origine nucléaire dans le système de production énergétique du pays dans le courant de cette décennie même.

En fait, la production d'énergie d'origine nucléaire n'est pas le seul bienfait offert par la physique atomique. Le développement des applications de la science nucléaire dans des domaines de plus en plus nombreux de l'économie et de la vie sociale est l'une des caractéristiques de l'époque contemporaine. Quoique la production d'énergie d'origine nucléaire n'en soit aujourd'hui qu'à son début en Roumanie, les applications des techniques atomiques ont déjà pénétré dans la vie quotidienne.

2. LE COMITE D'ETAT POUR L'ENERGIE NUCLEAIRE ET SES INSTITUTS — LE PROGRAMME NUCLEAIRE NATIONAL

Les activités en matière de recherche et d'applications pacifiques de l'énergie nucléaire ont pris un essor particulier après l'année 1955, lorsque, par décision du Gouvernement roumain, ont été créés le Comité pour l'énergie nucléaire, organe consultatif du Gouvernement, et, en 1956, l'Institut de physique atomique de Bucarest.

Depuis lors et jusqu'en 1969, l'accent a été mis surtout sur la formation de personnel, l'adaptation de l'enseignement aux conditions nouvelles, et l'équipement adéquat des laboratoires.

Afin d'accélérer le développement de cet important domaine, le Gouvernement roumain a approuvé en 1969 le premier Programme nucléaire national, dont les objectifs sont scientifiques, technologiques et industriels et qui prévoit des investissements importants et complexes. L'exécution de ce programme aura des effets sensibles sur le développement économique et social du pays; toutes les branches de l'industrie et de nombreux autres secteurs de l'économie nationale et de la vie sociale contribueront à sa réalisation.

Les principaux objectifs sont l'industrialisation de l'énergie nucléaire, à savoir la construction d'ici à 1980 de centrales nucléo-électriques d'une puissance totale de 1000 MW(e) environ et la mise sur pied d'industries connexes, ainsi que la promotion de recherches fondamentales visant à soutenir le programme et à introduire les techniques nucléaires dans un grand nombre de secteurs économiques et scientifiques.

Ces objectifs ayant été fixés par le Programme nucléaire national, un décret du Conseil d'Etat, émis le 30 décembre 1969, a créé le Comité d'Etat pour l'énergie nucléaire de la République socialiste de Roumanie, qui a remplacé l'ancien comité.

Le Comité d'Etat pour l'énergie nucléaire est l'organe administratif central; c'est lui qui exécute les décisions gouvernementales dans le domaine nucléaire; il lui incombe de développer la production d'énergie d'origine nucléaire et d'introduire les techniques nucléaires dans l'industrie et d'autres branches de la vie économique et sociale, tout en tenant compte des progrès de la science et des nécessités du pays. Le Comité est responsable, au niveau de l'Etat, de toutes les activités qui ont trait à la recherche, à l'établissement de projets et à la production, depuis les recherches fondamentales jusqu'à l'industrialisation de l'énergie nucléaire par la construction de centrales nucléaires.

A cette fin le Comité d'Etat pour l'énergie nucléaire possède son budget propre, approuvé par le plan d'Etat, il dispose d'unités pour la recherche, les études de projets et la production, il gère des centres d'enseignement et d'information et des entreprises chargées de l'étude et de la réalisation des centrales nucléaires et autres installations touchant au domaine nucléaire. Le Comité coordonne en matière de méthodologie et soutient matériellement les activités de plus de 300 établissements nucléaires sur tout le territoire du pays ainsi que les associations et sociétés scientifiques de physique pure ou nucléaire.

Les recherches scientifiques sont effectuées à l'Institut de physique atomique et à l'Institut de physique de Bucarest, ainsi qu'à l'Institut des isotopes stables de Cluj; ces établissements dépendent du Comité d'Etat pour l'énergie nucléaire. Le personnel comprend plus de 2300 employés et la majorité des disciplines nucléaires modernes y sont étudiées. Des recherches similaires sont effectuées dans les universités de Bucarest, Cluj, Iaşi et Timişoara et d'autres établissements encore.

Les recherches, fondamentales aussi bien qu'appliquées, s'étendent maintenant à des domaines variés de la physique et des techniques nucléaires: physique et technologie des réacteurs, production d'énergie d'origine nucléaire, étude des effets des rayonnements sur la matière, essais de matériaux nucléaires, physique des plasmas, étude de l'état condensé de la matière par la méthode de diffusion des neutrons lents, physique des radiations cosmiques et des particules élémentaires, étude des réactions nucléaires à énergie haute, moyenne et basse, spectroscopie nucléaire, etc.

L'Institut de physique atomique et d'autres centres roumains fabriquent les instruments qui, outre l'outillage importé, forment l'équipement de base des unités nucléaires qui fonctionnent dans les différentes branches de l'industrie, de l'agriculture, de la médecine, etc.

Une des tâches principales du Comité est de développer les recherches en matière de technologie nucléaire dans une mesure suffisante pour que puisse être atteint le but fondamental du Programme: l'industrialisation de l'énergie nucléaire. L'expérience nécessaire est acquise par des recherches originales ainsi que par une coopération avec des centres de recherche d'autres pays et une collaboration étroite avec l'industrie (construction de machines, métallurgie, chimie, production d'énergie, etc.).

Le passage au stade de la mise au point des technologies et de l'établissement des projets doit se faire dans un cadre adéquat; un centre technologique national, l'Institut de technologie nucléaire, a été fondé. Cette nouvelle unité, subordonnée au Comité d'Etat pour l'énergie nucléaire, assurera la liaison entre la recherche fondamentale, appliquée et industrielle; elle mettra au point les technologies nécessaires à la construction de centrales nucléaires et autres unités, en utilisant au maximum le potentiel de personnel technique et scientifique disponible.

Aussi parfaits que soient l'organisation et l'équipement d'un réseau d'instituts et de centres de recherche, les résultats escomptés ne peuvent pas être obtenus sans l'existence de personnel possédant les qualifications requises. C'est ainsi qu'on a fondé récemment, conformément aux objectifs du Programme nucléaire, un Centre de formation et de spécialisation dans les branches nucléaires, qui préparera des ouvriers, des techniciens et des spécialistes ayant fait des études universitaires.

Le Centre de la documentation et des publications nucléaires a, lui aussi, été fondé récemment. Son rôle sera d'entretenir des contacts étroits avec tous les centres similaires du monde pour être à même de recevoir rapidement les informations les plus récentes dans le domaine nucléaire, de les classifier et de les mettre immédiatement à la disposition des instituts de recherche, des laboratoires, de l'industrie et des établissements d'enseignement. Le Centre devra aussi fournir aux établissements similaires de l'étranger des informations sur les travaux effectués en Roumanie et leur faire parvenir les publications des spécialistes roumains.

La figure 1 représente l'organigramme des unités qui relèvent du Comité d'Etat pour l'énergie nucléaire.

Le Comité d'Etat pour l'énergie nucléaire est dirigé par un conseil d'administration (comité). Son Président est membre du Gouvernement roumain. Il est secondé par un premier vice-président, un vice-président et un secrétaire général ainsi que par des conseillers.

Un conseil technique et scientifique donne des avis sur les principaux problèmes soumis à l'approbation du Comité ou du Président.

Le Comité est subdivisé en plusieurs départements techniques, scientifiques et administratifs. La figure 2 en donne l'organigramme.

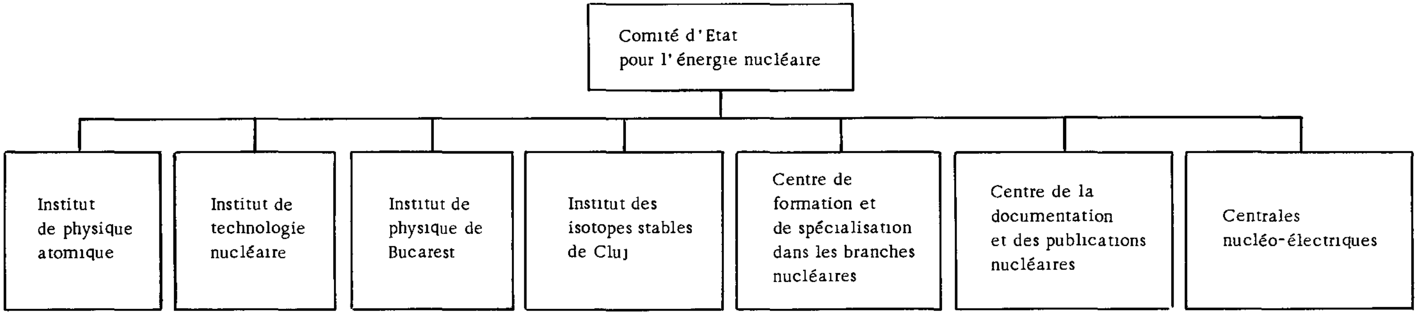

FIG.1. Le Comité d'Etat pour l'énergie nucléaire et ses instituts.

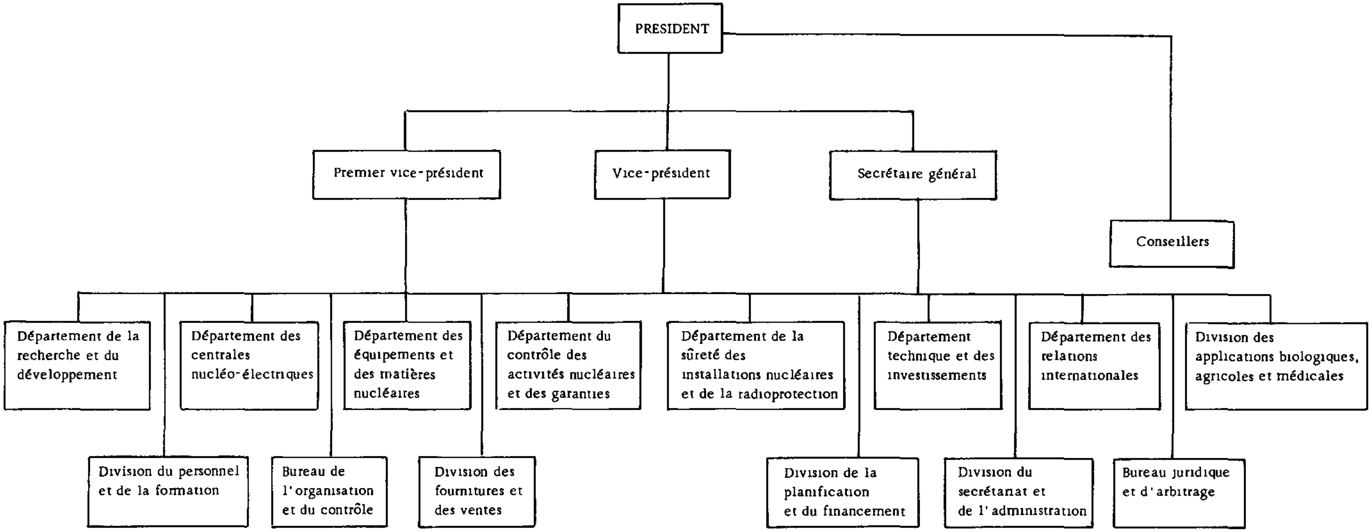

FIG.2. Organigramme du Comité d'Etat pour l'énergie nucléaire.

L'Inspectorat général de la sécurité et de la radioprotection délivre les autorisations sans lesquelles les unités nucléaires ne peuvent fonctionner. Toutes les activités nucléaires du pays sont contrôlées par un inspectorat d'Etat, qui fonctionne dans le cadre du Comité d'Etat pour l'énergie nucléaire.

3. COOPERATION INTERNATIONALE

Le Programme nucléaire national sera exécuté grâce à l'effort soutenu des spécialistes roumains et à une collaboration internationale. Conformément à sa politique de promotion de la coopération internationale, et compte tenu de la signification spéciale qu'il faut accorder dans ce contexte aux problèmes techniques et scientifiques, la Roumanie attache une importance toute particulière à la coopération avec d'autres Etats dans le domaine des applications pacifiques de l'énergie nucléaire.

La coopération internationale doit favoriser le développement de tous les pays, tout en contribuant à réduire le décalage existant entre eux. Une telle coopération, l'une des conditions essentielles du progrès de toutes les nations et l'une des prémices de la solution de nombreux problèmes d'intérêt général, implique nécessairement des relations multilatérales et diversifiées.

Ces relations ne pourront être développées et consolidées sans que soient respectées et appliquées rigoureusement dans les relations entre Etats, quel que soit leur régime social et politique, les normes fondamentales du droit et de la légalité internationale. Il s'agit en l'espèce des principes de l'indépendance et de la souveraineté, de l'égalité en droits des peuples et des Etats, de la non-ingérence dans les affaires intérieures d'autres Etats et de la réciprocité des avantages.

L'évolution de la coopération internationale à un rythme toujours plus rapide est un phénomène caractéristique de l'époque actuelle. Chaque pas fait par l'humanité sur la voie du développement des forces productives et du progrès scientifique, technique et social doit resserrer les liens qui unissent les Etats et conduire à augmenter le volume aussi bien que la qualité des échanges internationaux.

Par les activités qu'elle déploie dans le cadre des organisations et des réunions internationales, par ses initiatives et ses suggestions, la Roumanie entend contribuer au développement de la collaboration internationale, à la promotion de la justice et de la légalité dans le monde, et à la sauvegarde et à la consolidation de la paix.

La coopération internationale dans le domaine des applications pacifiques de l'énergie nucléaire est un problème complexe. Le besoin général de coopération qui domine l'époque contemporaine, en s'étendant aux aspects les plus dynamiques de la révolution technique et scientifique actuelle – l'avènement de la science nucléaire – révèle en même temps les contradictions générées par le caractère bivalent de l'utilisation de l'énergie atomique et le niveau inégal de développement des Etats.

Le domaine nucléaire, de par ses dimensions, de par les bienfaits qu'il peut apporter à l'humanité et les ressources humaines et matérielles qu'il exige, rend la coopération internationale indispensable.

Les applications pacifiques de l'énergie nucléaire constituent aujourd'hui un des domaines d'activité sans lesquels aucune nation ne peut avancer sur la voie du progrès. La production d'énergie électrique, les multiples applications des isotopes et des rayonnements dans l'industrie, l'agriculture, la médecine, etc., s'imposent comme une nécessité objective dans la vie économique et sociale de tout pays.

La production d'énergie électrique, de même que les autres applications des techniques nucléaires, exigent pour l'exécution des travaux de recherche et d'industrialisation des efforts financiers importants, une technique bien développée, et du personnel qualifié dans de nombreuses disciplines. Ces exigences dépassent bien souvent les moyens dont disposent les pays petits et moyens et posent parfois, même aux grands pays fortement industrialisés, des problèmes difficiles à résoudre.

Il est par conséquent essentiel que les Etats mettent un accent particulier sur la coopération internationale dans le domaine nucléaire.

L'existence dans la famille des Nations Unies d'une organisation spécialisée, les conférences internationales périodiquement organisées par l'ONU et l'AIEA, le nombre élevé d'accords bilatéraux de coopération consacrés exclusivement aux applications pacifiques de l'énergie nucléaire attestent le fait que la voie vers une coopération internationale dans ce domaine a déjà été ouverte.

Convaincue qu'une collaboration internationale mutuellement profitable facilite les efforts nécessaires au développement des Etats dans un domaine aussi important que celui des applications de l'énergie nucléaire, la Roumanie déploie une vaste activité dans ce domaine, dans le cadre des organisations internationales comme dans celui des accords bilatéraux.

On sait que la Roumanie est un des membres fondateurs de l'Agence internationale de l'énergie atomique. La parole du représentant le plus autorisé du peuple roumain, Son Excellence Monsieur Nicolae Ceauşescu, Président du Conseil d'Etat de la République socialiste de Roumanie, s'est fait entendre à la tribune de cette organisation l'année passée pour faire connaître la décision de notre pays de militer constamment en vue d'instaurer un climat propice à la coopération internationale, à la consolidation de la paix par un désarmement général et, en premier lieu, un désarmement nucléaire, à la mise à la disposition de tous les Etats, sans aucune discrimination, des résultats obtenus dans le domaine nucléaire.

Le Président du Conseil d'Etat de la Roumanie, dans son discours, a souligné que: «L'Agence internationale de l'énergie atomique peut contribuer par ses activités à l'introduction des grands avantages offerts par l'application de la physique nucléaire dans le circuit mondial des valeurs, à éliminer le sous-développement, à hausser le niveau de civilisation de tous les peuples. Une importance particulière est attachée, dans ce sens, à l'activité de l'Agence pour le développement de la coopération au profit de la recherche et de l'utilisation pacifique de l'énergie nucléaire, l'intensification de l'échange d'informations et d'expérience, pour soutenir les efforts des pays membres qui luttent pour combler leur retard dans ce domaine. C'est ainsi que l'Agence internationale de l'énergie atomique peut largement contribuer à la détente internationale, à l'entente entre les peuples, à la cause de la paix dans le monde.»

La délégation roumaine a pris une part active et constructive aux nombreux débats qui ont eu lieu dans le cadre de l'AIEA et a apporté une contribution positive au développement de cette organisation par les initiatives qu'elle a présentées.

Une coopération étendue et diversifiée avec l'AIEA a été en permanence au centre de l'attention dans ce pays, la Roumanie participant à différents programmes de l'Agence: assistance technique, bourses, échanges de scientifiques, de publications, etc. Les spécialistes roumains, dans le cadre de contrats signés avec l'Agence, ont effectué une série de recherches intéressantes et utiles. Ces recherches ont été faites ou sont en cours à l'Institut de physique atomique, à l'Institut des isotopes stables de Cluj, au Centre de chimie physique, à l'Institut polytechnique de Bucarest, à l'Institut d'études et de recherches hydrologiques, au Centre de recherches agricoles, à l'Institut oncologique de Bucarest, au Centre de gastro-entérologie, etc.

La Roumanie est membre fondateur de l'Institut unifié de recherches nucléaires (IURN) de Doubna et prend une part active à ses travaux. Les représentants de la Roumanie aux réunions des organes directeurs de l'IURN – Conseil des Représentants plénipotentiaires des Gouvernements des Etats membres et Conseil scientifique – ont soumis des propositions utiles qui ont été adoptées par l'Institut, et ont participé à l'élaboration des programmes de recherche et de coopération de manière à servir les intérêts de tous les Etats membres. A l'heure actuelle de nombreux spécialistes roumains travaillent en permanence à l'Institut de Doubna; de plus, des stages de travail sont organisés régulièrement. La collaboration avec l'Institut unifié de recherches nucléaires a été diversifiée; elle est axée sur des thèmes efficaces et les résultats obtenus sont positifs.

L'année dernière a été célébré le dixième anniversaire de la fondation de la Commission permanente du Conseil d'assistance économique mutuelle (CAEM) pour l'utilisation de l'énergie atomique à des fins pacifiques. Pendant toutes ces années la Roumanie a participé sans interruption aux activités de cette organisation. Conformément à la politique de notre pays, la délégation roumaine a toujours milité en faveur de l'élargissement et de la diversification de la coopération entre les pays socialistes membres du Conseil. Les instituts compétents de Roumanie ont pris part, sous l'égide du CAEM, à une série d'activités intéressantes pour le pays: recherches communes, échanges d'expérience, établissement de pronostics, d'étalons, etc.

Les physiciens roumains apportent en outre leur contribution aux travaux de deux organisations non gouvernementales, l'Union internationale de physique pure et appliquée et la Société européenne de physique, forums importants qui réunissent des physiciens du monde entier. Parmi les activités déployées en Roumanie on peut citer le Seizième Congrès international AMPERE, organisé en 1970 à Bucarest, qui a emporté un succès bien mérité.

La collaboration de la Roumanie dans le domaine des applications pacifiques de l'énergie nucléaire se déploie aussi par des relations bilatérales fondées sur des instruments juridiques au niveau du Gouvernement ou des ministères.

Le plan de coopération extérieure du Comité d'Etat pour l'énergie nucléaire prévoit la réactivation des accords existants et, chaque fois que cela est nécessaire et possible, leur remplacement et leur amélioration, ainsi que la signature de documents juridiques fixant des modalités de collaboration avec les Etats, lorsque de tels documents n'existent pas encore.

Des protocoles d'application fondés sur les accords existants ou ceux qui seront conclus dans l'avenir seront signés, qui prévoiront des visites d'information et de documentation, des échanges de spécialistes et de personnel enseignant, des stages de travail, l'octroi mutuel de bourses de spécialisation, l'organisation en commun de réunions scientifiques et techniques, l'échange de renseignements, de documentation, de publications, etc.

Cette forme de coopération commence à prendre corps: des conventions entre l'Institut de physique atomique, l'Institut des isotopes stables de Cluj et l'Institut de physique de Bucarest ont été conclues ou sont actuellement négociées avec des instituts ou laboratoires étrangers.

En 1970 les Gouvernements de la République socialiste de Roumanie et de l'Union des Républiques socialistes soviétiques ont signé un accord de coopération pour la construction en Roumanie d'une centrale nucléaire de 440 MW(e). La collaboration entre les spécialistes roumains et soviétiques a déjà commencé et le temps n'est pas loin où la construction proprement dite de la centrale sera entreprise.

Des négociations sont en cours avec des firmes étrangères en vue de réaliser d'autres objectifs du Programme nucléaire national; une coopération est aussi envisagée avec celles-ci en matière de recherche nucléaire et d'application des isotopes et des sources de rayonnements.

Une importance toute particulière est attachée à la coopération bilatérale et multilatérale dans les problèmes de formation du personnel. Le Comité d'Etat pour l'énergie nucléaire a organisé dans son Centre de formation et de spécialisation, en collaboration avec les unités du Ministère de l'enseignement, des cours couvrant une large gamme de spécialités et des niveaux de formation différents. Il existe ainsi une section des centrales nucléaires à l'Institut polytechnique de Bucarest, une section de physique et de technique des réacteurs à l'Université de Bucarest, des cours post-universitaires ou post-lycée concernant l'électronique nucléaire, les centrales nucléaires, la dosimétrie des rayonnements, les matériaux nucléaires, les applications des isotopes; des lycées spécialisés dans les techniques nucléaires ont aussi été fondés.

Cependant, pour compléter ces cours il a été et il est nécessaire d'envoyer des spécialistes à l'étranger surtout en ce qui concerne les techniques nucléaires. Le choix des stages se fait conformément au Programme nucléaire national. Un appui spécial a été reçu d'Etats avec lesquels la Roumanie a des relations bilatérales développées dans le domaine nucléaire, ainsi que de quelques organisations internationales comme l'AIEA, l'IURN, le CAEM, etc. A l'heure actuelle une des préoccupations majeures est le choix optimal des disciplines de spécialisation; ce choix est centré principalement sur les domaines directement liés à l'industrialisation de l'énergie nucléaire, où notre pays a moins d'expérience.

Par ailleurs, la Roumanie est prête à recevoir des spécialistes d'autres pays en vue de leur perfectionnement dans le cadre des nouvelles formes d'étude ainsi organisées et offre aussi des bourses tant sur la base d'accords bilatéraux que par l'intermédiaire de l'AIEA.

4. LE TRAITE SUR LA NON-PROLIFERATION DES ARMES NUCLEAIRES

Dans cette analyse il est nécessaire de souligner l'importance du Traité de non-prolifération, des éléments nouveaux qu'il introduit dans les relations internationales en matière nucléaire. La Roumanie s'est prononcée et continue à se prononcer en faveur du désarmement général, et avant tout du désarmement nucléaire. En sa qualité de membre de la

Commission du désarmement, à Genève, la Roumanie a pris part à l'élaboration du Traité de non-prolifération et a été l'un des premiers pays qui l'ait signé et ratifié. La Roumanie a aussi participé aux travaux du Comité des garanties de l'AIEA.

En vertu du Traité de non-prolifération, les Etats non dotés d'armes nucléaires Parties au Traité s'engagent à ne pas fabriquer ou acquérir d'armes nucléaires ou d'autres dispositifs nucléaires explosifs, obligation qui est soumise à un contrôle international dont l'exécution a été confiée à l'Agence internationale de l'énergie atomique.

D'autre part, le Traité contient l'obligation expresse pour les Parties de coopérer en contribuant, à titre individuel ou conjointement avec d'autres Etats ou des organisations internationales, au développement plus poussé des applications de l'énergie nucléaire à des fins pacifiques, en particulier sur les territoires des Etats non dotés d'armes nucléaires qui sont Parties au Traité, compte dûment tenu des besoins des régions du monde qui sont en voie de développement.

Pour ne pas avoir d'effets négatifs, un traité international ne doit pas porter atteinte au développement des Etats signataires, ni à la coopération entre eux. Le problème qui se pose avant tout est de veiller à ce que ce contrôle n'entrave pas le développement de la production et des recherches dans le domaine des applications pacifiques de l'énergie nucléaire et n'affecte pas la protection du secret industriel dans les établissements soumis au contrôle, phénomènes qui seraient à même d'influencer le développement d'un pays.

Le préambule du Traité énonce les principes dont le strict respect aura des effets positifs sur son application. L'automatisation du contrôle dont il est question dans le préambule peut permettre de renoncer à la présence physique des inspecteurs dans les installations ou de la réduire au minimum, tout en perturbant le moins possible la production et en contribuant ainsi à protéger le secret industriel.

Un tel traité, qui doit permettre de progresser sur la voie de la sécurité internationale, doit constituer un élément constructif du développement des Etats signataires, et de l'expansion et de la diversification des relations entre ces pays. C'est dans cet esprit que doivent être appliquées les clauses du Traité de non-prolifération, et que doivent être adoptées des mesures concrètes de nature à assurer l'accès de tous les Etats à la science et à la technologie nucléaires afin de faciliter le développement de leur industrie atomique.

Afin d'atténuer l'influence que pourrait avoir, sur le développement des applications pacifiques de l'énergie d'origine nucléaire, l'interdiction pour les Etats non dotés d'armes nucléaires d'avoir une activité propre dans le domaine des explosions nucléaires, on a inséré dans le Traité l'article V, destiné à garantir que les avantages potentiels découlant des applications pacifiques des explosions nucléaires seront mis à la disposition des Etats non dotés d'armes nucléaires Parties au Traité.

L'interdiction des utilisations militaires de l'énergie nucléaire et son contrôle pourraient être accompagnés d'une libéralisation de la diffusion de renseignements sur ses applications pacifiques, et l'octroi aux inspecteurs de l'AIEA du libre accès aux installations nucléaires des Etats non dotés d'armes nucléaires pourrait être contrebalancé par la libéralisation de l'accès des spécialistes de ces pays aux entreprises industrielles et de recherche nucléaire des Etats dotés d'armes nucléaires qui sont Parties au Traité.

La mise en pratique des dispositions de l'article IV impose une obligation majeure aux Etats Parties au Traité et fera, sans aucun doute, l'objet de négociations entre ces pays. L'application de cet article, qui affecte profondément la coopération internationale dans le domaine nucléaire, soulèvera des problèmes nouveaux autour de toutes les tables de négociation, des discussions bilatérales jusqu'à l'Assemblée générale des Nations Unies.

Un rôle particulier revient à cet égard à l'AIEA, dont les activités dans ce domaine devront s'étendre à la suite de l'entrée en vigueur du Traité.

Quoique le Traité ne stipule pas expressément le rôle qui reviendra à l'AIEA dans l'application de l'article IV du Traité, les objectifs fixés dans cet article imposent une obligation majeure, également stipulée dans le statut de l'Agence, à savoir: encourager la coopération internationale dans le domaine des applications pacifiques de l'énergie nucléaire et accorder une assistance technique aux pays en voie de développement dans ce domaine.

Un effort coordonné des Etats, avec la participation directe de l'AIEA et des commissions nationales de l'énergie nucléaire des Etats nucléaires, pourrait mener, par exemple, à une meilleure comparaison économique des différentes filières de centrales de puissance, à leur meilleure intégration dans l'économie des Etats petits et moyens, à l'accélération du développement; la formation de spécialistes dans le domaine des applications pacifiques de l'énergie atomique, et en particulier de la production d'énergie, la fabrication d'uranium enrichi pour les combustibles nucléaires et d'autres activités encore pourraient être organisées sur le plan international.

Vu le rôle que l'AIEA aura à jouer dans l'application de l'article III du Traité, la part des garanties dans l'ensemble de ses activités augmentera sensiblement dans les années à venir. Mais cet accroissement ne doit pas amener un déséquilibre des rapports entre les obligations fondamentales de l'AIEA et ses nouvelles obligations dans le domaine des garanties et du contrôle; tout en maintenant l'équilibre existant, il doit conduire à un développement substantiel des efforts dans le domaine de la coopération et de l'assistance technique. Ceci serait d'ailleurs dans l'esprit du Traité qui doit être, comme de juste, un accord positif qui non seulement n'entravera pas, par ses interdictions et ses effets, le développement pacifique de l'énergie nucléaire dans les états non dotés d'armes nucléaires, mais contribuera à leur progrès, avant tout en faisant passer à un stade nouveau la coopération et l'assistance technique organisées à l'échelle internationale.

Sans avoir la prétention d'épuiser le sujet, nous avons essayé dans ce mémoire, en nous fondant sur des considérations sur l'importance et le caractère spécifique du domaine nucléaire, ainsi que sur l'expérience du Comité d'Etat pour l'énergie nucléaire de la Roumanie, d'analyser à travers le prisme de la science des relations internationales, une série d'aspects, d'objectifs et de méthodes relatifs à la coopération internationale dans ce domaine. Nous sommes convaincus qu'une étude scientifique des problèmes d'organisation et de coopération dans le domaine nucléaire mérite maintenant une attention beaucoup plus soutenue, les résultats pouvant contribuer à resserrer les liens qui unissent les nations et à favoriser le développement des applications de l'énergie nucléaire à des fins pacifiques dans tous les pays.

INTERNATIONAL COOPERATION IN NUCLEAR PROJECTS AND EXCHANGE OF INFORMATION

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Abstract–Résumé–Аннотация–Resumen

INTERNATIONAL COOPERATION IN NUCLEAR PROJECTS AND EXCHANGE OF INFORMATION.

The paper shows the long United Kingdom experience in nuclear cooperation and the extensive assistance which the United Kingdom has provided by way of information, training, attachments, etc. International cooperation has gone through several phases. Around the time of the first Geneva Conference many very general intergovernmental agreements were concluded. In the late 1950s several projects were set up, e.g. Halden, Dragon, Eurochemic, which involved national laboratories and to a small extent industry as well as governments. Now that nuclear energy is strongly commercial, almost every collaborative project involves industry as well as government and national laboratories; and, where nuclear power is concerned, electrical utilities are involved also. The difficulty of concluding projects for international cooperation is closely related to the number of parties involved and the degree of commercialization. CERN enjoyed a halcyon era because the number of interests involved were relatively few, and the end product of CERN'S activity was of no commercial interest. Most of today's projects are at the other extreme, involving many parties and strong commercial interests. It is not surprising that these projects have a long gestation period. The tripartite centrifuge project took many months to launch; there were no serious disagreements, merely a lot of points requiring resolution, and at least three interests to be kept in line in each of three countries. European nuclear effort must be more closely integrated to cut out wasteful duplication and to create an industry strong enough to compete. This cannot however be done quickly or without great effort and patience. It requires, and is beginning to call forth, a new breed of executives, part lawyers part scientists, part patent experts and part diplomats. It requires also a new focus in which the several interests can be brought together. For Europe, Foratom has the right composition and should be strengthened.

COLLABORATION INTERNATIONALE EN MATIERE DE PROJETS NUCLEAIRES ET D'ECHANGE D'INFORMATIONS.

Le mémoire décrit la longue expérience du Royaume-Uni dans le domaine de la collaboration nucléaire, et l'aide considérable que le Royaume-Uni a fournie par la voie d'échanges d'informations, de programmes de formation, de périodes de détachement, etc. La collaboration internationale a connu plusieurs phases. A l'époque de la première Conférence de Genève, de nombreux accords d'un caractère très général ont été conclus entre Gouvernements. Pendant la deuxième moitié des années 1950, plusieurs projets ont été mis sur pied, par exemple Halden, Dragon, Eurochemic, qui intéressaient des laboratoires nationaux et, dans une moindre mesure, l'industrie aussi bien que les Gouvernements. Maintenant que l'énergie nucléaire a acquis un caractère commercial, presque tous les projets de collaboration intéressent l'industrie aussi bien que les laboratoires gouvernementaux et nationaux; par ailleurs, les projets ayant trait aux centrales nucléaires intéressent également les entreprises de production et de distribution d'électricité. La difficulté de conclure des projets de collaboration internationale est intimement liée au nombre de parties intéressées et au degré de commercialisation. Le CERN a connu une époque sereine parce que le nombre des parties intéressées était relativement réduit, et parce que le résultat des activités du CERN n'avait pas d'intérêt commercial. La plupart des projets actuels se trouvent à l'autre bout de l'échelle – entraînant la participation de nombreuses parties et d'intérêts commerciaux puissants. Il n'est pas surprenant que ces projets aient une longue période de gestation. Il a fallu attendre de nombreux mois pour lancer le projet tripartite de centrifugeuse; ce délai n'était pas dû à des désaccords sérieux, mais tout simplement à de nombreuses questions qu'il fallait éclaircir, et au moins trois domaines d'intérêt à aligner dans chacun des trois pays. Les efforts européens dans le domaine nucléaire doivent s'intégrer plus largement afin d'éliminer le dédoublement des efforts qui conduit au gaspillage, et créer une industrie suffisamment puissante pour être compétitive. Cela, toutefois, ne peut pas être réalisé rapidement ni sans beaucoup d'effort et de patience. Cette collaboration exige, et commence à faire naître, une nouvelle catégorie de cadres, qui sont en partie juristes, en partie scientifiques, en partie experts conseil en matière de brevets et en partie diplomates. Elle exige aussi un nouveau point de mire capable de réunir plusieurs intérêts. Dans le cas de l'Europe, Foratom présente la composition adéquate et il faudrait renforcer cette organisation.

МЕЖДУНАРОДНОЕ СОТРУДНИЧЕСТВО В ОБЛАСТИ ИСПОЛЬЗОВАНИЯ ЯДЕРНОЙ ЭНЕРГИИ И ОБМЕН ИНФОРМАЦИЕЙ.

В докладе освещается опыт международного сотрудничества Великобритании в области использования ядерной энергии и говорится о той большой помощи, которую она оказывала путем предоставления информации, подготовки специалистов и т.д. Международное сотрудничество прошло несколько этапов. В период после Первой Женевской конференции было заключено много межправительственных соглашений общего характера. В конце 50-х годов началось осуществление нескольких проектов – Халденский реактор, реактор DRAGON, проект "Еврохимик", – в которых приняли участие национальные лаборатории, промышленные предприятия, а также правительства некоторых стран. Сейчас, когда ядерная энергия стала иметь большое промышленное значение, в осуществлении почти каждого совместного проекта принимают участие промышленные круги, а также правительство и национальные лаборатории. Осуществление ядерных проектов не обходится также без участия предприятий коммунального энергоснабжения. Трудности выполнения проектов по линии международного сотрудничества в большой степени зависят от числа стран-участниц, а также от коммерческой значимости проекта. В прошлом ЦЕРН осуществлял деятельность в спокойном ритме, потому что заинтересованность в проектах была небольшой и конечный результат деятельности ЦЕРНа не представлял никакого коммерческого интереса. Большая часть современных проектов характеризуется другой крайностью – большим числом стран-участниц и сильной коммерческой заинтересованностью. Поэтому не удивительно, что такие проекты вынашиваются в течение длительного периода времени. Так, на принятие решения о начале осуществления трехстороннего проекта по центрифугам потребовались многие месяцы; при этом не было никаких серьезных разногласий, просто было много вопросов, требующих решения и, кроме того, нужно было согласовать интересы трех стран. Усилия европейских стран в области использования ядерной энергии должны быть более тесно связаны, чтобы исключить расточительное дублирование и создать достаточно конкурентоспособную промышленность. Однако, это требует времени и больших усилий. Выполнить данную задачу поможет новое поколение: юристов, ученых, патентоведов и дипломатов. Необходимо также изыскивать новые пути для совмещения различных специальностей. Форатом в этом плане имеет подходящую структуру для Европы и его необходимо укреплять.

COOPERACION INTERNACIONAL EN MATERIA DE PROYECTOS NUCLEARES E INTERCAMBIO DE INFORMACION.

Este trabajo demostrará cuánta experiencia tiene el Reino Unido en cooperación nuclear y qué gran asistencia ha proporcionado el Reino Unido por medio de información, entrenamiento, comisiones, etc. La cooperación internacional ha pasado por diversas fases. Hacia la época de la primera Conferencia de Ginebra, se firmaron muchos acuerdos entre gobiernos, de carácter muy general. Al final de la década de los años cincuenta se establecieron varios proyectos, por ejemplo, Halden, Dragon, Eurochemic, en los cuales estaban implicados tanto gobiernos como laboratorios nacionales e incluso, en pequeña proporción, la industria. Ahora que la energía nuclear ha adquirido un gran valor comercial casi no existe proyecto de colaboración en el que no intervenga la industria tanto como los gobiernos y los laboratorios nacionales y, cuando se trata de la producción de energía nuclear, también intervienen las empresas eléctricas. El grado de dificultad de llegar a un acuerdo al establecer proyectos de cooperación internacional depende mucho del número de partes interesadas y del interés comercial. El CERN disfrutó de una época dorada porque el número de los interesados era relativamente pequeño y el producto final de la actividad del CERN no tenía interés comercial. La mayor parte de los proyectos actuales están en el otro extremo; interesan a muchas partes y tienen un gran valor comercial. No puede sorprender que estos proyectos tengan un largo período de gestación. Llevó muchos meses poner en marcha el proyecto tripartito del método de centrifugación; no es que existieran desacuerdos graves, había simplemente muchos detalles que requerían una decisión y por lo menos tres intereses distintos que tener en cuenta en cada uno de los tres países. El esfuerzo nuclear europeo tiene que coordinarse mejor si se quiere cortar la duplicación baldía y crear una industria suficientemente fuerte para poder competir. Sin embargo, esto no se puede hacer rápidamente o sin gran esfuerzo y mucha paciencia. Requiere, y está empezando a promover, una nueva raza de ejecutivos, en parte hombres de leyes y en parte científicos, en parte expertos en patentes y en parte diplomáticos. También requiere un nuevo punto de vista de acuerdo con el cual se puedan compaginar intereses distintos. Foratom tiene la composición adecuada para Europa y debiera ser reforzado.

The military security barriers, which had severely limited post-war exchanges on nuclear energy, were effectively lowered when the first Geneva Conference met in 1955. Since then a flood of international exchanges in pursuit of the peaceful atom has followed. Surely no other new technology has been launched with a comparably large exchange. The motives which gave rise to these extensive exchanges on nuclear matters were probably very mixed. Initially the desire to catch up with an important scientific advance was very strong and was matched by a willingness to aid in the process and to exchange experiences. In some countries, especially those where energy resources are poor, the hope that nuclear energy could be quickly and simply harnessed to provide unlimited cheap power for all was raised unwarrantably high. Whatever the motives, information was sought and shared by every practicable means: reports and visits were exchanged, conferences, symposia and panels met.

The provision of training facilities by the countries most advanced in nuclear technology was particularly important. The U.K. Atomic Energy Authority has for twenty years run training courses which have attracted, in addition to U.K. nationals, a large number of students from other countries; an Isotope School was established in Harwell in 1951, followed by a Reactor School in 1954. These have been merged and added to over the years, and now constitute an Education and Training Centre which continues to attract a large attendance from overseas. In 1969/70 over half of the students at the main courses for students from outside the U.K.A.E.A. were from other countries. The word "student" is perhaps misleading. Because there are now available, in Universities and colleges, basic courses in reactor technology, the courses which the U.K.A.E.A. run in these fields are specialised and advanced. This means that they appeal mainly to scientists and engineers who are already experienced in the nuclear field.

For the past seven years, the Education and Training Centre has included a Reactor Safety Course, one of only two in the Western world (the other being at the Massachusetts Institute of Technology). This has so far attracted some 200 foreign students from 29 countries.

In 1957, the U.K.A.E.A. established a Reactor Operations School at Calder Hall; and at the present time a Fast Reactor Technology Training Centre is being established at Dounreay. This, like all of the U.K.A.E.A's other training facilities, will be open to students from other countries.

In the years following the 1955 Conference, a characteristic feature of the international nuclear scene was the many co-operation agreements concluded, some bilateral and others multilateral. During the last fifteen years the U.K. has been a party to some 65 such agreements, with worldwide coverage, in addition to commercial agreements concluded by the U.K.A.E.A. Some of these agreements have been between Governments, and some between the U.K.A.E.A. and its counterparts in other countries; some have been general and some detailed. The common theme of all of them has been the sharing of nuclear information, so that the countries concerned could advance more rapidly in partnership than would have been possible in isolation. Some of these agreements have been more fruitful than others. Where a genuine exchange of information has been possible between people working on similar topics, the results have been valued by those taking part and the exchanges have often continued for a very long time, even if sometimes only at a low level of activity. On the other hand, so-called exchanges, where in fact the information flow is predominantly in one direction, are likely to die an early death. For non-commercial exchanges to flourish, a political willingness alone is not enough, a common scientific and technical interest must also exist. Though this is perhaps most clearly true of bilateral exchanges, it does also apply in multilateral exchanges.

The need for straightforward information agreements has now very largely disappeared. Such agreements fulfilled a useful purpose in earlier days, when some of the technology was still classified, and when channels for the regular flow of nuclear information had not been opened up. Now, classification plays a very small part, and the number of media for the distribution of information is almost embarrasingly large. To the extent that some of these agreements were in part directed to ensuring safeguards against the non-peaceful use of nuclear material, equipment or information, their objectives can be largely met in future by widespread ratification of the Non-Proliferation Treaty and the conclusion of safeguards agreements with the I.A.E.A. under the Treaty. Agreements are still necessary, of course, for the exchange of commercially valuable information – and this is becoming increasingly important.

The limits on free flow of information are now rarely military security, but, increasingly, commercial interest. Even those limits leave very wide areas free for extensive exchanges, and here the international organisations like I.A.E.A. and E.N.E.A. have played, and will continue to play, a valuable role. Such activities of these agencies as neutron data compilation, computer programme library, I.N.I.S., have met a real need. They are the appropriate agencies for the organisation of multi-national groups of specialists; but here it is important to avoid duplication. Nobody is helped much if the same fashionable topic is taken up at international meetings arranged in two, three or four different countries within a short time interval and all aimed to attract the same group of experts.

The first batches of agreements concluded in the middle 1950s were, as already stated, primarily for the exchange of information. In the second half of the decade, some ambitious agreements were entered into constituting joint projects. The most far-reaching was of course the Treaty establishing the European Atomic Energy Community (Euratom). There has been an agreement for co-operation between U.K. and the Community since 1959. In the same period, three joint projects were established under the aegis of E.N.E.A. viz. Halden, Dragon and Eurochemic. The U.K.A.E.A. was a member of the Halden Project for many years, and has throughout been a member of the Dragon Project, subscribing at the present time nearly half of the budget.

Earlier – indeed the earliest of the international projects – was C.E.R.N., established under an agreement ratified in 1954. Many useful lessons can be drawn from the great achievements of C.E.R.N., e.g. the necessity for clarity of objective and for strong leadership. Nevertheless, C.E.R.N. can not be taken as a complete model for the setting up of international collaborative nuclear projects in today's circumstances. C.E.R.N., as has been frequently remarked, is fortunate in generating information which has no commercial value; moreover, its creation and its continuance have been largely the concern of Governments and to hardly any extent of industry.

Dragon enjoyed at its outset some of the same advantages as C.E.R.N., notably in that only the several participating Governments, and the national atomic energy bodies (C.E.A., U.K.A.E.A. etc.) were directly interested; and, as with C.E.R.N., industry saw as its initial role only the supply of reactor hardware. Moreover, Dragon has throughout been fortunate in its project leadership. Dragon shared with Halden another considerable initial advantage, in that the time-consuming labour of establishing a special legal entity was avoided. The Signatories were content to rely on the U.K.A.E.A. as their legal agent (similarly the Institut for Atomenergi has been the management agency throughout the history of the Halden Project). This enabled the Dragon Project to get off to a quick start.

Even so, it was feared that design of the reactor by a team drawn from twelve countries, followed by procurement after equally widespread tender action, would prove less than 100% efficient. In the event, the reactor reached criticality in just over five years after the coming into force of the Agreement – by no means an unreasonable time for the assembly of an international team, followed by design, construction and commissioning of the first experimental reactor of its kind. Moreover, international tender action was completed with virtually no friction; no more than two or three instances required consideration by the Dragon Board of Management.

It is relevant to note that between the establishment of the international nuclear projects just discussed and the conclusion of the Tripartite Centrifuge Agreement in March 1970 there was a dearth of international projects. This does not betoken any weakening of the will to collaborate internationally – though perhaps there was once, and no longer is, a tendency to believe that a project not worth undertaking nationally would become worthwhile by the mere act of being undertaken internationally.

The main reason why the 1960s saw no major international nuclear projects, lies in the greatly increased complexity of the nuclear scene. In the 1940s nuclear energy was exclusively the concern of Governments. In the next decade, national laboratories, Authorities, Commissions etc. began to have some degree of independence (rather limited, as all were virtually 100% financed by Governments); so in each country two sets of interests were concerned in any international project. The 1960s saw a great increase in the complexity of the pattern. Now there are few nuclear projects in which manufacturing industry is not directly concerned, and those (the majority) which are concerned with nuclear power cannot be taken far without requiring the support of the electrical utilities.

The later history of the Dragon Project provides an illustration. For most of its first decade, the tasks of the Project were technically challenging but administratively simple – to complete and test the first reactor experiment based on the high temperature system. Now, following the promising experience of Dragon, Peach Bottom, A.V.R., this system is being seriously considered by a number of utilities, and therefore the Dragon reactor is in great demand as a fuel test bed. The point to note is that the working out of the Dragon test programme now requires, in the case of several countries, the participation of at least three elements – national commission, industry and utility.

In the field of international nuclear collaboration, nothing is simple any more. One generalisation remains valid viz. that collaboration is easier the earlier it is embarked upon, and becomes progressively more difficult as the work proceeds independently in several countries and as vested interests are created. One of the attractions of the Tripartite Centrifuge Project was that, when discussions started, development in the three countries was still at a comparatively early stage and not too many vested interests had to be taken into account. Even so, discussion leading to the signature of the inter-Governmental Agreement on 4th March 1970 occupied many months and required the participation of a wide range of interests. In addition to Government and para-Government representatives, the Project required the collaboration of two branches of industry, viz. machinery manufacturers and also firms interested in uranium supply and enrichment.

Of course, the fact that the technology is classified (enrichment technology is now virtually the only part of the civil nuclear field which is still classified) added appreciably to the problems of the Centrifuge Agreement, requiring strict regulations concerning security. The other feature of the Centrifuge Agreement which dictated the time-table of its negotiation was that this Agreement provided for the establishment not merely of a general collaboration but also of an actual business enterprise, involving major financial commitments by the three partners and important financial and contractual relations between them. Given this fact, the number of interests involved, and also the classification factor, it is perhaps surprising that the participants did not take longer to reach agreement.

A problem arose in the case of the Centrifuge Agreement which will probably arise in future instances: it has already been encountered again in connection with the projected international collaboration over reprocessing. In the first two decades after World War II the characteristics of international nuclear collaboration were comprehensiveness and non-discrimination. This is most obvious in relation to I.A.E.A., but also to a lesser extent in such bodies as E.N.E.A. In the case of the international projects established during this period, participation by all interested countries was regarded as a matter of right and of good international behaviour. This gave rise to little difficulty as regards projects such as Halden and Dragon which had limited objectives and comparatively few commercial implications. Circumstances have changed, however, and the international projects currently under negotiation are fully as commercial as any private industrial deals on a national basis, and considerably more complicated. Current experience indicates that there is a strict limit to the number of countries which can participate in the formulation of such an international venture (bearing in mind, as already indicated, that in each country several disparate interests have to be concerned in the negotiations). The administrative inertia increases sharply with the number of countries involved. In a bilateral deal it is, or should be, a minor factor; in a tripartite deal it is, or should be, tolerable. Perhaps a quadripartite deal is achievable but there must be considerable doubt as to whether, in any more widespread negotiation, progress could overcome the administrative inertia. This inevitably means that those who wish to embark on international commercial projects must select their partners with great care and must be prepared to face the reproaches of those who are left out. As David Fishlock noted in a recent article,[1] this is the era of the "Club" as a means of nuclear collaboration; and there never was a club which was not regarded with some suspicion by those outside it. This is not an indication that those forming such "Clubs" are departing from good international practice; on the contrary, in the highly sophisticated and commercial stage which nuclear development has now reached, the alternative to selective collaboration would be no collaboration at all.

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[1] Financial Times, 14th December 1970.

It should be emphasised that the preceding paragraphs refer to the formulation of projects. For this purpose there must be leaders and these must be few. This does not exclude the possibility of widening the project after formulation to include others with similar interests; indeed, projects should be formulated with this in view.

In the modern, highly commercial and competitive world of nuclear energy, four types of international collaborative project have emerged, viz. Research and Development, fuel services, joint marketing, and inter-utility collaboration.

Collaboration in R & D normally involves governmental or semi-governmental agencies, as in most countries public funds still supply the main part of the finance required for nuclear R & D. Collaboration in reactor R & D almost invariably, under modern circumstances, requires the participation of industry and frequently, of utilities also. In consequence, such collaborative projects, involving the reconciliation of a number of differing interests, need patient negotiation.

There is one area of R & D in which collaboration would at the present stage involve less complexities but could be very fruitful. This is the area of fusion reactors. This area is at present entirely open, untrammelled by either security or commercial considerations, and there is a very extensive exchange of information between all the countries concerned. A further step could be taken to great mutual advantage. Until now, work has been largely at the laboratory stage, involving substantial but not unmanageable expenditure. Soon, however, the stage will be reached at which further progress will require the construction of large prototype machines, each of which will cost many millions of pounds sterling. The ideal solution would be the building of the prototype of one system in one country, and of another system in another country, with full exchange results; conversely, the worst would be to drift into another "fast reactor" situation, with essentially the same machine being built in several countries. The ideal is still attainable; it requires that between two, or conceivably three countries or organisations, exchange of information should be enlarged to include joint planning – and this must be done quickly. This may be the one important area where international collaboration can still be achieved relatively simply and with great mutual benefit; but there is not much time.

The second type of international collaborative project is in the fuel services area; the centrifuge enrichment project and the discussions concerning reprocessing having already been mentioned.

Thirdly, joint marketing arrangements have been made between equipment manufacturers or consortia, and others are currently under discussion. These are rarely simple; it is not often that the interests of the several participants are found to match exactly. Moreover, arrangements which would be advantageous from a nuclear viewpoint sometimes run counter to traditional technical partnerships in one or other country or across international frontiers.

Finally, there are links between utilities. Exchange of information is of course long-established, particularly concerning power station operation. In recent years there has been discussion between utilities as to the possibility of economising in effort and expense by collaboration in the financing, construction and operation of the first large station incorporating a new reactor system. It is to be regretted that these discussions do not seem to have progressed. However, E. de F. have been successful in negotiating the construction of nuclear power stations (not necessarily of new reactor systems) with neighbouring utilities on the French borders with Spain, Switzerland, Germany and Belgium.

It is hardly necessary, to argue the merits of international collaboration. They are well expressed in the following quotation from Sir Solly Zuckerman's recent book "Beyond the Ivory Tower": "The economics of modern technological industry demand bigger and bigger units and more and more resources, if research and development is not to prove a sterile enterprise. That, quite independently of longer and more assured production runs, is one of the main reasons why Britain's closer association with Europe in a Common Market should lead to major long-term benefits for all. Europe will never be able to compete effectively with the giant technological corporations of the United States unless its industries combine their efforts in what has been called a technological community."

International collaboration is necessary not only to eliminate wasteful duplication of R & D, but also – and probably more important – to expand the market. The record of achievement in recent years – particularly in Europe – has been disappointing. Europe cannot afford four independent fast reactor programmes, but there are at least four. A minimum of a dozen European manufacturing groups are competing for the European nuclear power market; the American market, which is at least three times as big, is supplied by no more than three or four groups.

The need for action is clear. There is however a tendency, manifest usually among those who know least about the subject, to believe that because the need is clear, the solution is clear also, and that progress is being obstructed only by insularity or lack of determination. There is a tendency to impatience that so much time should be consumed in achieving such apparently small advances. What has been said already will indicate that the problem is not simple and that there are no easy solutions. It would of course be a mistake to conclude that there are at present no international linkings; there are perhaps too many, and they are certainly too ineffective. The difficulty of creating effective international groupings is only increased by the necessity to thread one's way through the labyrinth of the existing bilateral and multilateral agreements, which have in many cases, been overtaken by the rapid advance of the nuclear industry.

It would not be helpful just to list the failures and the difficulties. A few recommendations of a more positive nature are therefore appended:

(a) The object of any collaborative project should be clearly defined from the outset. There should in addition be a conscious effort to shape it in the light not only of the industrial pattern as at the time of negotiation, but also of the industrial pattern as it may be expected to develop. Associated with this is the necessity to foresee not only how the project may start but also how it may be brought to a natural termination. If the Dragon Agreement suffers from any defects, it is on these latter points.

(b) The situation demands the exercise of creative imagination in order to identify at the earliest possible moment the projects which may make sense on an international scale. As already noted, the ease or difficulty of creating a collaborative project is related directly to the stage in its development at which collaboration is proposed.

It would in present circumstances be very difficult to negotiate a major European sodium-cooled reactor collaboration project; it would have been appreciably easier ten years ago. Of course, early decision involves risks. As in so many other situations, the disadvantages have to be balanced – on the one hand, the risk that a project chosen early in its development may fail to fulfil its promise; on the other hand, the barrier to collaboration which will be interposed by vested interests if the choice is left too long. Hence the need for creative imagination.

(c) Notwithstanding the desirability of early choice, it would be a mistake to look for early results. Learning to live with other people, in business as in marriage, is a process that takes time. On the other hand, there must be more ruthlessness than has sometimes been demonstrated in terminating a project once it has become clear that it has outlived its utility.

(d) Those who are endeavouring to make the project proceed should receive the full backing of their principals; in other words, collaboration is not likely to succeed unless it is whole-hearted. This is true of collaboration within a national framework, and even more the case in international ventures.

(e) A collaborative project, by definition, requires contributions from all the partners. The temptation to safeguard in advance that each partner will get as much out as he puts in (or preferably more) should be resisted. One should not enter into a collaborative project unless one can see a reasonable prospect of benefiting. Having made this assessment and decided that there is such a prospect, to go further and specify in advance that e.g. the staff must be recruited or the expenditure allocated in strict proportion to contributions, is the best means of ensuring that nobody profits from the venture.

(f) International collaboration in technology is calling into being new teams of executives, made up of scientists or engineers, lawyers, patent experts and diplomats. In reducing the time required for completion of a new project on a collaborative basis, the expertise of these people can be as important as that of those concerned in carrying out the development itself. Additionally, this could be a field of activity for a new type of management consultant. If the proposed International Institute for the Management of Technology comes into being, this could be the natural source for the future of such expertise.

(g) Finally, there is a real need for a more effective market place in which today's type of collaborative project can be discussed. Bodies like IAEA, ENEA, and Euratom fulfil valuable functions; but they are representative of Governments, whereas it has been stressed in this paper that today's projects typically require full participation also of manufacturing industry and, in many cases, of utilities. Nationally these various interests can usually be brought together in the national atomic energy forum or similar body. So far as Europe is concerned, these national bodies have been brought together in Foratom. Studies promoted by Foratom have played an important part in several of the international projects already mentioned in this Paper, notably uranium enrichment and reprocessing. It is to be hoped that it will be encouraged by its members, and given the resources, to play an even more active role in the future.

EL EFECTO DE LA COOPERACION INTERNACIONAL EN EL PLAN NUCLEAR ARGENTINO
Una experiencia de interés para los países en desarrollo

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Abstract–Résumé–Аннотация–Resumen

THE EFFECT OF INTERNATIONAL COOPERATION ON THE ARGENTINE NUCLEAR PLAN: AN EXPERIENCE OF INTEREST FOR DEVELOPING COUNTRIES.

International cooperation has played an important role in the preparation of the 10-year Argentine Nuclear Plan and is of fundamental importance in its execution. A detailed description of the assistance so far received is given, and the reasons why it has to be adapted to the present conditions are shown. The experience obtained may be of interest for countries where nuclear energy has followed an evolution similar to that in Argentina, because it may stimulate development by allowing them to profit to the maximum from international cooperation. Concrete solutions are given for adapting the type of assistance to the level of evolution reached; and particular attention is paid to the ways of meeting the requirements of a country that presents, as in the case of Argentina, an intermediate level of development in the nuclear field, and the need to start the corresponding industrial stage.

L'EFFET DE LA COOPERATION INTERNATIONALE SUR LE PLAN NUCLEAIRE ARGENTIN: UNE EXPERIENCE INTERESSANTE POUR LES PAYS EN VOIE DE DEVELOPPEMENT.

La coopération internationale a rempli une fonction importante dans la préparation du plan nucléaire argentin de dix ans et continue à jouer un rôle fondamental dans son exécution. Les auteurs analysent en détail les caractéristiques de l'aide reçue ainsi que les raisons pour lesquelles il a été nécessaire de l'adapter aux conditions actuelles. L'expérience obtenue peut présenter un intérêt pour les pays dans lesquels l'énergie nucléaire suit un processus évolutif semblable à celui de l'Argentine, parce qu'elle permet d'accélérer les étapes du développement si on l'utilise pour tirer un meilleur profit de la coopération internationale. Des solutions concrètes sont proposées pour adapter le type d'aide au degré d'évolution atteint et, en particulier, pour satisfaire les besoins des pays qui, se situant comme la République argentine à un niveau intermédiaire du développement nucléaire, se trouvent placés devant nécessité de passer à l'étape industrielle correspondante.

ВЛИЯНИЕ МЕЖДУНАРОДНОГО СОТРУДНИЧЕСТВА НА ЯДЕРНУЮ ПРОГРАММУ АРГЕНТИНЫ: ОПЫТ, ПРЕДСТАВЛЯЮЩИЙ ИНТЕРЕС ДЛЯ РАЗВИВАЮЩИХСЯ СТРАН.

Международное сотрудничество играло важную роль в ходе подготовки 10-летней программы Аргентины в области ядерной энергии и продолжает иметь важное значение для ее осуществления. Дается подробное описание полученной помощи и излагаются причины необходимости ее соответствия современным условиям. Приобретенный опыт может представлять интерес для стран с аналогичным уровнем развития ядерной энергии, поскольку это может содействовать развитию путем извлечения максимальной выгоды из международного сотрудничества. Предлагаются конкретные меры для того, чтобы масштаб и характер оказываемой помощи находился в соответствии с достигнутым уровнем развития; особое внимание уделяется способу удовлетворения потребностей такой страны, как Аргентина, находящейся на среднем уровне развития в ядерной области, а также необходимости перехода на новую промышленную стадию.

EL EFECTO DE LA COOPERACION INTERNACIONAL EN EL PLAN NUCLEAR ARGENTINO: UNA EXPERIENCIA DE INTERES PARA LOS PAISES EN DESARROLLO.

La cooperación internacional ha desempeñado un papel primordial en la preparación del Plan Nuclear Argentino a diez años, y es de importancia fundamental para su ejecución. En la memoria se analizan con detalle las características de la asistencia recibida y las razones de la necesidad de su adaptación a las condiciones actuales. La experiencia puede resultar de interés para países en los que la energía nuclear sigue un proceso evolutivo similar al de la Argentina, ya que permitiría acelerar las etapas del desarrollo, utilizándola para obtener un mejor aprovechamiento de la cooperación internacional. Se proponen soluciones concretas para adaptar el tipo de asistencia al grado de evolución obtenido, y en particular, para cumplir los requerimientos de un país que, como la República Argentina, presenta un nivel intermedio de desarrollo nuclear, y la necesidad de iniciar su correspondiente etapa industrial.

INTRODUCCION

La República Argentina se encuentra en un proceso de industrialización y elevación del nivel de vida, en el cual la energía nuclear interviene a través del Plan Nuclear Nacional. La ejecución de este plan implica las siguientes perspectivas mediatas de la energía nuclear en la Argentina:

a) Un definido cambio de escala en la actividad nuclear.
b) El desarrollo de un proceso de industrialización nuclear.

El estado actual de la energía nuclear

El estado actual de la energía nuclear puede evaluarse en los siguientes hechos:

- El plan nucleoeléctrico contempla la instalación de tres centrales, con una potencia total del orden de 2000 MW(e), antes de 1980. La primera de ellas, actualmente en construcción, es de 320 MW(e) de potencia; la segunda, en proceso de licitación, de 600 MW(e) y la tercera, programada para 1979, tendrá 1000 MW(e). En la primera mitad de la década 1980-89, se considera necesaria la instalación de 1000 MW(e) de origen nuclear cada dos años. La industria nacional participa en la construcción de la primera central nuclear con un 40% del total de la obra. El programa establece la participación creciente de la industria argentina en las próximas centrales. Estímase que será superior al 50% en la segunda central.
- Las reservas de minerales de uranio se elevan, en la categoría de recursos razonablemente asegurados, a precios menores de 10 U$S/lb a 11 600 toneladas de U_3O_8 y los recursos adicionales posibles en la misma categoría a 18 400 toneladas. Estas reservas se incrementan a razón de no menos de 1000 toneladas por año.
- La producción de concentrados que actualmente es de 50 t/año, se incrementará progresivamente, hasta llegar a 700 t/año antes de 1978.
- Se ha fabricado en la Argentina el total de los elementos combustibles de los reactores de investigación y producción que posee el país y algunos prototipos de potencia. Se trabaja en la instalación de una fábrica de elementos combustibles que satisfaga la demanda interna.
- Los 427 centros usuarios de radioisótopos existentes utilizaron 117 Ci en 1970. A partir de 1971, la producción nacional reemplaza gran parte de la importación. La extrapolación de esta demanda implica una producción de 450 Ci en 1980.
- El personal de la CNEA se eleva a 3000 agentes, 800 de los cuales son egresados universitarios. Su presupuesto, en 1971, asciende a 69,6 millones de pesos (equivalentes a 17,4 millones de U$S), excluyendo las erogaciones correspondientes a la central de potencia en instalación.

La cooperación internacional en la preparación del plan

El estado de desarrollo alcanzado y la formulación del Plan Nuclear a diez años demuestra claramente que la actividad nuclear en el país presenta dos etapas bien definidas, la primera de preparación básica que nos ha permitido obtener una capacidad propia de evaluación de nuestros problemas nucleares y la segunda, en la que se deciden realizaciones nucleares de interés nacional, y la iniciación y el desarrollo de la capacidad industrial correspondiente. El resultado logrado en la primera etapa es el que ha permitido encarar un programa adecuado a nuestra realidad.

La excéntrica posición geográfica de nuestro país, su distancia con los principales centros mundiales del conocimiento y desarrollo nuclear, y las condiciones de contorno en cuanto a la evolución científica y tecnológica, hubieran imposibilitado los resultados obtenidos, de no haberse contado con una eficiente y positiva ayuda de asistencia técnica exterior.

Las fuentes de asistencia técnica recibida fueron principalmente las siguientes:

- Los convenios bilaterales: Alemania, Estados Unidos, España, Francia, e Italia.
- Los organismos internacionales, tales como: Organización de los Estados Americanos (OEA), Comisión Interamericana de Energía Nuclear (CIEN), Comunidad Europea para la Energía Atómica (Euratom), Organización Mundial de la Salud (OMS), Organización de las Naciones Unidas para la Educación, la Ciencia y la Cultura (UNESCO), Organización de las Naciones Unidas para la Alimentación y la Agricultura (FAO), debiéndose destacar en forma especial la del Organismo Internacional de Energía Atómica (OIEA).

En esta primera etapa, han sido de fundamental importancia las siguientes formas de cooperación internacional: becas para entrenamiento de personal, expertos y profesores por períodos prolongados que han contribuido a completar la preparación de nuestros técnicos, equipos, cursos, reuniones y conferencias, visitas científicas y apoyo a proyectos de investigación y desarrollo.

Dentro de estas formas, debemos destacar la especial importancia de los expertos. Su contribución nos ha aportado enormes beneficios en relación a la inversión demandada. Estos beneficios, además de económicos, han demostrado tener gran significación para la formación de un clima adecuado en los grupos de trabajo.

Algunas veces hemos recibido asistencia que no hemos podido asimilar, a veces por exceso de nivel, otras por defecto. Sin embargo, es justicia destacar que el balance general de la ayuda exterior recibida es ampliamente satisfactorio y merece nuestro máximo reconocimiento.

La cooperación internacional en la ejecución del Plan

La segunda etapa, ligada a la ejecución del Plan Nuclear, se produce en un estado de desarrollo nuclear muy distinto al inicial y tiene características diferentes, dado que su acción tiende fundamentalmente a aspectos tecnológicos productivos.

Esta diferencia implica un cambio fundamental en los requerimientos de asistencia técnica y de cooperación internacional, esencialmente en su naturaleza, ya que los objectivos de éstas varían y tienden hacia la posibilidad de proyectar por sí mismos y la obtención de capacidad de realización.

Existen temas en los que ya no necesitamos al profesor generalizado, sino al especialista en un tema específico, con experiencia propia, voluntad de transmitirla y posibilidad de hacerlo. Generalmente la necesidad surge en forma totalmente imprevista, por lo que se lo requiere con urgencia aunque por cortos períodos. El consejo oportuno ante un problema determinado, permite evitar el derroche de esfuerzos y recursos económicos que no poseemos o que poseemos en cantidades limitadas.

Recíprocamente, necesitamos enviar nuestro especialista en una visita de consulta corta a un grupo o persona determinada, y contar con la buena disposición para la atención de la consulta. Es de desear que la parte de la asistencia que se invertía en equipo, sea derivada ahora a expertos. Esto implica menores presupuestos destinados a personal y equipo y mayor presupuesto dedicado a pasajes y viajes.

Necesitamos que se nos facilite el uso de instalaciones que por sus características o costo no resulten posibles montar en la Argentina por ahora, pero que son indispensables para el desarrollo de los programas.

Debe existir la posibilidad de llegar a acuerdos bilaterales o multilaterales para desarrollos específicos de mayor magnitud.

En síntesis, necesitamos transmisión de experiencia en realizaciones y asesoramiento tecnológico y, lo que es tan importante, necesitamos los mecanismos que posibiliten obtenerlos rápidamente.

CONCLUSION

La cooperación necesaria, que durante la primera etapa resulta fácil de obtener a través de las fuentes anteriormente mencionadas, se endurece en forma coincidente con la iniciación de la industrialización, por lógicas razones comerciales o de defensa de intereses.

En esta segunda etapa, la posibilidad de una efectiva cooperación bilateral sufre grandes limitaciones, y es entonces cuando los organismos internacionales, cuyos objetivos de creación son los de promover el desarrollo y deberían estar exentos de tales limitaciones, pueden cumplir un importante cometido.

A este fin se sugieren las siguientes medidas:

a) La creación en aquellos organismos de un cuerpo estable de expertos asesores en problemas más comunes de la tecnología nuclear, similar al de inspectores de salvaguardias del OIEA.
   Estos expertos deberían estar siempre disponibles a viajar sin demora al país que solicitare sus servicios.
   Sería conveniente poner también a disposición los especialistas ya existentes en los organismos, que estén en condiciones de prestar tales servicios, como ya lo hace ocasionalmente el OIEA.

b) La asignación de fondos especiales, a fin de poder resolver en forma expeditiva requerimientos como los enunciados.

c) Dada la importancia ya destacada de los expertos como forma de asistencia, considerar la posibilidad de extender el aprovechamiento de sus viajes en forma regional, indicándoles la visita a países que estén en su ruta o próximos a su destino.

Creemos que la adopción de estas medidas, facilitará a muchos países el necesario cambio de escalas en sus procesos de desarrollo nuclear.

СОЮЗ СОВЕТСКИХ СОЦИАЛИСТИЧЕСКИХ
РЕСПУБЛИК
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МЕЖДУНАРОДНОЕ СОТРУДНИЧЕСТВО СССР В ОБЛАСТИ МИРНОГО ИСПОЛЬЗОВАНИЯ АТОМНОЙ ЭНЕРГИИ

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Abstract–Résumé–Аннотация–Resumen

INTERNATIONAL COOPERATION BY THE USSR IN THE PEACEFUL UTILIZATION OF ATOMIC ENERGY.

The paper reviews international cooperation on the part of the USSR in the peaceful utilization of atomic energy during the period between the Third and Fourth Geneva Conferences. Information is given on the bilateral and multilateral agreements concluded during this period and on the development of cooperation on the basis of these agreements. Consideration is given to progress in the field of such traditional forms of international cooperation as the exchange of visits by scientists, the exchange of scientific and technical information, and participation in the work of international meetings, symposia, etc. Data are presented on the assistance given by the USSR in establishing scientific research centres and in training specialists for meeting the needs of nuclear science and industry in a number of countries. An assessment is made of the outlook for international cooperation in the context of the IAEA, and an account given of the contribution of Soviet scientists to the work of international organizations. Finally, the paper describes the further development of international cooperation in its various forms, and quotes examples of the organization and implementation of joint research and development projects by Soviet and foreign scientific research centres and personnel.

COOPERATION INTERNATIONALE DE L'URSS DANS LE DOMAINE DE L'UTILISATION DE L'ENERGIE ATOMIQUE A DES FINS PACIFIQUES.

Les auteurs traitent de la coopération de l'URSS avec d'autres pays dans le domaine de l'utilisation pacifique de l'énergie atomique pendant la période comprise entre les troisième et quatrième Conférences de Genève. Ils donnent des précisions sur les accord bilatéraux et multilatéraux conclus pendant cette période et sur le développement de la coopération dans le cadre de ces accords. Ils examinent les progrès accomplis dans la coopération internationale sous ses formes traditionnelles telles qu'échanges de chercheurs, échanges de renseignements scientifiques et techniques et participation aux réunions internationales, colloques, etc. Ils communiquent des renseignements sur l'aide que l'URSS accorde en vue de l'organisation de centres de recherche scientifique et de la formation de spécialistes pour les besoins de l'industrie et de la science atomiques de divers pays. Ils indiquent les perspectives qui s'ouvrent à la coopération internationale dans le cadre de l'AIEA et font état de la contribution des hommes de science de l'Union soviétique aux activités des organisations internationales. Enfin ils retracent l'évolution des diverses formes de coopération, et donnent des exemples d'études et travaux de recherche organisés et exécutés en commun par des centres de recherche et des spécialistes de l'Union soviétique et d'autres pays.

МЕЖДУНАРОДНОЕ СОТРУДНИЧЕСТВО СССР В ОБЛАСТИ МИРНОГО ИСПОЛЬЗОВАНИЯ АТОМНОЙ ЭНЕРГИИ.

В докладе освещается международное сотрудничество СССР в области мирного использования атомной энергии за период, прошедший между Третьей и Четвертой Женевскими конференциями. Приводятся данные о заключенных в этот период двусторонних и многосторонних соглашениях и о развитии сотрудничества на базе этих соглашений. Рассматривается прогресс в области таких традиционных форм международного сотрудничества, как обмен визитами ученых; обмен научно-технической информацией; участие в работе международных совещаний, симпозиумов и т.д. Сообщаются данные о помощи СССР в организации научно-исследовательских центров и подготовке специалистов для нужд атомной промышленности и науки ряда стран. Даются перспективы международного сотрудничества в рамках МАГАТЭ, приводятся сведения о вкладе советских ученых в деятельность международных организаций. Приводятся данные о развитии форм сотрудничества, а также примеры организации и осуществления совместных проектов исследований и разработок, проводимых советскими и зарубежными научно-исследовательскими центрами и специалистами.

COLABORACION INTERNACIONAL PRESTADA POR LA URSS EN LA UTILIZACION PACIFICA DE LA ENERGIA ATOMICA.

En la memoria se ponen de manifiesto algunos aspectos de la colaboración internacional prestada por la URSS en la utilización pacífica de la energía atómica durante el período comprendido entre la 3ª y la 4ª Conferencia de Ginebra. Se aportan datos acerca de los acuerdos bilaterales y multilaterales firmados en este período y del desarrollo de la colaboración basada en dichos acuerdos. Se considera el progreso alcanzado en el campo de las formas tradicionales de colaboración internacional, tales como el intercambio de visitas de científicos, el intercambio de información científico-técnica, la participación en los trabajos de reuniones internacionales, de simposios, etc. Se presentan datos acerca de la ayuda prestada por la URSS en la organización de centros de investigación científica y en la preparación de especialistas con vistas a las necesidades de la industria atómica y de la ciencia, de una serie de países. Se presentan las perspectivas de colaboración internacional dentro del marco de la OIEA y se proporciona información acerca de la contribución de los científicos soviéticos en las actividades de las organizaciones internacionales. Se facilitan datos relativos al desarrollo de las formas de colaboración internacional y se presentan ejemplos de organización y realización de proyectos colectivos de investigación y desarrollo llevados a cabo por centros científicos y especialistas soviéticos y extranjeros.

ВВЕДЕНИЕ

Семилетний период, который отделяет нас от III Международной конференции по мирному использованию атомной энергии, знаменует собой дальнейшее развитие атомной науки и техники и расширение международного сотрудничества в этой области.

В этот период Советский Союз неизменно выступал на международной арене с предложениями, направленными на смягчение международной напряженности, укрепление мира и сотрудничества, обеспечение использования ядерной энергии на благо прогресса и созидания.

Весьма существенным практическим шагом в этом направлении явился Московский договор о запрещении испытаний ядерного оружия в трех средах (1963 г.), который устранил наиболее опасный источник искусственной радиации, способной причинить ущерб здоровью людей, нанести непоправимый вред окружающей человека среде; а также Договор о нераспространении ядерного оружия (1970 г.), который, уменьшая опасность развязывания ядерной войны, открывает новые перспективы для мирного использования атомной энергии с должным учетом нужд развивающихся районов мира. Председатель Совета Министров СССР А.Н.Косыгин во время церемонии подписания Договора отметил в своем выступлении: "Участие сегодня в подписании Договора широкого круга государств убедительно говорит о том, что государствами могут быть найдены взаимоприемлемые решения сложных международных проблем, жизненно важных для всего человечества".

В настоящее время наука достигла такого уровня развития, когда многие научные проблемы могут быть решены только в результате творческого сотрудничества, объединения и координации усилий на международной основе.

Советский Союз неуклонно выступает за такое международное сотрудничество в области использования атомной энергии, которое в полной мере отвечало бы целям и принципам Уставов Организации Объединенных Наций, Международного агентства по атомной энергии (МАГАТЭ) и положениям Договора о нераспространении ядерного оружия. Ибо только на основе равноправия и учета интересов всех стран возможно плодотворное сотрудничество, способствующее экономическому и социальному прогрессу всего человечества.

Советский Союз осуществляет научно-техническое сотрудничество в области мирного использования атомной энергии с социалистическими, развивающимися и индустриально развитыми странами, а также с международными организациями.

Каждое из этих направлений включает в себя различные формы сотрудничества: проведение совместных научно-исследовательских и экспериментальных работ со специалистами из социалистических и капиталистических стран на основе двусторонних и многосторонних соглашений; оказание технической помощи и содействия в создании национальных атомных центров в социалистических и развивающихся странах; участие советских ученых и специалистов в международных конференциях, симпозиумах, совещаниях экспертов, семинарах; проведение взаимных ознакомительных поездок по конкретной тематике атомной науки и техники; международный обмен научно-технической информацией; участие СССР в зарубежных выставках.

СОТРУДНИЧЕСТВО С СОЦИАЛИСТИЧЕСКИМИ СТРАНАМИ

Как известно, еще в 1955 году были заключены первые соглашения Советского Союза с социалистическими странами на двусторонней основе о сотрудничестве в области мирного использования атомной энергии.

Основной задачей в те годы являлось оказание Советским Союзом научного и технического содействия в создании необходимой для них научно-технической базы и в подготовке кадров для развития национальной атомной науки и техники, в строительстве исследовательских ядерных реакторов, ускорителей элементарных частиц, физических и радиохимических лабораторий. В результате такого сотрудничества были созданы национальные атомные центры в Народной Республике Болгарии, Венгерской Народной Республике, Германской Демократической Республике, Польской Народной Республике, Социалистической Республике Румынии, Чехословацкой Социалистической Республике и Социалистической Федеративной Республике Югославии, оснащенные самыми современными типами исследовательских реакторов, ускорителей элементарных частиц и другими ядерными установками, помогающими вести научно-исследовательские работы на самом современном уровне.

В строительстве, монтаже, наладке и пуске в эксплуатацию этих научно-исследовательских атомных установок принимали участие советские специалисты, которые передавали свои знания и опыт. Создание атомных центров и их деятельность способствовали более широкому развитию в социалистических странах исследований, инженерных разработок и организации в дальнейшем новых институтов и ядерных установок.

В самом социалистическом строе заложены огромные возможности мирного сотрудничества. Эти возможности определяются полной гармонией интересов всех социалистических стран, объединенных общими целями. Именно поэтому с каждым годом расширялись и совершенствовались формы научного сотрудничества. И это обстоятельство нашло свое выражение в содержании новых соглашений с перечисленными выше социалистическими странами о дальнейшем развитии сотрудничества в области использования атомной энергии в мирных целях.

В январе 1969 года состоялось открытие атомного учебного центра Республики Куба, который был создан при техническом содействии Советского Союза на основе Соглашения от 15 сентября 1967 года.

В основе этих соглашений лежат положения о проведении совместных научно-исследовательских работ в области ядерной физики, физики твердого тела, физики и техники ядерных энергетических реакторов, физики плазмы, радиохимии, разработки и организации производства радиоизотопных приборов и т.д. Осуществляются также обмен научно-технической информацией, прием стажеров, проведение взаимных консультаций, поставка из СССР и взаимная поставка друг другу специальных материалов и оборудования для проведения научно-исследовательских работ.

Наиболее важным направлением в развитии научно-технических связей с социалистическими странами является сотрудничество в области атомной энергетики. Эти соглашения предусматривают сооружение атомных электростанций на установленную мощность около 6000 МВт(эл).

Атомная энергетика из периода поисков и экспериментов встала сегодня на рельсы быстрого промышленного развития. Лучшим свидетельством этого является состав участников нашей конференции. Ни на одной из предыдущих конференций не были так широко представлены деловые круги всех стран, не было так много докладов на чисто экономические и инженерные темы.

Соглашения о сотрудничестве СССР с социалистическими странами в строительстве атомных электростанций (АЭС) предусматривают тесное взаимное сотрудничество ученых, инженеров и специалистов, участвующих в разработке, проектировании и сооружении АЭС, обмен информацией и технической документацией по выполненным работам и исследованиям, а также проведение двусторонних консультаций, связанных с созданием АЭС.

По Соглашению с ГДР от 17 июля 1956 года Советский Союз оказал техническую помощь в строительстве атомной электростанции мощностью 70 МВт с реактором водо-водяного типа в районе г.Райнсберга. В мае 1966 года АЭС была сдана в эксплуатацию и уже 5 лет успешно и надежно работает на проектной мощности.

14 июля 1965 года было заключено новое Соглашение о дальнейшем расширении сотрудничества в сооружении и вводе в эксплуатацию до 1980 года в ГДР атомных электростанций общей мощностью 2000 МВт(эл). Первым этапом в осуществлении этого плана явится сооружение АЭС "НОРД-1" мощностью 800 МВт, состоящей из двух блоков с реакторами типа ВВЭР. При этом планируется ввести в эксплуатацию первый блок в 1973 году и второй – в 1974 году.

Пуск в эксплуатацию двух блоков АЭС "НОРД-2" с аналогичной мощностью намечен соответственно на 1977-1978 годы.

В стадии завершения находятся работы по подготовке в 1971 году пуска первой АЭС Чехословацкой Социалистической Республики (мощностью 150 МВт с реактором корпусного типа с газовым охлаждением на естественном уране). В ходе совместного сотрудничества советские и чехословацкие ученые, инженеры и специалисты успешно выполнили сложные технические задачи, связанные с разработкой и изготовлением всего комплекса оборудования для АЭС. На основе полученного опыта промышленность ЧССР освоила производство корпусов высокого давления и другого технологического оборудования.

В апреле 1970 года было подписано новое Соглашение о строительстве Советским Союзом в ЧССР начиная с 1977 года двух АЭС общей мощностью около 1700 МВт(эл), состоящих из четырех блоков с реакторными установками типа ВВЭР.

В 1966 году были также заключены соглашения с НРБ и ВНР о сооружении атомных электростанций мощностью 800 МВт(эл), каждая из которых состоит из двух блоков с реакторами ВВЭР; а в мае 1970 года – соглашение с СРР о строительстве АЭС с реактором типа ВВЭР-400.

Таким образом, благодаря широкому и плодотворному сотрудничеству в социалистических странах с помощью СССР создана или создается крупная научно-техническая база в области атомной энергетики, включающая в себя научно-исследовательские и проектно-конструкторские институты, заводы и предприятия, которые могут решать сложные научно-технические задачи в этой области.

Сотрудничество СССР с социалистическими странами не ограничивается только соглашениями на двусторонней основе.

В связи с созданием научно-технических предпосылок возникли новые проблемы, связанные с использованием достижений атомной науки и техники в различных отраслях народного хозяйства. Для решения таких проблем потребовались значительные средства, дорогостоящие установки, приборы, аппараты и материалы. Возникла необходимость решения совместными усилиями ряда важнейших научно-технических проблем.

В 1956 году объединенными усилиями социалистических стран, для обеспечения совместного проведения технических и экспериментальных исследований в области ядерной физики, в Дубне был создан Объединенный институт ядерных исследований (ОИЯИ). И вот уже 15 лет этот институт и его многонациональный коллектив научных сотрудников проводит важные и интересные исследования, результатами которых пользуются все страны-участницы этого института. Многие свои работы ОИЯИ выполняет совместно с научно-исследовательскими институтами стран-участниц. Сотрудничество Объединенного института ядерных исследований с научно-исследовательскими институтами Советского Союза приносит большую пользу обеим сторонам.

Примером такого тесного сотрудничества могут служить совместные научно-исследовательские работы ОИЯИ и Института физики высоких энергий ГКАЭ СССР на Серпуховском ускорителе.

18 июня 1970 года между ОИЯИ и ГКАЭ СССР было заключено соглашение о научно-техническом сотрудничестве, по которому обе стороны обязались способствовать дальнейшему расширению сотрудничества в области ядерной физики, обеспечивая максимальное и эффективное использование имеющихся в их распоряжении ускорителей, исследовательских реакторов, аппаратуры для обработки информации и других экспериментальных и исследовательских установок, а также создавать новое оборудование для этих целей.

Для выполнения этих задач ОИЯИ и Институты Госкомитета будут заключать двусторонние договоры с определением тематики исследований, сроков проведения экспериментов и т.д.

Продолжается успешное сотрудничество советских ученых с учеными из социалистических стран в рамках Постоянной Комиссии СЭВ по использованию атомной энергии в мирных целях, образованной в 1960 году, в работе которой принимают участие делегации НРБ, ВНР, ГДР, ПНР, СРР, ЧССР и СССР.

Целью Комиссии является содействие дальнейшему развитию многостороннего экономического и научно-технического сотрудничества между странами-членами СЭВ в интересах более планомерного применения атомной энергии в мирных целях.

Постоянная Комиссия организует важнейшие научно-исследовательские работы и инженерные разработки в области реакторной науки и техники и атомной энергетики, ядерного приборостроения, производства изотопов и источников ядерных излучений, применения радиоизотопных методов и аппаратуры, радиационной безопасности и защитной техники, удаления радиоактивных отходов и других интересных и важных проблем. Для лучшей организации и координации работ по использованию атомной энергии и удовлетворения растущих энергетических потребностей стран-членов СЭВ, многие из которых не имеют больших запасов классического топлива, в рамках Комиссии создана специальная рабочая группа специалистов по вопросам проектирования, сооружения и эксплуатации АЭС.

Рабочей группой был разработан план координации научных и технических исследований, который предусматривал выполнение работ по 37 темам, из них 10 тем по реакторной технике и ядерной энергетике. Советские специалисты участвовали в работах по:

– исследованию и разработке новых и усовершенствованию существующих энергетических реакторов на тепловых нейтронах мощностью более 400 МВт(эл), особенно реакторов с водой под давлением;

– исследованию и проектным проработкам энергетического реактора на быстрых нейтронах с различными теплоносителями электрической мощностью свыше 1000 МВт;

– разработке и исследованию технологии производства и регенерации ядерного горючего;

– исследованию в области производства новых реакторных материалов, специального оборудования и средств радиационной защиты и безопасности энергетических реакторов и др.

Советские специалисты принимают участие в совместных научно-исследовательских работах в рамках Постоянной Комиссии СЭВ по производству и применению изотопов, меченых соединений и источников излучений, в области ядернофизических приборов и радиоизотопной аппаратуры, по вопросам радиационной безопасности и защитной техники, обезвреживанию жидких, твердых и газообразных радиоактивных отходов, дезактивации загрязненных поверхностей и др.

Широко сотрудничают страны – члены СЭВ и в области ядерного приборостроения.

К настоящему времени общий объем производства изделий ядерного приборостроения в странах – членах СЭВ составляет более 65 млн. рублей, широта номенклатуры – более 100 типов приборов и до 1000 наименований. Суммарная номенклатура радиоизотопной продукции охватывает свыше 5000 препаратов и источников излучений.

В июне 1970 года на XVIII заседании Комиссии была принята программа дальнейшего углубления сотрудничества в области изотопной продукции на 1971-1975 годы, которая предусматривает комплексное решение вопросов по специализации и кооперированию, унификации и стандартизации, научно-техническое сотрудничество, совершенствование системы информации.

Развивается и совершенствуется также сотрудничество в области ядерной медицины, радиационных процессов и установок.

Сотрудничество социалистических стран в области мирного атома в рамках СЭВ непрерывно развивается: устанавливаются конкретные практические связи, ведется постоянный взаимный поиск путей решения новых задач и проблем.

СОТРУДНИЧЕСТВО С РАЗВИВАЮЩИМИСЯ СТРАНАМИ НА ДВУСТОРОННЕЙ ОСНОВЕ И В РАМКАХ МАГАТЭ

Проекты по использованию атомной энергии в мирных целях становятся мощным стимулом экономического и научного прогресса развивающихся стран. Осуществлению этой цели во многом способствует научно-техническое сотрудничество этих стран с Советским Союзом на основе двусторонних соглашений и в рамках Международного агентства по атомной энергии.

Советский Союз, расширяя сотрудничество с развивающимися странами в области мирного использования атомной энергии, стремится поделиться своим опытом с учеными этих стран, оказать техническое содействие в создании национальных научно-исследовательских центров и подготовке местных национальных кадров для самостоятельного проведения научных исследований.

Созданный в 1961 году на основании межправительственного соглашения СССР с ОАР Научно-исследовательский атомный центр вблизи Каира значительно расширил за последние годы тематику совместных работ, включив в план исследования по теплофизике и физике плазмы, а также увеличил объем исследований по использованию радиоактивных изотопов.

В состав Центра входит экспериментальный водо-водяной реактор мощностью 2000 кВт, высокостабильный электростатический ускоритель на энергию 2,5 МэВ, а также мастерские и специальные лаборатории для проведения исследовательских работ в области ядерной физики, химии, металлургии и биологии.

С 1964 года по настоящее время в Атомном центре ОАР выполнено около 100 научных работ. Советские ученые прочитали египетским специалистам более 400 лекций и провели большое число семинаров.

В 1963 году на базе Атомного центра в ОАР в Каире был создан Средне-восточный региональный радиоизотопный центр, в работе которого принимают участие 13 стран.

С помощью Советского Союза создан также Центр ядерных исследований в Ираке с реактором типа ИРТ-2000, который был пущен 6 января 1968 года. Центр имеет отдел по производству радиоизотопов, отдел физики, геологии, радиационной безопасности, биологии и сельского хозяйства, а также ремонтные и технические службы.

Для оказания содействия в строительстве, монтаже и наладке поставленного оборудования в Ирак было командировано около 50 советских специалистов.

В 1969 году с Ираком был подписан Протокол о дальнейшем расширении научно-технического сотрудничества в области мирного использования атомной энергии. Предусмотрена модернизация исследовательского реактора, имеющая целью повысить мощность реактора.

В мае 1970 года между ГКАЭ СССР и КАЭ Пакистана было заключено соглашение о сотрудничестве, которое предусматривает взаимный обмен специалистами и экспертами по технологии ядерных энергетических реакторов, производству и переработке ядерного топлива, разведке и добыче ядерных сырьевых ресурсов, по исследованиям в различных областях атомной науки и техники, технологии двухцелевых ядерно-энергетических установок и т.д. Госкомитет будет ежегодно предоставлять до 5-ти стипендий (до одного года каждая) для специализации и получения практического опыта пакистанскими учеными в советских научно-исследовательских учреждениях, а также оказывать содействие в приобретении в СССР необходимого оборудования.

Содействуя развитию атомной энергетики Республики Индии, Советский Союз по соглашению от 6 октября 1961 года передал ей полную техническую документацию по реактору на быстрых нейтронах электрической мощностью 50 МВт. Осуществляется обмен делегациями специалистов между СССР и Индией.

Советский Союз оказывает также большую помощь развивающимся странам, принимая активное участие в реализации программы техпомощи МАГАТЭ, важность которой существенно возрастает в связи с вступлением в силу Договора о нераспространении ядерного оружия, ибо отказ от производства и приобретения ядерного оружия позволит развивающимся странам освободиться от больших непроизводительных затрат и создаст дополнительные возможности использования имеющихся ресурсов для экономического и социального прогресса.

В распоряжение МАГАТЭ Советским Союзом предоставлены также добровольные взносы на общую сумму 712 500 руб. в виде поставки в развивающиеся страны установок, оборудования, материалов, приборов и изделий.

Советским Союзом безвозмездно предоставлен специальный добровольный взнос в виде оборудования для четырех радиологических центров: в 1967 году – в Марокко, в 1968 году – в Пакистане, в 1970 году – в Ираке; кроме того, принято решение о строительстве в 1972-1973 годах центра в Бирме.

Советское правительство приняло решение увеличить в 1971 году добровольный взнос СССР в фонд технической помощи МАГАТЭ со 150 до 250 тыс.руб. для приобретения оборудования, приборов и материалов, а также для проведения в СССР совещаний, учебно-ознакомительных поездок, курсов и семинаров.

В настоящее время практически реализованы все 20 стипендий (до одного года каждая), предоставленные в 1966 году в распоряжение МАГАТЭ для обучения в научно-исследовательских центрах СССР специалистов из развивающихся стран – членов Агентства. В 1970 году на XIV сессии Генеральной конференции МАГАТЭ Советский Союз предоставил Агентству еще 25 стипендий.

СССР подтвердил также свою готовность предоставлять ежегодно 10 стипендий с целью подготовки специалистов для работы на установках, построенных с помощью СССР, или для выполнения совместных работ в рамках двусторонних соглашений с этими странами.

В соответствии с Программой Развития ООН и Регулярной Программой МАГАТЭ Советский Союз направил в развивающиеся страны высококвалифицированных экспертов-консультантов для оказания помощи в области радиационной безопасности, облучения пищевых продуктов, применения радиоизотопов в гидрологии, иммунологии, в области ускорительной и реакторной техники, ядерной физики, анализа ядерных сырьевых материалов и т.д.

Развивающиеся страны проявляют возрастающий интерес к участию в научно-ознакомительных поездках по Советскому Союзу с проведением однодневных семинаров. За последние 3 года по просьбе Агентства были организованы семинары по использованию изотопов в промышленности, по вопросам обращения с радиоактивными отходами, по радиоизотопным методам измерений "in vivo" в медицине, использованию изотопов и излучений в сельском хозяйстве, по стандартизации радиационной дозиметрии. В состав каждой группы входило около 25 иностранных специалистов.

Очевидно, что особенно актуальным становится вопрос об обеспечении развития атомной энергетики ядерным горючим и, в первую очередь, обогащенным ураном. На нынешнем этапе развития атомной энергетики относительно простыми по конструкции и в то же время достаточно надежными и экономичными являются атомные реакторы, использующие обогащенный уран.

Многие страны располагают естественным ураном, а для тех, у кого его нет, не составляет особого труда купить его. Однако обогатить этот уран до нужной кондиции большинство даже развитых стран в настоящее время не в состоянии, так как это очень дорогостоящий технологический процесс.

Исходя из потребности неядерных стран в обогащенном уране и желая способствовать развитию атомной энергетики этих стран, Советский Союз на XII сессии МАГАТЭ заявил о готовности оказывать услуги по обогащению урана,принадлежащего неядерным странам. Мы рассматриваем это как весьма важный вклад СССР в международное сотрудничество по мирному использованию атомной энергии и с пониманием относимся к тому интересу, который проявляют многие страны к сотрудничеству с Советским Союзом в этой области.

Услуги, оказываемые СССР в обогащении урана, могут явиться выгодной,надежной и долговременной базой для атомной энергетики стран, пожелающих воспользоваться этими услугами.

Естественно, что уран других стран, обогащенный в Советском Союзе, должен использоваться только в мирных целях, под контролем МАГАТЭ, как это и предусматривается Договором о нераспространении ядерного оружия.

СОТРУДНИЧЕСТВО С ИНДУСТРИАЛЬНО РАЗВИТЫМИ СТРАНАМИ

За истекший период наблюдалось расширение сотрудничества СССР в области мирного использования атомной энергии с индустриально развитыми странами. Заключение соглашений о сотрудничестве с США, Англией, Францией, Канадой, Италией, Швецией, Бельгией, Голландией и Данией явилось важным шагом на пути установления более тесных деловых контактов в области атомной науки и техники.

Этим же целям во многом способствовал обмен делегациями на уровне руководителей национальных атомных комиссий, а также учеными и специалистами для ознакомления и проведения совместных исследований по отдельным научным проблемам.

В соответствии с Меморандумом о сотрудничестве в области использования атомной энергии в мирных целях между ГКАЭ СССР и КАЭ США был проведен взаимный обмен делегациями по ядерным энергетическим реакторам, физике плазмы, физике твердого тела, ядерной физике, проблемам захоронения радиоактивных отходов и в других областях. С мая

1970 года в Институте физики высоких энергий (ИФВЭ, Серпухов) проводится совместный советско-американский эксперимент по пион-электронному рассеянию.

Согласован обмен делегациями по промышленным радиационным процессам и работам по использованию энергетических пучков для нагрева плазмы, осуществляется обмен учеными для проведения совместных работ в области физики плазмы и управляемого термоядерного синтеза.

В развитие Меморандума о сотрудничестве в Вашингтоне 30 ноября 1970 года был подписан Протокол между ГКАЭ СССР и КАЭ США о проведении совместных работ в области физики высоких энергий на ускорителях ИФВЭ (Серпухов) и Национальной ускорительной лаборатории (Батавия). В настоящее время ведутся переговоры о постановке совместного эксперимента по протон-протонному рассеянию на малые углы на ускорителе в Батавии.

Кроме того, на основе взаимной договоренности были проведены в Вене, Москве и Вашингтоне три этапа советско-американских технических переговоров по использованию ядерных взрывов в мирных целях.

Соглашение о сотрудничестве атомных организаций Англии и Советского Союза, подписанное 19 мая 1961 года, продлено в настоящий момент до 1976 года.

В соответствии с Соглашением состоялся обмен делегациями для ознакомления с работами по ядерной физике, физике плазмы, ускорителям, физике высоких энергий, радиационной безопасности и т.д.

Достигнута также договоренность о сотрудничестве в области энергетических реакторов (на быстрых и тепловых нейтронах) и по реакторным материалам. Новым этапом явилось проведение совместных экспериментов в Институте атомной энергии им.И.В.Курчатова по измерению электронной температуры плазмы на установке "Токамак-3" с помощью лазерного луча.

Научно-техническое сотрудничество с Францией в области мирного использования атомной энергии осуществляется на основе Соглашения от 20 мая 1967 года, которое было пролонгировано несколько раз с расширением базы для обмена делегациями, информацией, проведения совместных научных мероприятий.

Параллельно выполнялось Соглашение между ГКАЭ СССР и КАЭ Франции, подписанное в Москве 11 октября 1966 года, о проведении совместных научно-исследовательских работ в области физики высоких энергий на советском протонном ускорителе с энергией 70 ГэВ в г.Серпухове с использованием французской жидководородной пузырьковой камеры "Мирабель" с полезным объемом 6000 л.

Сейчас можно с удовлетворением отметить, что, начав с обмена делегациями по ознакомлению с научными центрами, наше сотрудничество переросло в проведение крупных совместных научных экспериментов. Подписание и реализация этого Соглашения является не только выдающимся вкладом в дело развития физики высоких энергий, но и примером плодотворного сотрудничества двух стран с различным социальным строем в духе дружбы и взаимопонимания.

В связи с заявлением Советского Союза на XII сессии Генеральной конференции МАГАТЭ о готовности обогащать урановое сырье заинтересованных стран до 2,5-5% по ^{235}U, в мае 1971 года в Париже подписан контракт о предоставлении французской стороне услуг по обогащению французского уранового сырья на советских предприятиях на взаимовыгодных условиях.

По соглашению между ГКАЭ СССР и Европейской организацией ядерных исследований (ЦЕРН) (июль 1967 г.) при активном участии советских специалистов в ЦЕРНе разрабатывается такое оборудование для Серпуховского ускорителя, как система быстрого вывода пучка протонов, высокочастотный сепаратор элементарных частиц, а также различная электронная аппаратура. После поставки этого оборудования в Серпухов приедет большая группа ученых ЦЕРНа для проведения совместных научных работ на ускорителе. Таким образом, после монтажа и наладки этого оборудования в ИФВЭ совместными усилиями ученых разных стран будет создан уникальный комплекс, включающий многокубовую жидководородную камеру "Мирабель" и крупнейший в мире канал заряженных частиц.

В обработке информации с камеры "Мирабель", получаемой в виде стереофотографий, примут участие советские институты, научно-исследовательские организации Франции и стран – участниц ЦЕРНа.

Осуществляется также сотрудничество с канадской государственной организацией "Атомик энерджи оф Канада лимитед" на основе соглашения 1964 года, с Национальным комитетом по ядерной энергии Италии, Реакторным центром Нидерландов, Комиссариатом по атомной энергии Бельгии (с 1965 г.) и КАЭ Дании (с 1968 г.).

За последние годы заметно расширилось сотрудничество СССР со Швецией в области атомной науки и техники.

В соответствии с договоренностью, зафиксированной в советско-шведском коммюнике от 13 июня 1968 года, в Москве в январе 1970 года было подписано соглашение сроком на 30 лет между Правительством СССР и Швеции о сотрудничестве в области использования атомной энергии в мирных целях. Соглашение предусматривает расширение объема сотрудничества по сравнению с подписанным в феврале 1968 года "Протоколом о сотрудничестве в области использования атомной энергии в мирных целях между ГКАЭ СССР и Шведской Королевской академией инженерных наук", по которому происходит только обмен делегациями ученых и научно-технической информацией.

Указанное Соглашение предусматривает взаимную поставку оборудования, включая ядерные реакторы и топливо для них, материалов и специальных ядерных материалов на коммерческой основе, услуги по обогащению урана на предприятиях СССР, причем любые материалы, предоставленные по настоящему Соглашению, будут использоваться только для мирных целей.

Устанавливаются контакты с ФРГ в области мирного использования атомной энергии: в ноябре 1970 года в Москве были проведены переговоры о перспективах сотрудничества между группами экспертов ГКАЭ СССР и Федерального министерства образования и науки ФРГ; в апреле 1971 года СССР посетила делегация специалистов ФРГ в области физики высоких энергий, в июне 1971 года советские специалисты были приняты в ФРГ по вопросам термоядерного синтеза.

В сентябре 1969 года был подписан Протокол между правительствами Советского Союза и Финляндии о строительстве в Финляндии при техническом содействии СССР атомной электростанции мощностью 440 тыс. кВт, имеющей реактор с водой под давлением. Готовность станции к промышленной эксплуатации будет обеспечена до 30 июня 1976 года.

УЧАСТИЕ СССР В ДЕЯТЕЛЬНОСТИ МЕЖДУНАРОДНЫХ ОРГАНИЗАЦИЙ

Как уже отмечалось, Советский Союз оказывает большую помощь развивающимся странам в рамках МАГАТЭ – организации, специально созданной для содействия применению атомной энергии в целях мира и прогресса и призванной осуществлять международное сотрудничество в этой области.

С момента создания Агентства Советский Союз принимает активное участие в его деятельности, всячески содействуя выполнению стоящих перед ним задач.

За истекший период советские ученые и специалисты значительно расширили свое участие в проводимых Агентством конференциях, симпозиумах, семинарах, совещаниях экспертов, рабочих групп и представили большое количество докладов и сообщений о последних достижениях советской атомной науки и техники. Только за один 1970 год было представлено около 100 советских научных докладов. Такое участие позволяет устанавливать и укреплять связи с зарубежными учеными, делиться богатым опытом, накопленным советской атомной наукой и техникой.

Среди мероприятий, которые проводились на территории СССР, следует отметить заседание Международного комитета по ядерным данным (Москва, 1967 г.); III конференцию по исследованиям в области физики плазмы и управляемых термоядерных реакций, на которой присутствовало более 250 зарубежных ученых из 20 стран – членов МАГАТЭ (Новосибирск, 1968 г.); совещания экспертов по исследованиям строения ядра, по вопросам консервирования и трансплантации костного мозга, фиксации радиоактивных отходов в битуме; заседание Международной группы связи по термоэмиссионному преобразованию и др.

Практикуются также частые встречи в ГКАЭ с сотрудниками Секретариата МАГАТЭ для обсуждения различных вопросов, связанных с участием СССР в деятельности Агентства.

Советские специалисты активно участвовали в регламентационной деятельности Агентства по выработке норм, наставлений, правил и рекомендаций, главным образом по вопросам ядерной безопасности.

В настоящее время советскими научно-исследовательскими учреждениями выполняется 11 контрактов и исследовательских соглашений (6 из них на бесплатной основе) с МАГАТЭ по техническим аспектам гарантий, удалению радиоактивных отходов, радиоспектроскопическим исследованиям, по использованию индуцированных мутаций в селекции растений и т.д.

Советский Союз придает также большое значение таким важным аспектам деятельности МАГАТЭ, как осуществление Агентством контрольных функций в связи с Договором о нераспространении ядерного оружия, использование ядерных взрывов в мирных целях, Международная система ядерной информации (ИНИС) и координация работ в области термоядерного синтеза.

Говоря о сотрудничестве с МАГАТЭ, нельзя не сказать о новой, очень важной деятельности этой организации в связи с Договором о нераспространении ядерного оружия. Чувство большого удовлетворения вызывает тот факт, что Агентство за сравнительно короткий срок сумело при конструктивном сотрудничестве стран-участниц выработать те положения, которые должны служить основой соглашений о контроле между МАГАТЭ и неядерными странами – участницами Договора о нераспространении. Это – замечательный пример международного сотрудничества стран. Хочется надеяться, что в результате проделанной работы к Договору присоединится еще больше государств, а это будет эффективно содействовать делу мира.

Важным аспектом деятельности Агентства, непосредственно вытекающим из Договора о нераспространении, является его деятельность в исследовании проблемы мирных ядерных взрывов.

Советский Союз, осуществляя исследования в этой области и сотрудничая с другими странами на двусторонней основе, активно содействует Агентству в его работе, с тем чтобы приблизить время реализации положений статьи V Договора о нераспространении.

Участвуя в мероприятиях МАГАТЭ по исследованию проблемы мирных ядерных взрывов, советские специалисты поделились своим опытом проведения работ и разработок технических проектов по применению ядерных взрывов в различных областях народного хозяйства СССР. На XIV сессии Генеральной конференции МАГАТЭ советская делегация передала Агентству кинофильмы об использовании ядерных взрывов в мирных целях (ликвидация горящего газового фонтана и создание искусственного водохранилища) и сборник научно-технических материалов о некоторых работах, проведенных Советским Союзом в этой области.

Рассматривая широкий международный обмен информацией как средство ускорения научно-технического и экономического прогресса, Советский Союз явился одним из инициаторов создания в рамках МАГАТЭ первой в мире Международной системы ядерной информации (ИНИС), которая начала действовать с апреля 1970 года. В деятельности рабочих органов МАГАТЭ, занимавшихся разработкой организационных и технических принципов этой системы, участвовали ведущие советские специалисты.

С момента создания ИНИС Советский Союз, исполняя взятые на себя обязательства, осуществляет ежемесячный регулярный ввод в систему отечественных материалов, подпадающих под ее тематический охват.

Всячески содействуя дальнейшему усовершенствованию ИНИС, мы считаем, что успешное функционирование этой системы поможет развитию атомной науки и техники в развивающихся странах, а также позволит индустриально развитым странам более эффективно обмениваться научно-технической информацией на базе многостороннего сотрудничества.

Советский Союз поддержал намерение МАГАТЭ учредить в рамках Агентства Международный совет по термоядерным исследованиям в целях лучшей международной координации работ в области создания термоядерного реактора. СССР представлен в этом Совете академиком Л.А.Арцимовичем.

Созданный в 1964 году Агентством Международный центр теоретической физики в Триесте, управление деятельностью которого осуществляется в настоящее время совместно с ЮНЕСКО, способствует дальнейшему развитию всех областей теоретической физики посредством подготовки молодых физиков, особенно из развивающихся стран, проведения совместных исследований и международных форумов.

В мероприятиях Центра принимали участие видные советские ученые, которые читали лекции, проводили научно-исследовательские работы (заседание рабочей группы по физике плазмы в 1970 г.), участвовали в работе симпозиумов (например, Международный симпозиум по проблемам современной физики, 1968 г.).

Международное сотрудничество, осуществляемое в рамках МАГАТЭ, во многом способствует расширению экономических и научно-технических связей между государствами, в результате чего исключается дублирование в проведении научных исследований, в значительной степени экономятся время и средства.

Советский Союз принимает деятельное участие в работе Научного комитета ООН по действию атомной радиации, который подготовил ряд докладов для Генеральной Ассамблеи ООН о радиоактивных осадках вследствие испытаний ядерного оружия, о действии естественной и искусственной радиации на окружающую среду, о радиоактивном заражении окружающей среды и т.д. Оценки и выводы, сделанные Комитетом, сыграли положительную роль в борьбе за прекращение ядерных испытаний в атмосфере, космическом пространстве и под водой и способствовали расширению знаний об уровнях и действии атомной радиации, исходящей из всех источников.

Стремясь содействовать расширению международного сотрудничества в области стандартизации, советские специалисты активно участвуют в деятельности Технического Комитета 45 ("Электроизмерительная аппаратура для регистрации ионизирующих излучений") Международной электротехнической комиссии, его подкомитетов и рабочих групп, а также Технического комитета 85 ("Атомная энергия") Международной организации стандартизации.

Советский Союз оказал гостеприимство в проведении в Москве в 1969 году с участием 60 иностранных специалистов очередного заседания Технического комитета 45, на котором рассматривались вопросы, связанные с классификацией терминологии, а также с унификацией радиоизотопной аппаратуры и методик испытаний.

УЧАСТИЕ В МЕЖДУНАРОДНЫХ ЯРМАРКАХ И ВЫСТАВКАХ

Важную роль в укреплении международного сотрудничества и развития экономических и торговых связей СССР с зарубежными странами играют советские выставки, проводимые как за границей, так и внутри страны, и отражающие достижения Советского Союза в области мирного использования атомной энергии.

Неизменным успехом пользуются выставки "Атом для мира", которые демонстрировались во многих странах Азии, Африки, Европы, Северной и Южной Америки.

На Всемирной выствке в Монреале "ЭКСПО-67" в экспозиции раздела "Атом для мира" был показан путь от первой в мире советской атомной электростанции до современных АЭС промышленного типа, а также успехи СССР во многих других областях использования атомной энергии.

В 1967 году в ВНР и СРР демонстрировались юбилейные выставки "Научно-технические достижения СССР", на которых были показаны научные достижения Советского Союза за 50 лет и их практическое применение в народном хозяйстве.

Советский Союз участвовал в Международной ярмарке атомной промышленности "НУКЛЕКС-69" в Базеле (Швейцария). В советском павильоне были представлены макеты атомных реакторов, изотопные источники тока, ускорители для промышленных целей, плазменные установки для резки металлов, лазерные установки и другие изделия. Во время выставки была проведена научно-техническая конференция представителей из 22 стран мира, в которой приняли участие и советские специалисты.

Советская атомная наука и техника была также широко представлена на всемирной выставке "ЭКСПО-70" в Осаке (Япония). Основным содержанием советского павильона являлся показ достижений науки и техники, с которыми советский народ пришел к славному юбилею организатора советского государства В.И.Ленина.

Об успехах советской атомной науки и техники рассказывает и наш павильон на выставке в Женеве, приуроченной к проведению IV Женевской конференции по использованию атомной энергии в мирных целях.

Всего за 16 лет Советским Союзом было проведено 152 выставки по атомной тематике, в том числе зарубежных выставок в 45 странах мира. Число посетителей этих выставок за границей – свыше 80 млн. человек – свидетельствует о том большом интересе, который проявляется к успехам советской атомной науки и техники.

Со времени III Международной конференции по мирному использованию атомной энергии получили дальнейшее развитие основные направления работ в этой области, возросла роль атомной энергии в жизни человека. Мирный атом стал объектом активного общения между государствами, превратился в важный фактор современной международной жизни.

Советский Союз, являясь могучей ядерной державой, исходит во взаимоотношениях с другими государствами не с позиции войны, а с позиции мира, на которой основывается наша политика мирного сосуществования, выработанная В.И.Лениным.

Внешнеполитическая деятельность нашей партии и правительства направлена на дальнейшее всестороннее совершенствование и расширение экономических и научно-технических связей со всеми странами мира на условиях взаимной выгоды, равноправия, в интересах мира и справедливости. Этим же целям служит и международное сотрудничество СССР в области мирного использования атомной энергии.

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THE INTERNATIONAL NUCLEAR INFORMATION SYSTEM (INIS)
An exercise in international cooperation and a service to nuclear scientists and engineers

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Abstract–Résumé–Аннотация–Resumen

THE INTERNATIONAL NUCLEAR INFORMATION SYSTEM (INIS): AN EXERCISE IN INTERNATIONAL COOPERATION AND A SERVICE TO NUCLEAR SCIENTISTS AND ENGINEERS.

The International Nuclear Information System (INIS) describes and indexes information published in 36 countries and by 8 international organizations. The descriptions are distributed on computer magnetic tape, in an announcement bulletin and on microfiches. Users of the system can select information on specific subjects from the total file. Thus individual scientists and engineers can be provided with both recent and retrospective information from world-wide sources. The unique and distinctive feature of INIS is its decentralized operation, an approach never attempted before on an international scale. Input to the system is provided by the country or organization in which the information is first published, so the amount of work required of each participant is normally proportional to the scale of its nuclear program. Input is received by the IAEA in Vienna, where it is checked and processed by documentalists and by a computer; output files are distributed for use by the participating countries. Also, the IAEA provides the forum in which the participants meet to give overall direction to INIS and its future development. The IAEA also organizes seminars and other means of training the personnel providing input to INIS and utilizing its output. The INIS system design was prepared by an international group of consultants and approved at meetings of experts from the participating countries. A large part of the cost is carried by the various countries and organizations in financing their own participation. The cost of INIS's central operations in the IAEA, partly offset by sales of output products, is provided for in the regular IAEA budget. Participating countries, particularly developing countries without computer-based information-processing capabilities, are encouraged to combine to form centres either for INIS activities alone or for INIS activities in association with information services covering other fields of science and technolgoy.

LE SYSTEME INTERNATIONAL DE DOCUMENTATION NUCLEAIRE AU SERVICE DES ATOMISTES (INIS): UN EXEMPLE DE COOPERATION INTERNATIONALE.

Le Système international de documentation nucléaire (INIS) décrit et indexe la documentation publiée dans 36 pays et par huit organisations internationales. Les notices bibliographiques sont distribuées par les moyens suivants: bandes magnétiques pour ordinateur, bulletin signalétique et microfiches. Les usagers du système peuvent choisir dans le fichier général des renseignements sur des sujets précis. Ils peuvent donc fournir aux spécialistes une documentation complète, récente et ancienne en provenance du monde entier. La caractéristique unique d'INIS est son fonctionnement décentralisé, entreprise qui n'avait jamais été tentée auparavant sur le plan international. Les données d'entrée du système sont fournies par le pays ou l'organisation qui publie l'élément d'information pour la première fois, de sorte que la quantité de travail incombant à chaque participant est normalement proportionnelle à la taille de son programme nucléaire. Ces données d'entrée sont reçues par l'AIEA à Vienne, où elles sont contrôlées et traitées par des documentalistes et sur ordinateur. Les fichiers «produits» sont distribués pour exploitation aux pays participants. L'AIEA organise des réunions au cours desquelles les participants décident de l'orientation générale d'INIS et définissent les modalités de son développement futur. Elle organise aussi des journées d'études et d'autres moyens de former le personnel qui établit les données d'entrée pour INIS et exploite ses «produits». L'étude d'INIS a été faite par un groupe international de consultants et approuvée au cours de réunions d'experts des pays participants. Les divers pays et organisations assument, en finançant leur propre participation, la majeure partie des coûts. Le coût des services centraux de l'AIEA, compensé partiellement par le produit des ventes, est inscrit au budget ordinaire de l'AIEA. On encourage les pays participants, et notamment

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les pays en voie de développement qui n'ont pas de moyens de traitement automatique de l'information, à s'associer pour former des centres, soit pour exécuter les seuls travaux relatifs à INIS, soit pour combiner les travaux d'INIS avec des services de documentation couvrant d'autres domaines de la science et de la technologie.

МЕЖДУНАРОДНАЯ СИСТЕМА ЯДЕРНОЙ ИНФОРМАЦИИ (ИНИС): ПРИМЕР МЕЖДУНАРОДНОГО СОТРУДНИЧЕСТВА В УДОВЛЕТВОРЕНИИ ПОТРЕБНОСТЕЙ В ИНФОРМАЦИИ ПО АТОМНОЙ ТЕМАТИКЕ УЧЕНЫХ И ИНЖЕНЕРОВ.

Международная система ядерной информации (ИНИС) включает в себя описание информации, публикующейся 36 странами и 8 международными организациями. Информация распространяется в форме магнитных лент, обработанных посредством ЭВМ, печатного бюллетеня и микрофишей. Лица, пользующиеся услугами системы, могут выбрать из сводного бюллетеня информацию по отдельным конкретным вопросам. Таким образом, ИНИС предоставляет ученым и инженерам новейшую и специфическую информацию из источников, публикуемых во всем мире. Уникальной и отличительной особенностью ИНИС являются децентрализованные операции по подготовке ввода информации – практика, никогда не применявшаяся ранее в широком международном масштабе. Входные данные для системы предоставляются страной или организацией, где информация публикуется впервые, так что объем требуемой от каждого участника работы обычно пропорционален масштабу ядерной программы его страны. Входные данные поступают в МАГАТЭ, где они проверяются и обрабатываются документалистами с помощью ЭВМ. Выходные данные распространяются для использования в странах-участницах. Именно МАГАТЭ собирает форумы, на которых участники ИНИС определяют общее направление деятельности системы и ее будущего развития. МАГАТЭ проводит семинары и осуществляет другие формы обучения персонала, который готовит входные данные для системы и использует ее выходные данные. Проект ИНИС был подготовлен международной группой консультантов и одобрен на совещаниях экспертов стран-участниц. Основная часть расходов по системе покрывается различными странами и организациями, финансирующими их деятельность в рамках системы. Расходы на персонал центрального аппарата ИНИС частично покрываются МАГАТЭ за счет продажи выходной продукции, а также оплачиваются из средств обычного бюджета Агентства. Странам-участницам, особенно развивающимся странам, не имеющим возможности использовать электронно-вычислительные машины для обработки информации, рекомендуется объединять свои усилия в создании центров, предназначенных служить либо только целям ИНИС, либо целям удовлетворения потребностей в информации в других областях науки и техники.

SISTEMA INTERNACIONAL DE DOCUMENTACION NUCLEAR (INIS): EJEMPLO DE COOPERACION INTERNACIONAL EN SERVICIO DE LOS CIENTIFICOS E INGENIEROS NUCLEARES.

El sistema internacional de documentación nuclear (INIS) recoge y clasifica documentación publicada en 36 países y por 8 organizaciones internacionales. Las descripciones se distribuyen en cinta magnética producida por una computadora electrónica, en un boletín y en microfichas. Los usuarios del sistema pueden seleccionar información sobre materias específicas de la serie total de datos. Así, los científicos e ingenieros pueden disponer de información pasada o reciente procedente de fuentes en una escala mundial. Característica única y distintiva del INIS es su funcionamiento descentralizado, procedimiento que no se ha intentado antes en escala internacional. Los datos que se registran en el sistema son suministrados por el país o por la organización que primero publicaron la información, de modo que la labor de cada país u organización participante es normalmente proporcional a la escala de su programa nuclear. Los datos de entrada los recibe el OIEA en Viena, donde son comprobados y tratados por documentalistas y por una computadora electrónica; los datos de salida se distribuyen para su utilización por los países participantes. Además, el OIEA proporciona los locales para las reuniones de los participantes en que se determinan las directrices globales del INIS y su futuro desarrollo; también organiza seminarios y otros métodos de formación del personal encargado de proporcionar los datos de entrada al INIS y de emplear los datos de salida. El proyecto del sistema INIS se preparó por un grupo internacional de asesores y se aprobó en reuniones de expertos de los países participantes. La parte principal del costo está sufragada por los diversos países y organizaciones, que financian su propia participación. El costo de las actividades de la central del INIS en el OIEA, parcialmente cubierto por la venta de los productos de salida, se carga al presupuesto ordinario del OIEA. Se estimula a los países participantes, especialmente los países en desarrollo que no poseen facilidades para el tratamiento computacional de información a reunirse para formar centros ya sea para actividades del INIS exclusivamente o como complemento de otros servicios de información referentes a distintos campos de la ciencia y la tecnología.

1. INTRODUCTION

The International Nuclear Information System (INIS) now provides new services for the world's nuclear scientists and engineers and for the librarians and documentalists that work with them. The services have been in existence only since May 1970 and, as yet, the scope is by no means comprehensive [1]. INIS, however, has the potential for meeting most of the information needs of the nuclear community and represents an unique experiment in international cooperation (see Table I).

Over the years, some excellent information services have come into operation under national or regional management. Very broad coverage is provided by Nuclear Science Abstracts [2], which is published in the United States of America. Similarly broad coverage in French and Russian is provided, respectively, by Bulletin Signalétique [3] and Referativnyj Zhurnal [4]. The Euratom Nuclear Documentation System (ENDS) provides a computer-based retrieval system primarily for nuclear scientists and engineers in the six countries of the European Community [5]; the United States and the Soviet Union [6] have also been developing computer-based systems dealing with the whole general field of atomic energy. While INIS cannot yet compete in volume or scope with the services provided by these existing systems, it is already a useful supplement, particularly for nuclear research workers in developing countries.

2. THE INIS PRODUCTS

Four main products are now offered by INIS and are described below.

2.1. Computer magnetic tapes

These tapes contain detailed bibliographic records and subject descriptors for all items of literature reported by INIS. They permit the selection of items by any of a large number of different parameters (subjects, titles, authors, institutions, countries of origin, dates of publication, forms of publication etc.), the printing of lists in preferred sequences, and the generation of new indexes. The carrier language of the computer records is English, although titles are also given in the original language (transliterated from non-Roman alphabets when necessary).

A new supplement to the magnetic-tape file is produced each month and copies are available to any international organization or to the government of any Member State participating in INIS. The governments, in turn, may copy and distribute these tapes as they see fit. The records in each tape are recorded serially, and both 7-track and 9-track formats are available. Eventually, the IAEA expects to offer specially condensed tapes designed for rapid searching, as well as appropriate software packages.

2.2. An indexed announcement bulletin

Known as INIS Atomindex, this publication is issued once each month and provides an ordered record of all items that have been identified in the magnetic-tape service. It is, in fact, printed directly from the magnetic tape by the IAEA's computer in Vienna. One free subscription is given to the depository nominated by the government of any Member State of the IAEA,

TABLE I. SUMMARY OF FUNCTIONS AND PRODUCTS OF THE INTERNATIONAL NUCLEAR INFORMATION SYSTEM

Member States:	IAEA:
(a) Identifying those pieces of newly published literature, both conventional and non-conventional, that come within the INIS subject scope; (b) Preparing a "bibliographic description" (i.e. names of authors, titles, where and when published, etc.) for each piece, according to standard rules; (c) Assigning "keywords" from a thesaurus to each bibliographic description so as to identify the subjects treated in the piece of literature described; (d) Recording the bibliographic descriptions and keywords in specified formats, either on magnetic computer tape, or as punched paper-tapes or typewritten worksheets, and transmitting them to the Agency; (e) Providing the Agency with a type-written "abstract" of each piece of literature in a specified format; and (f) Providing the Agency with the full text of each piece of non-conventional literature, either as originally published or as microfiches to a standard publication.	The Agency edits, checks and otherwise processes all input as it is received. It is stored in the following ways: (a) Bibliographic descriptions and keywords on magnetic computer tape; and (b) Abstracts of all literature and full texts of non-conventional literature on microfiches. Member States can obtain the following output products from INIS: (a) Copies of the magnetic tapes on which bibliographic descriptions and keywords are recorded, new tapes being distributed once monthly; (b) A once-a-month printed bulletin containing the same information as the magnetic tapes; (c) Twice-a-year cumulative indexes (author, corporate authors, bulletin number) to the bulletins; (d) Complete sets of abstracts of both conventional and non-conventional literature on microfiches; and (e) Full texts of pieces of non-conventional literature, either individually or as complete sets, on microfiches.

and additional copies are sent to the centres that provide input to INIS. INIS Atomindex is also available for sale to any person or institution anywhere in the world. The subscription price includes airmail postage to all addresses outside Europe; as with all its publications, the IAEA accepts payment in the currency of any of the many countries in which it maintains bank accounts. Entries in INIS Atomindex are grouped according to a relatively broad subject category scheme; computer-printed indexes are included in every issue and permit searching for authors, for institutions and for report numbers. Cumulative indexes are prepared twice each year.

2.3. Abstracts on microfiches

Every item in the magnetic-tape record and in INIS Atomindex is identified by a serial number. For every item, an abstract is available in at least one of the official languages of the IAEA (English, French, Russian or Spanish). These abstracts are sequenced according to the serial numbers and microfiches are prepared at a reduction factor of about 18:1. Up to sixty such microfiches are reproduced on a single sheet of film (148 mm × 105 mm) and provided with a title that can be read by the naked eye. An instrument is needed to read the individual abstracts on each microfiche, but such instruments are commercially available at prices ranging from about US $100 upwards.

The INIS abstracts-on-microfiches are available, like INIS Atomindex, on annual subscription and may be received airmail by any person or institution anywhere in the world. (Surface mail is used on the European Continent.)

2.4. Full texts on microfiches

Many of the items recorded by INIS are articles in scientific and engineering journals or commercially published books. However, many of the other items – which we identify as "non-conventional" literature – are not readily available through commercial channels, e. g. laboratory technical reports, conference paper preprints, and theses. These non-conventional items currently comprise over 30% of the items reported in INIS Atomindex.

The IAEA acquires copies of the full texts of all "non-conventional" literature reported by INIS and converts these to microfiches. The microfiches may be ordered, either individually or in sets, from the IAEA.

3. COVERAGE

The Board of Governors of the IAEA decided that INIS should begin with a "limited" subject scope and envisaged a step-by-step approach to complete coverage of the world's nuclear literature. INIS is still operating only within its initial scope, which nevertheless covers the following fields of activity:

Reactors and reactor materials;
Uranium production and fuel cycles;
Nuclear techniques in food and agriculture;
Health, safety and waste management;
Isotope production;
Industrial applications of radiation;
Peaceful nuclear explosions;
Safeguards, legal and economic questions.

TABLE II. COUNTRIES AND ORGANIZATIONS PARTICIPATING IN INIS[a]

Countries:

+ Argentina
+ Australia
+ Austria
+ Belgium
+ Bulgaria
Byelorussian Soviet Socialist Republic
Brazil
+ Canada
Chile
+ Czechoslovakia
+ Denmark
+ Finland
+ France
+ Federal Republic of Germany
+ Hungary
+ India
+ Israel
+ Italy
+ Japan
Korea
Mexico
+ Netherlands
+ New Zealand
+ Norway
+ Pakistan
+ Philippines
+ Poland
Portugal
Romania
+ South Africa
+ Sweden
Switzerland
Thailand
Ukrainian Soviet Socialist Republic
+ Union of Soviet Socialist Republics
+ Arab Republic of Egypt
+ United Kingdom
+ United States of America
Vietnam
+ Yugoslavia

Organizations:

CERN (European Organization for Nuclear Research)
ENEA/OECD (European Nuclear Energy Agency/Organization for Economic Co-operation and Development)
+ Euratom (Commission of European Communities)
+ FAO (Food and Agricultural Organization of the United Nations)
+ IAEA (International Atomic Energy Agency)
+ ICRP (International Commission on Radiological Protection)
+ ISO (International Organization for Standardization)
OAU (Organization of African Unity)
+ UN (United Nations Organization)
WEC (World Energy Conference)
+ WHO (World Health Organization)

[a] As of August 1971.
+ Those inputting to INIS.

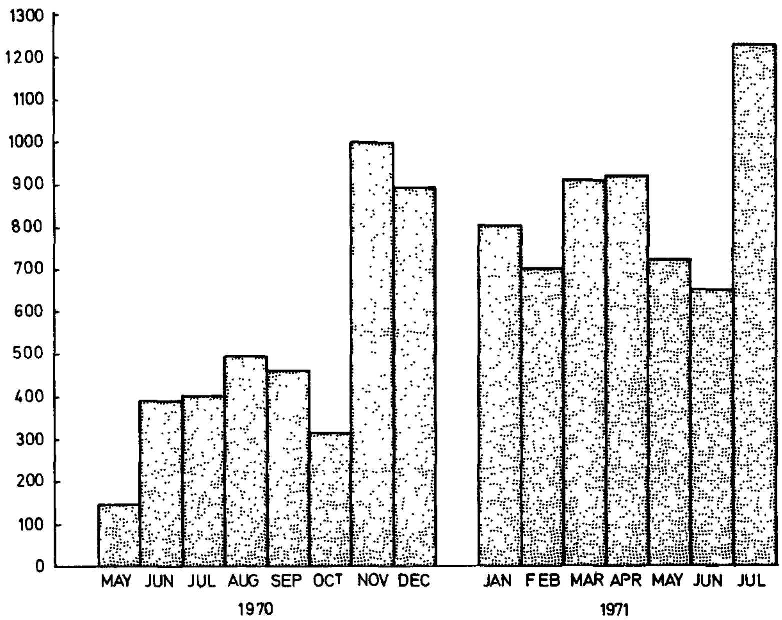

FIG.1. INIS Atomindex — items published monthly.

In addition, when INIS began, many of the countries that had agreed to participate were not yet ready to report all that was published in their territories. Some countries are still having difficulty in preparing complete input; nevertheless, there has been a progressive growth in the number of items reported out by the system (Fig. 1). When INIS has reached its full scope of coverage and participants are fully organized to cover their literature, it is expected that 85 000 items will be reported yearly.

4. PARTICIPATION IN INIS

Participation in INIS is currently limited to IAEA Member States and to international organizations with which the Agency maintains working relationships. The 36[1] countries and the eight[2] organizations now participating are shown in Table II. Also indicated in the table are the names of the Member States and organizations that have input items to the system.

Countries and organizations that qualify for participation may begin inputting upon formal agreement with the Agency. The specific rules for inputting are contained in a series of documents called the INIS Reference Series. These documents are made available in limited quantities without cost to participants and at modest charges to others.

[1] As of Aug. 1971, 40 countries are now participating.

[2] As of Aug. 1971, 11 organizations are now participating.

5. THE NEED FOR INIS

As early as 1964, the IAEA had become concerned about the fact that it was not adequately meeting its statutory obligations to foster the exchange of nuclear information amongst its members. This arose mainly from the fact that new literature dealing with the use of nuclear science for peaceful purposes was accumulating faster than it could be handled by the abstracting journals of the world, with their limited budgets; the concern was aggravated by disquieting indications that one of the three leading journals might not continue to be available indefinitely. There was also evidence that computer techniques might be usefully employed in processing descriptions of the literature.

6. DEVELOPMENT OF THE SYSTEM

In 1965, the Director General of the IAEA invited two consultants, one from the Union of Soviet Socialist Republics and the other from the United States of America, to outline an information-handling scheme that would provide comprehensive coverage of the literature, incorporating up-to-date cooperative procedures for obtaining data and the latest computerized techniques for its storage and retrieval. The consultants' proposals for an international nuclear information system were discussed by a working group of 29 experts from 16 Member States and four international organizations which met in December 1966; its recommendations were that the Agency should assume a "leading role" in the development of such a system, under which national and regional nuclear information services would work together in a network for the preparation of data to go into the system and for the dissemination of its products. The working group's other main recommendation was that English should be the language used for storing data on computer tape.

An essential requirement for a mechanized information-handling system is that the input data for it be prepared according to standard formats. Since the working group's recommendation that the preparation of input data for INIS should be decentralized had been accepted, it became necessary to formulate rules which national and regional services could use in preparing bibliographic descriptions. A draft set of rules was accordingly prepared by three consultants working with the IAEA, and was discussed by a panel of experts convened in December 1967; as a result of the experts' suggestions, a first working set of rules was elaborated. These rules were communicated to several different information services, which made a valuable contribution to the development of INIS by preparing sample bibliographic descriptions in accordance with them. These descriptions, amounting to 1231 from five different sources, were stored on magnetic computer tape, from which output data were then experimentally printed. The results of these experiments were most encouraging.

Parallel with this work, a small group of experts from the USSR, the United Kingdom and the United States of America was called together in the second half of 1967 to advise on the next stage in the development of INIS. In essence, their advice was that INIS should initially be set up as a system whereby the Agency would store on computer tape bibliographic descriptions to be supplied by Member States, each description to be provided with keywords to identify the subjects dealt with; the Agency would then circulate copies of this tape and of a periodical bulletin printed directly from it, and a microfiche service for non-conventional literature would also be operated by the Agency. The experts also advised that a complete systems study of INIS conceived along these lines should be made.

To make this study, an international team of seven consultants worked with the Agency from March to June 1968; seven further experts were called in to help for varying periods of time. This team reconciled the different objectives of the countries producing the bulk of the world's nuclear literature and described an overall concept for operating INIS. In July, the team's report was communicated to a number of organizations throughout the world which were considered capable of appraising it. The critical comments thus obtained, together with the report itself, were laid before an international panel, composed of 37 experts from 23 Member States and four international organizations, which met at IAEA Headquarters in Vienna in late October 1968.

One of the important recommendations stemming from these studies was that the Agency should have a highly developed and centrally maintained thesaurus for effective subject control of documents input into the system. This was an absolute essential if a decentralized system was to operate effectively. Since a well-functioning system had been created and was operating in Euratom, a contract was subsequently negotiated with them to furnish an INIS thesaurus and indexing instruction manual. Also included was a set of computer programs for processing the indexing of items in INIS input. These included error-detection and error-correction routines.

In 1969, the Board of Governors of the Agency gave its approval for the establishment and operation of INIS. The nucleus of the staff to operate the system came from existing personnel of the Documentation and Computer Sections of the Agency, reinforced by additional specialists recruited from Member States.

7. AIMS AND COSTS

The International Nuclear Information System aims to improve and expedite the exchange of scientific and technical information between IAEA Member States on the basis of multilateral cooperation and to eliminate the overlapping and duplication in the processing of literature which occurs at present in atomic energy centres and results in wasteful expenditure of manpower and funds. Cost-sharing is one of the main principles of a decentralized system. National information centres designated by IAEA Member States are responsible for processing the literature published in their areas in accordance with the standards and rules of INIS and for providing their input in the proposed volume and range; they are also responsible for the cost of the operation. In accordance with those principles, a large part of the cost of INIS is borne by the various countries and organizations in financing their own participation. This results in each participating Member State undertaking an effort scaled about in proportion to the size of its nuclear program.

The costs of the central operations in Vienna are covered by the regular budget of the IAEA and partly offset by the sales of output products. The central operation of INIS in the IAEA Headquarters consists of coordinating and checking the work of the national centres; processing the input and output data; regularly distributing to the Member States magnetic tapes, the printed INIS Atomindex and abstracts; making available, through the INIS Clearinghouse, reports and conference papers in microfiche form; maintaining INIS standards and rules; organizing training courses; co-ordinating the work of INIS with that of other international information systems and abstracting services.

Countries participating in INIS, particularly developing countries without computer-based information-processing capabilities, are encouraged to form cooperative centres, either for INIS activities alone or for INIS activities in association with information services covering other fields of science and technology. Such centres provide a means of processing information more quickly and by more experienced personnel, thereby assuring a higher quality of input to INIS. Also, their centralized staffs provide greater resources to the users for locating information contained in INIS output or other sources. In particular, they usually have the means of identifying items of known interest through the provision of regular Selective Dissemination of Information (SDI) services resulting in faster awareness of pertinent information by scientists, engineers and other users.

For a State or organization which chooses to participate within the framework of its own resources, there are reasonable minimum requirements relative to the size of the participant's nuclear program. First of all, as previously mentioned, there is a requirement that all the information published in a participant's territory must be scanned to determine whether it is within the subject scope of INIS. This, of course, must be done by technically qualified individuals. Countries or organizations with small nuclear programs and no organized information program might find it advantageous to depend upon designated scientists and engineers within laboratories, universities, etc. to identify pertinent items for inclusion in INIS and forward them to a central processing site or what is termed an "INIS Reporting Centre".

At the Centre, information would be catalogued, abstracted, and indexed in accordance with INIS rules and forwarded to Vienna to be merged with material from other sources. Where resources are even smaller, the designated scientists would have to perform the cataloguing, abstracting and indexing, and the input would then be reviewed and consolidated by a Liaison Officer for submission to the IAEA. There are many variations of the methods and means which might be employed, and the INIS staff of the IAEA has been available for advice on the organization and training of individuals in participating countries and organizations. Although each organization must tailor its structure to individual requirements, there are many similarities in needs despite the possible variations.

8. EQUIPMENT REQUIREMENTS

For developing countries inputting on worksheets (the simple method of inputting), the equipment requirements are at most a typewriter with an English keyboard. More advanced countries may be capable of inputting on punched paper tape, which would require the availability of a Flexowriter or similar machine costing approximately US $5000. Major producers of information, of course, would be expected to report on magnetic tape. In every case there is a convenient means for a country to contribute to the system. However, for maximum economy and effectiveness, prospective participants with small programs are well advised to seek cooperative arrangements with other national, regional or multi-national centres. Such arrangements as previously mentioned can also be advantageous for the effective use of INIS output for purposes of SDI or retrospective searching in fields of particular interest. Since INIS Atomindex in printed form is designed for manual searching, effective, if slower, use can be made of this tool where fast computer capability does not exist. Thus countries at all levels of development can make practical use of the system.

One of the products of INIS noted earlier is non-conventional literature on microfiches, which requires as a minimum the use of a $100 reader. The number of readers, of course, varies with the size of the country's program. Usually, the means of printing out from microfiches is desirable and a reader-printer is required. The cost for this is approximately $1400.

9. TRAINING

To assist new participants, the IAEA provides two types of training opportunities. One is a three-week seminar covering cataloguing, abstracting and indexing, including related computer demonstrations. While the use of computers may not be of primary interest to developing nations, a knowledge of their use in the system is of future value. In addition, it provides further appreciation for accuracy in reporting — a naturally important element in any good information system.

Additional training is provided on-the-job at IAEA Headquarters in Vienna for varying periods of time based upon specific needs of selected individuals. Careful selection of a trainee by his employer is vitally important. Ideally, he should be selected after the following factors have been considered:

1. His assignment to the INIS program in his own organization is to be of a reasonably long duration, preferably three years or more.
2. The position to be occupied upon completion of training is clearly identified before training is requested so that instruction can be properly tailored to the individual.
3. The trainee's background and capabilities, including a thorough knowledge of English, should be carefully evaluated.

In each form of training, limited funds have been available to provide partial support for individuals from developing countries. To provide a more complete training program, particularly in recognition of the need for self-training or the reinforcement of instruction a trainee has previously received, an additional aid is being developed. This is the acquisition of programmed learning courses in the critical aspects of INIS input — descriptive cataloguing, indexing and abstracting. A contract has been arranged for the first course in this series — descriptive cataloguing — and should be available by early 1972 if the testing program proceeds as anticipated. If this anticipation proves true, then the other two courses in abstracting and indexing should follow soon afterwards.

10. INIS OPERATING POLICY

As previously mentioned, the Agency has primary responsibility for the operation of INIS. In this connection, it is also responsible for the continuous review of the methods and procedures incorporated into the system. However, INIS is a service to Member States in which they have invested through their funding of the Agency's budget and in which they have invested personnel and equipment resources at the national level. Therefore, the Agency follows a policy of consulting with participants in a variety of ways before major changes are instituted. This is essential to assure that no important points are overlooked or, more particularly, that revisions or new requirements that might be imposed do not cause any unusual hardship.

In implementing this policy, several means are employed. First of all, contact is maintained with the established Liaison Officers of INIS members (designation of Liaison Officers is a requirement for participants in the system) through the medium of INIS Circular Letters. These letters primarily cover announcements that include such items as descriptions of changes and their effective dates. The process leading to an announced change may take several paths, depending upon its depth, extent, or financial implication. In most instances involving relatively minor changes, the proposals are first circulated to Liaison Officers by means of INIS Technical Notes. The responses are thoroughly evaluated and the appropriate decision made. To consider complex problems, special study or working groups of experts are formed. In addition, operation of the system is reviewed by the INIS Advisory Committee, which is composed of representatives from Member States whose experience covers the administration and management of national information systems, and also of members who are users of information. In the case of major changes, such as those involving scope or larger computers, a final review is made by the Agency's Board of Governors and its responsible committees.

While from the foregoing it might appear that the Agency is concerned only with changes and their effect on the internal workings of INIS, this is not the case. Staff members continually serve on working groups developing systems such as UNISIST[3] and AGRIS[4] to help ensure future compatibility, and some serve on committees of the International Organization for Standardization (ISO).

At all stages of review, the ultimate purpose is to maintain the integrity and efficiency of a system whose development represents not only a significant monetary investment, but also the collective intellectual effort of internationally recognized experts in information services. Thus, INIS was created through a spirit of international cooperation and continues as a cooperative venture for the benefit of all members.

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[4] Agricultural Information System.

СЕКРЕТАРИАТ СОВЕТА
ЭКОНОМИЧЕСКОЙ ВЗАИМОПОМОЩИ
A/CONF.49/P/683

О ДЕЯТЕЛЬНОСТИ СОВЕТА ЭКОНОМИЧЕСКОЙ ВЗАИМОПОМОЩИ В ОБЛАСТИ ИСПОЛЬЗОВАНИЯ АТОМНОЙ ЭНЕРГИИ В МИРНЫХ ЦЕЛЯХ

СЕКРЕТАРИАТ СОВЕТА ЭКОНОМИЧЕСКОЙ
ВЗАИМОПОМОЩИ *

Abstract–Résumé–Аннотация–Resumen

THE ACTIVITIES OF THE COUNCIL FOR MUTUAL ECONOMIC ASSISTANCE CONNECTED WITH THE USE OF ATOMIC ENERGY FOR PEACEFUL PURPOSES.

The purpose of the paper is to set forth the basic principles, practical organization and results of multilateral cooperation among the States Members of the Council for Mutual Economic Assistance (CMEA) in the use of atomic energy for peaceful purposes. Data are given on the initial period of cooperation in this field among the socialist countries, when their national atomic science and technology infrastructures and research centres were established with the technical assistance of the Soviet Union. In view of the growing complexity of the problems associated with the introduction of atomic energy into the national economies, a Standing Commission on the use of atomic energy for peaceful purposes was set up under CMEA as long ago as 1960, with the aim of co-ordinating multilateral cooperation among the States Members of the organization. The paper deals with the basic problems, aspects and methods of multilateral cooperation under the most important headings: nuclear power, nuclear instrumentation, isotope production and applications, and safety and protection against ionizing radiations.

It is pointed out that the work of CMEA has now substantially contributed to establishing the prerequisites for solving the problems of nuclear power generation and of developing radiation processes and facilities and other promising trends in the peaceful use of atomic energy in the States Members of CMEA. Mention is made of the positive value of contacts between CMEA and IAEA and other international organizations, and of the desire of CMEA for the mutually advantageous exchange of working experience. A description is also given of the principal aspects and forms of a new stage of cooperation in the peaceful uses of atomic energy, intended to implement the resolutions of the XXIII (special) session of CMEA. The XXV session of CMEA, held in Bucharest in June 1971, unanimously adopted an overall program for the further strengthening and consolidation of cooperation and of socialist economic integration among States Members of CMEA. Inter alia, the program provides for measures to accelerate the development and introduction of nuclear power in the national economies of Members.

ACTIVITES DU CONSEIL D'ASSISTANCE ECONOMIQUE MUTUELLE DANS LE DOMAINE DE L'UTILISATION DE L'ENERGIE ATOMIQUE A DES FINS PACIFIQUES.

Le rapport expose les principes généraux, l'expérience, l'organisation et les résultats de la collaboration multilatérale des pays membres du CAEM dans le domaine de l'utilisation de l'énergie atomique à des fins pacifiques. Il rappelle les débuts de cette collaboration, qui remontent à l'époque à laquelle l'aide technique de l'Union soviétique a permis à ces pays de créer une science et une technologie atomiques nationales et d'établir des centres d'études nucléaires. En 1960, la complexité croissante des problèmes que les applications de l'énergie atomique posaient à l'économie nationale des divers pays a entraîné la création, dans le cadre du CAEM, d'une commission permanente de l'utilisation de l'énergie atomique à des fins pacifiques, dont la tâche principale est d'organiser la collaboration multilatérale des pays membres du CAEM. Le rapport met en lumière les principales questions, formes et méthodes de collaboration multilatérale dans les grands domaines suivants· production d'énergie d'origine nucléaire; instrumentation nucléaire; production et emploi des isotopes; sécurité radiologique et radioprotection.

Les activités du CAEM ont beaucoup aidé ses membres à remplir les conditions nécessaires pour résoudre les problèmes liés à la production d'énergie d'origine nucléaire, aux applications industrielles des rayonnements, aux installations d'irradiation et à de nombreuses autres applications de l'énergie atomique à des fins pacifiques; à ce propos le rapport souligne le rôle positif des relations que le CAEM entretient avec l'AIEA et d'autres organisations internationales, ainsi que les efforts qu'il déploie en vue de promouvoir un échange mutuellement profitable de renseignements pratiques. Enfin, le rapport expose les principaux aspects et

* Адрес: СССР, Москва, Г-205, Проспект Калинина, 56.

formes de la nouvelle étape de la collaboration dans le domaine des applications pacifiques de l'énergie atomique, au cours de laquelle les décisions de la XXIII^{e} session (spéciale) du CAEM seront mises en œuvre. Lors de la XXV^{e} session du CAEM, qui s'est tenue en juillet 1971, à Bucarest, les pays membres ont approuvé à l'unanimité l'ensemble du programme qui tend à approfondir et à améliorer leur collaboration et à activer l'intégration de leurs économies socialistes. Ce programme prévoit entre autres l'élaboration de mesures pour accélérer le développement et l'utilisation efficace de l'énergie atomique dans l'économie nationale des divers pays.

О ДЕЯТЕЛЬНОСТИ СОВЕТА ЭКОНОМИЧЕСКОЙ ВЗАИМОПОМОЩИ В ОБЛАСТИ ИСПОЛЬЗОВАНИЯ АТОМНОЙ ЭНЕРГИИ В МИРНЫХ ЦЕЛЯХ.

Целью доклада является изложение основных принципов, опыта организации и результатов многостороннего сотрудничества стран – членов СЭВ в области использования атомной энергии в мирных целях. Приводятся сведения о начальном периоде сотрудничества социалистических стран в данной области, когда с технической помощью Советского Союза в них создавались национальная атомная наука и техника и исследовательские центры. Отмечается, что в связи с растущими задачами по внедрению атомной энергии в народное хозяйство стран, в 1960 году в рамках СЭВ была образована Постоянная Комиссия по использованию атомной энергии в мирных целях, задачей которой является организация многостороннего сотрудничества стран – членов СЭВ. Освещаются основные вопросы, формы и методы многостороннего сотрудничества по важнейшим направлениям: атомной энергетике, ядерному приборостроению, производству и применению изотопов, радиационной безопасности и защитной технике. Отмечается, что деятельность СЭВ в значительной мере способствовала созданию к настоящему времени необходимых предпосылок для решения вопросов развития атомной энергетики, разработки радиационных процессов и установок, а также по другим перспективным направлениям мирного использования атомной энергии в странах – членах СЭВ; при этом отмечается положительная роль контактов СЭВ с МАГАТЭ и другими международными организациями и его стремление к взаимополезному обмену опытом работы. Излагаются основные аспекты и формы нового этапа сотрудничества в области мирного использования атомной энергии, направленные на реализацию решений XXIII (специальной) сессии СЭВ. Отмечается, что XXV сессия СЭВ, состоявшаяся в июле 1971 года в Бухаресте, единодушно приняла Комплексную программу дальнейшего углубления и совершенствования сотрудничества и развития социалистической экономической интеграции стран – членов СЭВ. В Программе, в числе других проблем, предусмотрена разработка мероприятий для ускорения развития и эффективного внедрения атомной энергии в народное хозяйство стран.

LA UTILIZACION DE LA ENERGIA ATOMICA CON FINES PACIFICOS DENTRO DEL MARCO DEL CONSEJO DE AYUDA ECONOMICA MUTUA.

En la presente memoria se esbozan, en sus rasgos fundamentales, los principios, experiencia, organización y resultados de la colaboración de carácter multilateral entre los Estados Miembros del CAEM en la esfera de la utilización de la energía atómica con fines pacíficos. Se describe el período inicial de estas actividades de colaboración entre los países socialistas, cuando se estaban desarrollando, con la asistencia técnica soviética, la ciencia y la tecnología nucleares y los centros de investigación nuclear en los países socialistas. En 1960, la creciente complejidad de los problemas que entrañan las aplicaciones económicas de la energía atómica condujo a la creación de la Comisión Permanente del CAEM para le Utilización de la Energía Atómica con Fines Pacíficos. Incumbe a esta Comisión organizar la colaboración multilateral entre los Estados Miembros del CAEM. La memoria versa sobre los problemas fundamentales, las formas y los métodos de la colaboración multilateral en los principales sectores: energía nucleoeléctrica, instrumental nuclear, producción y uso de isótopos, seguridad y protección radiológicas.

La labor del CAEM ha contribuido de manera decisiva a crear, en los Estados Miembros que lo integran, las condiciones previas necesarias para resolver los problemas relacionados con la generación de energía nucleoeléctrica, los procedimientos e instalaciones de irradiación y otras alentadoras perspectivas del empleo de la energía atómica con fines pacíficos. Se subraya el carácter positivo de las relaciones del CAEM con el OIEA y otras organizaciones internacionales al objeto de fomentar un intercambio de información mutuamente ventajoso. Se examinan también los principales aspectos y modalidades de esta nueva etapa de colaboración en materia de utilización de la energía atómica con fines pacíficos, encaminados a plasmar en realidad las decisiones aprobadas en el 23º período extraordinario de sesiones del CAEM. Se indica que el 25º período de sesiones del CAEM, celebrado en julio de 1971 en Bucarest, aprobó por unanimidad un programa detallado encaminado a intensificar y mejorar la cooperación y el desarrollo de la integración económica socialista entre los Estados Miembros del CAEM. El programa, entre otras actividades, prevé la adopción de medidas a fin de acelerar el desarrollo y la implantación eficaz de la energía atómica en la economía nacional de los distintos países.

ВВЕДЕНИЕ

В 1960 году, в соответствии с постановлением XIII сессии Совета Экономической Взаимопомощи, была образована Постоянная Комиссия СЭВ по использованию атомной энергии в мирных целях, в работе которой принимают участие делегации стран: Народной Республики Болгарии, Венгерской Народной Республики, Германской Демократической Республики, Польской Народной Республики, Социалистической Республики Румынии, Союза Советских Социалистических Республик и Чехословацкой Социалистической Республики, возглавляемые Председателями национальных Государственных Комитетов или Комиссий по атомной энергии.

Постоянная Комиссия является органом Совета Экономической Взаимопомощи и осуществляет свою деятельность на основе принципов: полного равноправия, уважения суверенитета и национальных интересов, взаимной выгоды и товарищеской взаимопомощи. Комиссия имеет целью содействовать дальнейшему развитию экономических связей между странами-членами СЭВ, а также организации многостороннего экономического и научно-технического сотрудничества между ними в интересах более планомерного применения атомной энергии в мирных целях. Образование Постоянной Комиссии было закономерным и естественным процессом развития научно-технического сотрудничества стран в области мирного использования атомной энергии, которое началось с 1955 года на основе двусторонних соглашений.

В странах-членах СЭВ при научном и техническом содействии Советского Союза в короткие сроки были сооружены и введены в эксплуатацию исследовательские ядерные реакторы, ускорители элементарных частиц, радиохимические и физические лаборатории, а также организована подготовка кадров в этой области. Создание и деятельность научно-исследовательских центров в странах-членах СЭВ способствовали более широкому развитию научных исследований, инженерных разработок и организации в дальнейшем новых институтов и лабораторий. Наряду с созданием научно-технических предпосылок, возникли новые задачи, связанные с использованием достижений атомной науки и техники в различных отраслях народного хозяйства.

В связи с этим Постоянная Комиссия в начале своей деятельности определила такие важные направления сотрудничества стран-членов СЭВ, как исследования и разработки в области ядерного приборостроения, производство изотопов и источников ядерных излучений, применение радиоизотопных методов и аппаратуры, радиационная безопасность и защитная техника. С 1965 года было организовано сотрудничество по реакторной науке и технике и атомной энергетике.

Последние два года деятельность Постоянной Комиссии развивается на основе решений XXIII (специальной) и XXIV сессий СЭВ, которые определяют главные направления дальнейшего углубления и совершенствования сотрудничества и развития социалистической экономической интеграции стран-членов СЭВ, изыскания новых, более эффективных форм и методов сотрудничества.

В данном докладе излагаются опыт организации и некоторые результаты многостороннего сотрудничества стран-членов СЭВ по основным направлениям мирного использования атомной энергии.

I. СОТРУДНИЧЕСТВО В ОБЛАСТИ РЕАКТОРНОЙ НАУКИ И ТЕХНИКИ И АТОМНОЙ ЭНЕРГЕТИКИ

В материалах Третьей международной конференции по использованию атомной энергии в мирных целях (Женева, 1964 год) впервые было показано, что для значительной части районов мира, располагающих сравнительно дорогими источниками органического топлива, атомные электростанции (АЭС) в ближайшее время станут более экономичными по сравнению с тепловыми электростанциями (ТЭС), работающими на органическом топливе. Успешное развитие атомной энергетики в ряде стран мира в последующие годы показало, что АЭС становятся экономичнее ТЭС даже в районах с относительно недорогими классическими источниками топлива.

Эти положения явились важной предпосылкой при организации в 1965 году сотрудничества стран в рамках Совета Экономической Взаимопомощи по вопросам реакторной науки и техники и атомной энергетики. Для подготовки материалов и предложений по этим вопросам была создана рабочая группа специалистов стран-членов СЭВ в Постоянной Комиссии по использованию атомной энергии в мирных целях. С 1968 года в рамках Постоянной Комиссии СЭВ по электроэнергии начала работать секция специалистов стран-членов СЭВ по вопросам проектирования, сооружения и эксплуатации АЭС.

В условиях быстрого развития в странах-членах СЭВ научно-технических, а также промышленных предпосылок внедрения атомной энергетики в народное хозяйство стран важное значение имеет, прежде всего, научно-техническое сотрудничество. Это сотрудничество осуществляется путем обмена опытом, научно-технической документацией и информацией главным образом на основе координации научных и технических исследований и опытно-конструкторских работ, путем кооперирования в решении наиболее сложных проблем.

В этих целях Постоянной Комиссией СЭВ по использованию атомной энергии в мирных целях был разработан план координации научных и технических исследований на 1966-1970 годы, который предусматривал выполнение странами работ по 37 темам, в том числе по 10 темам в области реакторной техники и ядерной энергетики, как например:

– исследования и разработка новых и усовершенствование существующих энергетических реакторов на тепловых нейтронах мощностью более 400 МВт(эл), особенно реакторов с водой под давлением;

– исследования и проектные проработки энергетического реактора на быстрых нейтронах с различными теплоносителями электрической мощностью до 1000 МВт;

– разработки и исследования технологии производства ядерного топлива и регенерации ядерного горючего;

– исследования в области производства новых реакторных материалов, специального оборудования и средств радиационной защиты и безопасности энергетических реакторов.

Для проведения работ по плану координации научно-технических исследований странами-членами СЭВ привлечено более 100 институтов, проектных и конструкторских организаций с использованием лабораторных установок, опытных и экспериментальных баз.

Результаты выполненных странами-членами СЭВ научно-технических работ Постоянная Комиссия систематически обсуждает на координационных совещаниях специалистов, симпозиумах и конференциях. По плану работы Комиссии только за период с 1967 по 1970 год такие научно-технические мероприятия были проведены в ВНР, ГДР, СССР и ЧССР по следующим темам:

1. Состояние и перспективы работ по созданию АЭС с реакторами на быстрых нейтронах.

2. Исследования в области переработки облученного топлива.

3. Состояние и перспективы развития АЭС с водо-водяными реакторами.

4. Исследования проблем защиты от проникающего излучения реакторных установок.

5. Контроль и управление ядерными реакторами и оборудованием АЭС.

6. Водные режимы водо-водяных реакторов, радиационный контроль теплоносителей и снижение радиационной опасности теплоносителей.

7. Атомная энергетика, топливные циклы, радиационное материаловедение.

На указанных симпозиумах и конференциях было представлено более 400 докладов и сообщений, в них участвовало около 800 специалистов. Эти мероприятия являются эффективной формой обмена результатами выполненных работ по главным направлениям научных и технических исследований. Кроме ученых и специалистов стран СЭВ, в работе отдельных симпозиумов принимали участие также специалисты Демократической Республики Вьетнам, Республики Куба, Социалистической Федеративной Республики Югославии и Международного агентства по атомной энергии.

Научно-технические, проектно-конструкторские и технологические разработки и материалы, полученные странами при проведении исследований по плану координации работ, рассмотрение в Комиссии СЭВ технико-экономических данных по проекту АЭС электрической мощностью более 800 МВт с двумя водо-водяными энергетическими реакторами (ВВЭР), а также обмен опытом по проектированию, сооружению и эксплуатации в СССР и ГДР атомных электростанций сыграли решающую роль в разработке странами-членами СЭВ своих национальных программ по атомной энергетике и принятии решений о строительстве АЭС.

В соответствии с этими программами в странах-членах СЭВ (без СССР) в период до 1980 года намечается построить АЭС общей мощностью до 10 000 МВт.

В Советском Союзе на 1971-1975 годы предусмотрено значительное развитие атомной энергетики, намечено ввести в действие мощности на АЭС в размере 6000-8000 МВт. В этом пятилетии СССР приступает к осуществлению широкой программы строительства атомных электростанций, прежде всего в Европейской части страны. Эта программа предусматривает ввести в действие в течение 10-12 лет АЭС мощностью 30 000 МВт с применением реакторных установок мощностью 1000 МВт и выше.

В некоторых странах-членах СЭВ в связи с высокими темпами промышленного развития и большим ростом потребления топлива и электроэнергии АЭС становятся реальным и надежным источником покрытия возрастающей потребности в электрической энергии.

Планы развития атомной энергетики в странах-членах СЭВ в ближайший период базируются на применении разработанных в настоящее время водо-водяных энергетических реакторов на тепловых нейтронах единичной электрической мощностью 440 МВт (тип ВВЭР-440).

Реакторные блоки ВВЭР-400 применяются в СССР при сооружении третьей и четвертой очереди Нововоронежской атомной электростанции, Кольской и Армянской АЭС, в Болгарии – на АЭС "Козлодуй", в ГДР – на АЭС "Норд", а также на атомных электростанциях, намеченных к сооружению в Венгрии, Румынии и Чехословакии.

В Польше научно-исследовательские и проектные организации широко привлечены к разработке ряда тем по плану координации научных и технических исследований, проводимых странами-членами СЭВ в области ядерной энергетики. В Институте ядерных исследований на базе созданных исследовательских реакторов и в проектных энергетических организациях проводятся исследования и разработка оптимальных решений по сооружению первой атомной электростанции с реакторами на тепловых нейтронах типа ВВЭР, а в перспективе – с реакторами на быстрых нейтронах.

В настоящее время в рамках Совета Экономической Взаимопомощи разработана программа проведения совместными усилиями научно-исследовательских и проектно-конструкторских работ по реактору ВВЭР единичной электрической мощностью 1000 МВт и выше, что будет способствовать ускорению разработки проекта АЭС с такими реакторами, развитию специализации и производственного кооперирования при изготовлении энергетического оборудования, приборов и средств автоматизации АЭС.

На перспективный период генеральной линией развития атомной энергетики в странах-членах СЭВ является разработка и сооружение атомных электростанций с реакторами на быстрых нейтронах, которые обеспечивают наиболее полное использование природного урана и, как следствие, снижение величины топливной составляющей стоимости электроэнергии. Уже в этом пятилетии (1971-1975 годы) ставится задача промышленного освоения реакторов на быстрых нейтронах.

II. СОТРУДНИЧЕСТВО В ОБЛАСТИ ПРОИЗВОДСТВА И ПРИМЕНЕНИЯ ИЗОТОПОВ, МЕЧЕНЫХ СОЕДИНЕНИЙ И ИСТОЧНИКОВ ИЗЛУЧЕНИЙ

В странах-членах СЭВ производство радиоактивных изотопов организовано, в основном, на исследовательских атомных реакторах и ускорителях заряженных частиц. Это позволяет странам развивать сотрудничество по вопросам разработки методов получения изотопов, контроля изотопной продукции, специализации производства, унификации основных параметров и характеристик, научно-технического сотрудничества и обмена опытом в этой области.

В настоящее время суммарная номенклатура изотопной продукции в странах-членах СЭВ охватывает свыше 5000 препаратов и источников излучения, в том числе около 800 наименований радиоактивных изотопов и неорганических соединений, примерно 900 меченых органических соединений, до 300 радиоактивных медицинских препаратов, 400 видов эталонных растворов и светосоставов, 900 наименований стабильных изотопов и изделий с обогащенными стабильными изотопами и свыше 2000 видов закрытых источников излучений.

Постоянной Комиссией СЭВ по использованию атомной энергии в мирных целях за период с 1961 по 1967 год приняты рекомендации по специализации производства более 50 радиоактивных изотопов, которые используются для изготовления около 300 неорганических препаратов и примерно 600 меченых органических соединений. Принятые рекомендации позволили значительно увеличить производство изотопной продукции за счет сокращения номенклатуры в отдельных странах, они сыграли положительную роль в развитии специализированного производства изотопов и меченых соединений в странах-членах СЭВ.

Комиссия одобрила рекомендации по унификации 46 важнейших радиоактивных медицинских препаратов по их параметрам и характеристикам, маркировке и паспортизации, что облегчает организацию производства, контроля и взаимных поставок, позволяет проводить сравнение качественных характеристик, содействует повышению удельной активности препаратов и улучшению радиоизотопной и радиохимической чистоты.

Комиссией в 1967-1970 годы принято 17 рекомендаций по стандартизации радиоизотопных препаратов и закрытых источников излучений по их основным характеристикам, методам контроля и испытаний, маркировке и паспортизации.

Постоянная Комиссия уделяла особое внимание научно-техническому сотрудничеству в области производства и контроля изотопов и меченых соединений. Научные исследования, проводимые в странах-членах СЭВ, координировались по методам получения изотопов и синтеза меченых соединений, по методам анализа, контроля и измерения активности радиоизотопных препаратов.

В результате этих исследований в странах-членах СЭВ разработаны новые методы получения сложных органических соединений, меченных тритием и углеродом-14, методы получения радиоактивных изотопов; усовершенствованы технологические процессы для получения обогащенных стабильных изотопов; разработаны методы их анализа, особенно без применения сложных масс-спектрометрических установок.

Комиссией в период 1963-1970 годов организовано 10 симпозиумов и совещаний специалистов стран-членов СЭВ по вопросам производства и контроля изотопной продукции. По решению Комиссии были изданы сводные каталоги изотопной продукции, выпускаемой в странах-членах СЭВ: "Радиоактивные изотопы и меченые соединения" и "Стабильные изотопы". По мере развития производства изотопной продукции и расширения ассортимента изделий в 1967-1968 годы изданы дополнения к указанным каталогам.

За прошедшее десятилетие в работе Комиссии большое внимание уделялось развитию сотрудничества стран-членов СЭВ по применению радиоактивных изотопов и ядерных излучений в научных исследованиях и в народном хозяйстве; были разработаны:

— рекомендации по внедрению в промышленность изотопных методов и приборов, проверенных в производственных условиях и показавших определенный технико-экономический эффект;

— обзоры применения радиоактивных методов и приборов в различных отраслях промышленности (металлургии, машиностроении, геофизике, добыче полезных ископаемых, химии, строительстве, нефтепереработке и т.д.);

— единая методика определения экономической эффективности применения радиоактивных изотопов и ядерных излучений.

На основе указанных рекомендаций и методических материалов Постоянные Комиссии СЭВ по сельскому хозяйству, пищевой промышленности, геологии, черной металлургии и другие комиссии в своих планах работы предусматривают внедрение радиоизотопных методов и аппаратуры в конкретных производственных процессах.

Проводимые работы в этой области способствовали развитию применения изотопов и излучений в различных отраслях промышленности, в сельском хозяйстве и медицине стран-членов СЭВ. В настоящее время в этих странах изотопы, меченые соединения и источники излучений применяются примерно в 7000 организациях, в том числе на 3600 промышленных предприятиях, в 900 медицинских учреждениях и более чем в 1600 научно-исследовательских институтах. Ежегодный прирост количества предприятий и организаций, применяющих изотопы и меченые соединения, составляет в сумме по странам-членам СЭВ около 10%, а в отдельных странах – даже до 30-40%. Использование ядерных и радиационных процессов в науке и практике приносит странам-членам СЭВ значительный экономический эффект.

III. СОТРУДНИЧЕСТВО В ОБЛАСТИ ЯДЕРНОФИЗИЧЕСКИХ ПРИБОРОВ И РАДИОИЗОТОПНОЙ АППАРАТУРЫ

В связи с развитием в странах-членах СЭВ атомной энергетики и расширением применения изотопов и ионизирующих излучений в научно-технических исследованиях, народном хозяйстве и медицине значительно возрастает потребность стран в изделиях ядерного приборостроения. При этом характерной особенностью приборов ядерной техники является их широкий ассортимент, более 1000 наименований, но малые серии в производстве, что требует значительных затрат средств на исследования, разработку, испытания образцов и подготовку производства.

В этих условиях особую важность приобретает сотрудничество стран-членов СЭВ в процессе разработки и производства, специализация и кооперирование, унификация и стандартизация изделий.

Учитывая, что в техническом прогрессе, в обеспечении качества, надежности и долговечности приборов большую роль играет унификация и стандартизация, Комиссией принято 69 рекомендаций по стандартизации (РС СЭВ) электроннофизической, дозиметрической и радиометрической аппаратуры, детекторов ядерных излучений, радиоизотопных приборов и ядерномедицинской аппаратуры. Эти работы проводятся с учетом рекомендаций других международных организаций по стандартизации (ИСО, МЭК и др.).

На основе принятых Комиссией РС СЭВ страны разрабатывают национальные стандарты и нормативную документацию, что позволяет создавать необходимые условия для проведения специализации и кооперирования производства, развития взаимной торговли.

За время своей деятельности Постоянная Комиссия разработала и приняла рекомендации по специализации производства более 70 номенклатурных групп ядернофизических приборов и радиоизотопной аппаратуры, используемых в науке, промышленности, сельском хозяйстве и медицине. Примерами установившейся специализации производства изделий ядерного приборостроения между странами-членами СЭВ являются:

– ядерномедицинская аппаратура, производимая в ВНР;
– приборы для научных исследований, производимые в ГДР;
– сцинтилляторы, производимые в ВНР и ЧССР;

– счетчики ядерных излучений, производимые в ГДР и ПНР;
– гамма-дефектоскопическая аппаратура, производимая в ПНР и СССР.

В целях взаимной информации и обмена опытом о состоянии и техническом уровне разработок и производства приборов и аппаратуры ядерной техники в странах-членах СЭВ, с учетом результатов работ, выполненных странами при координации научных и технических исследований, в рамках СЭВ проводятся семинары, симпозиумы, конференции. Для этого были также организованы научно-технические выставки в Москве, Варшаве и Лейпциге.

По решению Постоянной Комиссии СЭВ в сентябре 1969 года в Москве была проведена научно-техническая конференция на тему "Повышение технического уровня радиоизотопной аппаратуры, приборов для ядернофизических исследований и организация централизованных систем для обработки данных физических экспериментов в ядерных центрах стран-членов СЭВ". На пленарных и секционных заседаниях конференции было прочитано и обсуждено 78 докладов, в работе конференции приняло участие 160 специалистов стран-членов СЭВ.

Рассмотренные на Комиссии итоги конференции показали, что задачи, решаемые в настоящее время с помощью ядерных и радиационных методов, все более расширяются. Высокая чувствительность современных ядерных приборов, позволяющая проводить поэлементный анализ ряда веществ без отбора проб, без разрушения образца, открывает большие перспективы эффективного применения ядерных приборов в самых разнообразных сферах науки, техники и производства.

Вместе с тем, такое разнообразие применения ядернофизической и радиоизотопной аппаратуры, широкая номенклатура приборов не всегда создают условия для экономически выгодной разработки и производства изделий в каждой отдельной стране.

Учитывая, что на основе принципов сотрудничества стран-членов СЭВ имеется объективная возможность международного социалистического разделения труда и кооперирования в научных исследованиях и производстве, Комиссия, в соответствии с решением XXIII (специальной) сессии СЭВ об углублении сотрудничества стран-членов СЭВ, подготовила рекомендации о новых, более эффективных формах сотрудничества в области ядерного приборостроения, в том числе по созданию Международного хозяйственного объединения стран-членов СЭВ "Интератоминструмент".

IV. СОТРУДНИЧЕСТВО ПО ВОПРОСАМ РАДИАЦИОННОЙ БЕЗОПАСНОСТИ И ЗАЩИТНОЙ ТЕХНИКИ

В области радиационной безопасности и защитной техники в рамках СЭВ осуществляется координация научных и технических исследований, проводимых странами-членами СЭВ, разработка нормативных документов, рекомендаций по стандартизации, специализации и кооперированию производства изделий защитной техники.

В 1965 году Постоянной Комиссией были разработаны и рекомендованы для стран-членов СЭВ: "Нормы радиационной безопасности", "Правила работы с радиоактивными веществами" и "Правила перевозки радиоактивных веществ". Позднее, в 1966-1967 годы, эти документы были уточнены и дополнены.

В связи с тем, что Международным агентством по атомной энергии (МАГАТЭ) систематически проводятся работы по совершенствованию нормативных документов в области радиационной безопасности, и учитывая, что эти документы обобщают мировой опыт, Комиссия приняла решение рекомендовать странам-членам СЭВ в качестве исходных материалов при разработке национальных Правил использовать нормативные документы МАГАТЭ по радиационной безопасности и защите.

Учитывая необходимость организации в странах-членах СЭВ систематического наблюдения за радиационной обстановкой и обеспечения полной радиационной безопасности всех лиц, работающих с радиоактивными веществами, а также населения, Комиссией, в дополнение к нормативным документам, были разработаны:

1. Общие рекомендации по осуществлению контроля за соблюдением норм радиационной безопасности.

2. Рекомендации по дезактивации поверхностей помещений, оборудования, средств индивидуальной защиты и кожных покровов.

3. Методика отбора проб для оценки загрязнения воды радионуклидами.

4. Методика отбора проб для систематического определения загрязнения продуктов питания стронцием-90 и цезием-137.

5. Рекомендации по оценке препаратов, предназначенных для очистки кожных покровов от радиоактивных загрязнений.

6. Рекомендации по дезактивации технологического оборудования, применяемого в атомной энергетике.

В области защитной техники Комиссия приняла около 40 рекомендаций по унификации, стандартизации и специализации производства изделий защитной техники, как например, упаковочные комплекты для перевозки радиоактивных материалов, лабораторная мебель для работы с радиоактивными веществами, гамма-терапевтические аппараты, гамма-дефектоскопы, блоки защитные свинцовые и т.д.

В рамках СЭВ все большее внимание уделяется сотрудничеству по обеспечению чистоты окружающей среды. В связи с этим проводится работа по координации научных и технических исследований в области обезвреживания жидких, твердых и газообразных радиоактивных отходов и дезактивации загрязненных поверхностей, разработана "Методика для определения экономической эффективности различных методов переработки и захоронения радиоактивных отходов", проведены две научно-технические конференции по обезвреживанию радиоактивных отходов.

В связи с указанной выше деятельностью Совета Экономической Взаимопомощи в области мирного применения атомной энергии в различных областях науки, техники и производства следует отметить положительную роль контактов Совета Экономической Взаимопомощи с Международным агентством по атомной энергии.

V. НОВЫЙ ЭТАП УГЛУБЛЕНИЯ И СОВЕРШЕНСТВОВАНИЯ СОТРУДНИЧЕСТВА В ОБЛАСТИ МИРНОГО ИСПОЛЬЗОВАНИЯ АТОМНОЙ ЭНЕРГИИ

Важное значение в сотрудничестве стран-членов СЭВ на современном этапе явились решения XXIII (специальной) сессии Совета Экономической Взаимопомощи.

В соответствии с этими решениями разработана и на XXV сессии СЭВ в июле 1971 года в Бухаресте единодушно принята Комплексная программа дальнейшего углубления и совершенствования сотрудничества и развития социалистической экономической интеграции стран-членов СЭВ, в которой предусматривается использование новых, более эффективных форм и методов сотрудничества. В частности, при осуществлении научно-технического сотрудничества намечено проводить исследования путем кооперирования на основе договоров, соглашений и контрактов, создавая при этом координационные центры, международные научно-исследовательские коллективы, хозрасчетные научно-производственные объединения и другие организации, в зависимости от характера и условий работ по конкретным проблемам.

По мирному использованию атомной энергии в программе сотрудничества на длительный период и в плане координации научных и технических исследований, проводимых странами-членами СЭВ в 1971-1975 годы, Постоянной Комиссией предусмотрена разработка ряда тем и проблем с использованием более эффективных форм сотрудничества.

В области ядерной энергетики разработана программа работ по проведению в рамках СЭВ совместного технико-экономического прогноза. Этот прогноз будет охватывать период до 1990 года с выявлением основных тенденций до 2000 года. Он будет являться составной частью общего прогноза развития генерирующих мощностей и топливно-энергетического баланса стран-членов СЭВ.

Подготовлены предложения по координации и кооперированию на договорных основах научно-исследовательских и конструкторских работ, проводимых странами-членами СЭВ, в целях ускорения создания атомных реакторных установок на тепловых и быстрых нейтронах единичной мощностью 1000 МВт и выше, отработки технологического процесса и оборудования для переработки облученного ядерного топлива и обезвреживания радиоактивных отходов.

В области производства изотопов, меченых соединений и источников излучений Постоянная Комиссия приняла пятилетний план работы по сотрудничеству в области производства изотопной продукции на 1971-1975 годы, который охватывает основные направления сотрудничества: прогноз потребления и производства изотопной продукции на длительный период, проведение технико-экономических исследований по развитию производства, разработку рекомендаций по специализации и кооперированию работ в производстве, вопросы унификации и стандартизации изделий.

По проблеме "Разработка и внедрение в народное хозяйство стран-членов СЭВ радиационной техники и технологии", Комиссией в 1970 году создан Координационный научно-технический совет (КНТС). Утвержденными на Комиссии Положением о КНТС и Программой научно-технического сотрудничества на 1971-1975 годы предусматривается координация усилий стран-членов СЭВ в целях ускорения внедрения в промышленную технологию радиационных процессов и установок для стерилизации медицинских материалов, радиационного сшивания полимерных материалов, модификации древесины, лучевой обработки пищевых и сельскохозяйственных продуктов.

В числе других предложений важно отметить разработку мероприятий по организации заинтересованными странами-членами СЭВ временного международного научно-исследовательского коллектива для проведения совместных ядернофизических исследований на критической сборке типа

ВВЭР (водо-водяных энергетических реакторов) большой мощности, а также создание координационных научно-технических советов по ряду проблем и тем плана координации научных и технических исследований.

Осуществление намеченных мероприятий в области мирного применения атомной энергии с использованием более эффективных форм научно-технического сотрудничества будет способствовать дальнейшему углублению и совершенствованию сотрудничества стран-членов СЭВ, ускорению технического прогресса и подъему экономики этих стран.

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APERÇU DES ACTIVITES DU CENTRE COMMUN DE RECHERCHE DE LA COMMISSION DES COMMUNAUTES EUROPEENNES

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Abstract–Résumé–Аннотация–Resumen

OUTLINE OF ACTIVITIES OF THE JOINT RESEARCH CENTRE, COMMISSION OF THE EUROPEAN COMMUNITIES.

As a result of development in industry, the activities of the Joint Research Centre (CCR), which has now been operating for some twelve years, need to be given a new direction. Its institutional structure having been modified, a new program covering several years is now being drawn up and will be aimed essentially at reactor development in areas requiring costly equipment or special knowledge; public service studies, particularly in areas where the Commission has a special responsibility; basic research, to be carried out in close collaboration with universities, that will form the scientific basis for project development work and doubtless be of interest to young scientists. Diversification into certain non-nuclear but related areas is a logical and technically legitimate consequence of this new orientation. The CCR's future activities will be developed in the light of the installations available at Ispra, Petten, Karlsruhe and Geel and the personnel at the disposal of these four establishments. In collaboration with industry and with other centres, four reactors are being used in work which is of importance for practically all existing reactor types in the Community. Laboratories are actively engaged in research on transuranic elements and other studies. Long-term technological work is related mainly to materials, safety matters, and non-power-generating uses of nuclear energy. In the area of public service studies, mention should be made of the work being done by the Central Nuclear Measurements Office (BCMN) at Geel and the Calculations Centre (CETIS), and also of programs in reactor physics, fissile material control, and biology. Basic research is directed mainly towards solid state physics; once completed, the SORA pulsed reactor, an Ispra-developed project, is likely to prove a specially powerful tool in this work.

APERÇU DES ACTIVITES DU CENTRE COMMUN DE RECHERCHE DE LA COMMISSION DES COMMUNAUTES EUROPEENNES.

L'évolution du contexte industriel nécessite une réorientation des activités du Centre commun de recherche (CCR), qui existe maintenant depuis 12 ans. Après une restructuration du cadre institutionnel, un nouveau programme pluriannuel est en préparation, qui sera axé essentiellement sur le développement des réacteurs dans des domaines exigeant des équipements coûteux ou des connaissances particulières; des études à caractère de service public, notamment dans les domaines dans lesquels la Commission a une responsabilité particulière; des activités de recherche fondamentale, à exercer en contact étroit avec les universités, qui constitueront la base scientifique des travaux orientés vers les projets et pourront intéresser de jeunes scientifiques. Une diversification vers certains domaines voisins, non nucléaires, est une suite logique et techniquement légitime d'une telle orientation. Les activités futures du CCR seront développées compte tenu des installations disponibles dans les quatre établissements d'Ispra, Petten, Karlsruhe et Geel et de leurs ressources en personnel. Quatre réacteurs sont utilisés en collaboration avec l'industrie et d'autres centres pour des travaux intéressant pratiquement tous les types de réacteurs existant dans la Communauté. Des laboratoires actifs servent pour des recherches sur les éléments transuraniens et d'autres études. Les activités technologiques à long terme concernent surtout les matériaux, la sécurité et l'utilisation non électrogène de l'énergie nucléaire. Pour ce qui est des études à caractère de service public il convient de mentionner les travaux du Bureau central de mesures nucléaires (BCMN) de Geel et ceux du Centre de calcul (CETIS), ainsi que les programmes de physique des réacteurs, de contrôle des matières fissiles et de biologie. La recherche fondamentale est surtout orientée vers la physique de l'état solide; la réalisation du projet de réacteur pulsé SORA, mis au point à Ispra, pourrait lui fournir un instrument particulièrement puissant.

ОБЗОР ДЕЯТЕЛЬНОСТИ ОБЪЕДИНЕННОГО ЦЕНТРА ИССЛЕДОВАНИЙ КОМИССИИ ЕВРАТОМА.

Промышленное развитие требует переориентации деятельности Объединенного центра исследований (ОЦИ), который существует уже 12 лет. После реорганизации центра разрабатывается новая многолетняя программа, которая будет сосредоточена главным образом на разработке реакторных узлов, требующих дорогостоящего оборудования или специальных знаний, на исследованиях в сфере коммунального обслуживания, в основном там, где Комиссия несет особую ответственность; фундаментальные исследования, которые требуют установления тесных контактов с университетами, будут являться научной базой для проведения работ по конкретным проектам и несомненно будут представлять интерес для молодых ученых. Охват некоторых смежных неядерных областей является логичным и технически закономерным следствием такой ориентации. В дальнейшем деятельность ОЦИ будет развертываться с учетом установок, имеющихся в четырех центрах – в Испре, Петтене, Карлсруэ, Геле, – и их обслуживающего персонала. В сотрудничестве с промышленными предприятиями и научными центрами на этих реакторах проводятся исследования, имеющие практическое значение для усовершенствования любых типов реакторов, имеющихся в системе Евратома. В радиолабораториях исследуются трансурановые элементы. Долгосрочные технологические работы ведутся главным образом по ядерным материалам, вопросам безопасности и использованию ядерной энергии в областях, не имеющих целью производство электроэнергии. Что касается исследований, проводимых на контрактной основе, то следует указать на деятельность Центрального бюро ядерных измерений в Геле (BCMN) и вычислительного центра (CETIS), а также на программы в области физики реакторов, контроля за расщепляющимися материалами и в области биологии. Фундаментальные исследования направлены прежде всего на решение проблем физики твердого тела; осуществление проекта по импульсному реактору SORA, разработанного в Испре, может оказать большую помощь в проведении научных исследований.

SINOPSIS DE LAS ACTIVIDADES DEL CENTRO COMUN DE INVESTIGACION DE LA COMISION DE LAS COMUNIDADES EUROPEAS.

La evolución del contexto industrial requiere una nueva orientación de las actividades del Centro Común de Investigación, creado hace doce años. Después de haberse reorganizado su marco institucional, se está preparando ahora un nuevo programa plurianual que se centrará esencialmente en los siguientes puntos: desarrollo de reactores en esferas que exigen equipos costosos o conocimientos especiales; estudios con carácter de servicio público, sobre todo en las esferas en los que la Comisión tiene una responsabilidad particular; actividades de investigación fundamental, que se realizarán en estrecha colaboración con las universidades y constituirán la base científica de los trabajos orientados hacia los proyectos, interesando así a los científicos jóvenes. Una diversificación hacia ciertas esferas vecinas de carácter no nuclear será la continuación lógica y técnicamente legítima de tal orientación. Las actividades futuras del Centro Común de Investigación se desarrollarán teniendo en cuenta las cuatro instituciones de Ispra, Petten, Karlsruhe y Geel, y sus equipos de personal. Se utilizan cuatro reactores en colaboración con la industria y con otros centros, en trabajos de interés práctico para todos los tipos de reactores de la Comunidad. En algunos laboratorios activos se realizan investigaciones sobre los elementos transuránicos y otros estudios. Las actividades tecnológicas a largo plazo se refieren sobre todo a los materiales, a la seguridad y a la utilización de la energía nuclear en campos diferentes del de la generación de electricidad. Por lo que se refiere a los estudios que tienen carácter de servicio público, conviene subrayar los trabajos de la Oficina Central de Medidas Nucleares (Geel) y los del Centro de Cálculo (CETIS), así como los programas de física de los reactores, de control de materias fisionables y de biología. La investigación fundamental se refiere esencialmente a la física del estado sólido, para lo cual la construcción del reactor pulsado SORA, proyectado en Ispra, proporcionará un instrumento extraordinariamente eficaz.

1. INTRODUCTION

Conclu en 1957 dans le cadre de la coopération économique entre les six pays de la Communauté, le Traité EURATOM jetait les bases d'un effort commun dans le domaine de l'énergie nucléaire. Aux termes de cet accord, l'Allemagne, la Belgique, la France, l'Italie, le Luxembourg et les Pays-Bas s'engageaient à promouvoir le développement de leur industrie pour les applications pacifiques de l'énergie nucléaire et décidaient de mettre en commun les résultats de leurs recherches grâce à la coordination très étroite de leurs activités nationales et à la création d'un Centre commun de recherche (CCR).

Il y a quatorze ans, l'énergie nucléaire, en Europe du moins, était loin d'avoir atteint le stade industriel. L'initiative et la responsabilité de la recherche fondamentale, du développement technologique et de la formation d'un personnel qualifié incombaient à des organismes publics, car les bénéfices étaient trop incertains et éloignés pour que les entreprises privées se risquent à des investissements massifs. Des centres de recherche nucléaire furent en fait créés dans un grand nombre de pays pour combler ce vide et fournir à l'industrie les informations techniques dont elle avait besoin.

A l'heure actuelle, la situation évolue très rapidement. L'industrie nucléaire parvenant à maturité, il convient maintenant que l'initiative et la responsabilité passent des institutions publiques aux entreprises privées. Cette étape, délicate à franchir en soi, est encore aggravée par la pression que l'augmentation impressionnante de la puissance des centrales et l'accélération soudaine du progrès technique exercent sur l'industrie électro-mécanique européenne.

Il n'y a donc rien de surprenant au fait qu'on ait dû ces dernières années réfléchir sérieusement à la réorientation à donner à l'activité des centres de recherche nucléaire dans le monde. A ces difficultés s'est ajoutée, dans le cas de la Communauté, l'obligation de concevoir des structures industrielles nouvelles capables de profiter au maximum du vaste marché créé par le Traité CEE.

Le CCR a été ainsi conduit à réexaminer son rôle dans le cadre de la politique économique et industrielle de la Commission, afin de l'adapter aux conditions nouvelles.

La première phase de ce processus a amené, en décembre 1970, le Conseil de Ministres de la Communauté et la Commission à réorganiser le CCR par l'octroi d'une plus large autonomie et d'une plus grande souplesse dans la préparation et l'exécution des programmes de recherche. Simultanément, de nouvelles voies de communication et de discussion ont été créées, non seulement avec les gouvernements, mais encore avec les représentants des milieux scientifiques et industriels.

Bien que ce processus de réorganisation et de réorientation du CCR soit encore en cours, la mission future du CCR se dessine déjà sur les bases suivantes:

— Le développement à court et à moyen terme des réacteurs sera progressivement assumé par le secteur privé, mais pendant de nombreuses années encore, les organismes publics et notamment le CCR devront consentir un effort important dans toute une série de domaines qui exigent un équipement élaboré et coûteux, des délais de mise au point prolongés ou des connaissances multidisciplinaires très particulières. On peut citer, à titre d'exemple, le développement de matériaux, leur tenue sous irradiation, les problèmes de sécurité, l'élaboration de méthodes de calcul complexes.

— En dépit du succès que l'énergie nucléaire a rencontré comme source de production d'électricité, il reste encore à lui trouver à long terme un rôle économique plus large dans le contexte global de la production et de la consommation d'énergie. Telle sera vraisemblablement la tâche des grands centres de recherche pendant les années soixante-dix.

– Les activités des services publics gagnent en importance et il est reconnu qu'elles nécessitent un effort de recherche plus intense que par le passé. Dans la mesure où certains des problèmes posés sont liés directement aux travaux et aux responsabilités de la Commission des Communautés européennes, il semblerait logique d'en faire un domaine d'activité privilégié du CCR. D'une manière générale, le Centre devrait tendre de plus en plus à devenir un instrument technique aidant la Commission à préparer et à exécuter ses tâches politiques et administratives.

– Les activités de recherche fondamentale sans lien direct ou évident avec les objectifs industriels ou le bien-être public seront exercées en contact étroit avec les universités et fourniront une base scientifique satisfaisante aux travaux orientés vers les projets.

L'élaboration du nouveau programme fera apparaître de plus en plus clairement que la distinction entre le nucléaire et d'autres domaines de recherche est souvent injustifiée. Conscients de ce phénomène, beaucoup d'autres grands centres de recherche nucléaire dans le monde ont déjà optimalisé leur rôle dans la société dans le sens d'une extension de leur champ d'action à des domaines non nucléaires bien définis.

Nous décrivons ci-après le potentiel du CCR, ses activités actuelles et leur évolution possible sur la base des grandes lignes précitées.

2. SITUATION, EFFECTIF ET BUDGET DU CCR

Le CCR comporte quatre établissements implantés dans quatre pays différents:

- l'Etablissement d'Ispra, situé dans le nord de l'Italie, est un centre de recherche et de développement de caractère général;
- l'Etablissement de Petten, situé aux Pays-Bas dans l'enceinte du «Reactor Centrum Nederland», s'occupe essentiellement de recherches sur les matériaux de structure et les matériaux résistant aux hautes températures ainsi que de l'exploitation du réacteur HFR,
- l'Institut européen des transuraniens près de Karlsruhe, situé dans le Centre de recherches nucléaires allemand, étudie le plutonium et les transplutoniens;
- le Bureau central des mesures nucléaires (BCMN), situé à Geel en Belgique, est un laboratoire qui détermine des données nucléaires et établit des étalons.

Le CCR dispose d'un effectif de 2000 personnes environ, dont 500 cadres de niveau universitaire. Ispra en compte 1500, tandis que les autres établissements occupent chacun de 160 à 200 personnes. L'effectif est constitué presque exclusivement de ressortissants des six pays membres.

Le budget annuel est alimenté par les gouvernements des Etats membres. Il s'élève en 1971 à environ 45 millions UC[1]/an, soit approximativement 5,5% du montant total des dépenses engagées par les administrations publiques des pays membres au titre de la recherche et du développement nucléaire. En outre, la Commission consacre quelque 14 millions UC à des «activités indirectes» (exercées dans le cadre de contrats et d'associations). L'équipement des établissements du CCR est adapté aux différentes tâches qui leur ont été confiées au cours des dernières années. Dans l'ensemble, il couvre un domaine

[1] 1 UC (unité de compte) est égale à 1 dollar des Etats-Unis.

assez étendu et permet à la Commission d'exercer des activités dans des secteurs très divers.

3. LES GRANDES INSTALLATIONS NUCLEAIRES ET LEUR EXPLOITATION

3.1. Réacteurs nucléaires et activités annexes

Le CCR compte quatre réacteurs expérimentaux dont trois (ISPRA I, ESSOR, ECO) sont implantés à Ispra et un (HFR) à Petten. Ensemble, ils forment un instrument de travail adapté aux expériences d'irradiation couvrant un large éventail de types de réacteurs. Ils sont en effet utilisés, en collaboration étroite avec l'industrie et d'autres centres de recherche, pour des travaux concernant les réacteurs à eau légère et à eau lourde, les réacteurs refroidis au gaz et les surgénérateurs rapides.

Les expériences nécessitant un flux élevé de neutrons rapides sont réalisées de préférence dans le HFR (High Flux Reactor) de l'établissement de Petten. Ce réacteur, dérivé de l'ORR d'Oak Ridge, a été construit par le «Reactor Centrum Nederland» (RCN) et donné à la Communauté en 1962.

Son exploitation courante est assurée, sous contrat, par le département des réacteurs du RCN, et une équipe mixte EURATOM/RCN se livre à des travaux de développement à long terme visant à moderniser ce réacteur et à l'adapter aux programmes à exécuter.

C'est ainsi que la puissance du HFR a été progressivement portée de 20 à 45 MW(th) et que ses composants ainsi que la configuration du cœur ont été adaptés aux besoins des utilisateurs qui demandent des flux plus élevés et des rapports accrus de neutrons rapides sur neutrons thermiques. A l'appui des programmes d'irradiation, un groupe EURATOM s'occupe de la conception, du développement et de la fabrication de capsules et de dispositifs auxiliaires, avec un succès particulier dans le domaine des irradiations à haute température et de la mesure en continu de paramètres physiques, tels que l'évolution des gaz de fission, les changements dimensionnels et la puissance thermique des éléments de combustible pendant l'irradiation.

De nombreuses irradiations ont été effectuées dans ce réacteur tant à l'intention des établissements du CCR qu'à celle de laboratoires de recherche nationaux, d'organisations commerciales et de départements universitaires.

<u>ISPRA-I</u> est un réacteur de recherche du type Argonne CP5, principalement utilisé comme source de faisceaux de neutrons pour les recherches sur la physique de l'état solide. Certains autres travaux directement liés à des problèmes industriels y sont également exécutés. Dans une boucle organique centrale, où le flux de neutrons thermiques peut atteindre 10^{14} n/cm$^2 \cdot$ s, on irradie des crayons et des capsules de combustible expérimentaux. D'autres canaux servent à l'irradiation de matériaux de structure et à la production de radioisotopes. Le convertisseur EURACOS à uranium enrichi, associé à ISPRA-I, sert à des expériences fondamentales et conceptuelles de blindage.

ECO est un assemblage critique modéré à l'eau lourde de faible puissance (2 kW). Ses dispositifs spéciaux permettent d'étudier l'influence d'une série de paramètres, sans qu'il soit nécessaire de démonter et de remonter l'ensemble de l'installation. A titre d'exemple, le pas du réseau peut être modifié automatiquement dans deux directions et deux éléments combustibles superposés peuvent être mis en oscillation. En plus il est possible de faire varier la température de l'eau lourde entre 10 et 80°C. ECO constitue un instrument de travail souple pour les expériences de physique des réacteurs, conçu en tant qu'auxiliaire des divers programmes nationaux et industriels et reposant par conséquent sur une étroite collaboration avec les centres de recherche et les industries. Les principales activités expérimentales effectuées au cours des dernières années ont consisté en des mesures de température et de coefficient de vide de réseaux à D_2O contenant de l'uranium et du plutonium, ainsi qu'en la détermination de valeurs de réactivité par la méthode de l'oscillation. Avec les mesures faites en collaboration avec le CNEN et AGIP Nucleare dans les installations RB1 et RB2 à Bologne, ces activités forment la base des travaux théoriques suivants:

- élaboration de sections efficaces groupées et leur évaluation sur la base d'expériences propres
- élaboration de programmes de calcul et leur application au calcul statistique de cœurs de réacteurs, analyse de l'évolution de leur combustible et estimation économique de leurs cycles de combustible
- élaboration de programmes de dynamique dépendant de variables spatiales.

Les deux bibliothèques de programmes de calcul d'Ispra (ENEA et CETIS) sont d'une grande utilité pour ces activités.

ESSOR est un réacteur d'essai destiné à l'étude du comportement des composants des cœurs de réacteurs de puissance et notamment de grappes de combustible de grandes dimensions. A l'origine il a été conçu et construit en vue du développement du projet du réacteur ORGEL, réacteur refroidi par liquide organique; il est modéré à l'eau lourde et atteint une puissance de 27 MW(th) dans la zone nourricière, à laquelle on peut ajouter 15 à 30 MW(th) dans la zone expérimentale. Son flux de neutrons thermiques, de $3 \cdot 10^{14}$ n/cm$^2 \cdot$ s, est constant sur une hauteur utile de près de 2 m. La cuve a environ 4 m de haut et 2,4 m de diamètre. Elle contient une zone expérimentale centrale dotée de 12 canaux verticaux d'environ 120 mm de diamètre utile, qui hébergent des tubes de force recevant les éléments combustibles à irradier. Une zone nourricière de 16 éléments fortement enrichis et refroidis à l'eau lourde est disposée en couronne autour de la zone expérimentale.

Plusieurs circuits de refroidissement indépendants (boucles) alimentent les canaux expérimentaux: le caloporteur et les paramètres de fonctionnement peuvent donc être choisis en fonction des essais envisagés. Il existe actuellement deux boucles: la boucle CART, de 1,3 MW(th) avec refroidissement par eau légère en double phase pour un canal, utilisée pour le programme italien CIRENE, et une boucle organique de 18 MW(th), capable d'alimenter cinq canaux en parallèle. ESSOR est le seul réacteur de la Communauté spécifiquement conçu pour l'irradiation de grappes de crayons combustibles de grandes dimensions (par exemple, diamètre 110 mm et longueur 2 m). La possibilité d'installer des boucles à eau légère à hautes performances a été étudiée; de tels dispositifs permettraient l'irradiation d'assemblages de combustible dans des conditions particulièrement sévères (cyclage de puissance, perte de caloporteur, etc.) susceptibles d'entraîner la défaillance des crayons expérimentaux. Une enquête a été entreprise pour évaluer l'intérêt des industries et des entreprises européennes envers la mise en place de telles boucles, dont le coût devrait être amorti par une plus grande fiabilité de sécurité d'éléments combustibles futurs mis au point grâce à leur utilisation.

3.2. Laboratoires radioactifs et cellules chaudes

Les laboratoires de recherche sur les matériaux radioactifs les plus importants du CCR se trouvent à l'Institut européen des transuraniens. Ses 350 boîtes à gants contiennent les installations nécessaires à l'étude de propriétés physiques et physico-chimiques, à des analyses chimiques et radiochimiques ainsi qu'au développement de combustibles. Sept cellules prévues pour 10^6 Ci (1 MeV) destinées au démantèlement, au découpage et à des études de physique, cinq cellules pour 10^4 Ci destinées à des travaux de chimie, et cinq cellules pour 10^2 Ci destinées à la manipulation des activités moins importantes constituent le complexe des cellules chaudes qui, à l'aide de son équipement pour essais non destructifs (radiographie, photographie aux rayons X, balayage gamma, etc.) et destructifs permet des examens post-irradiatoires très précis.

Deux autres complexes de cellules chaudes, dotés d'un appareillage expérimental varié, sont situés à Ispra. Leur ensemble, constitué d'une vingtaine de cellules en plomb ou en béton, offre la possibilité de procéder à toute une gamme d'examens post-irradiatoires allant des grands assemblages de combustible jusqu'aux petits échantillons et éprouvettes. Il s'est avéré de la plus grande utilité pour l'étude des éléments combustibles déchargés des réacteurs de puissance.

Les travaux poursuivis dans les laboratoires actifs et les cellules de moyenne et haute activité sont essentiellement liés au développement des réacteurs. L'Institut des transuraniens de Karlsruhe joue un rôle important dans le domaine des surgénérateurs rapides. Le développement de combustible contenant du plutonium, l'étude de ses propriétés physiques et physico-chimiques avant et après irradiation, les analyses chimiques et radiochimiques, les analyses isotopiques en vue de la détermination du taux de combustion et le contrôle des matières fissiles, les recherches sur les caractéristiques des éléments transplutoniens (américium, curium) font partie des activités qui nécessitent un matériel spécial et coûteux et s'appuient sur une collaboration étroite avec l'industrie et les centres de recherche nationaux.

Les cellules chaudes installées à Ispra et utilisées surtout pour des études de développement des matériaux, par exemple dans le cadre du programme HTR, servent également à l'examen post-irradiatoire d'éléments de combustible provenant de réacteurs de puissance, tels que le réacteur de Trino Vercellese.

4. ACTIVITES TECHNOLOGIQUES A LONG TERME

Bien qu'il soit généralement admis que la technologie moderne, et en particulier la technologie des réacteurs, soit largement conditionnée par le développement de matériaux adéquats, il faut souligner que les délais de réalisation d'un matériau nouveau sont très longs, souvent de l'ordre de 10 ans. Les projets devant se fonder sur des matériaux existants, plutôt que sur des matériaux hypothétiques, le développement de matériaux constitue une activité par excellence pour les centres de recherche financés par des fonds publics, surtout lorsque des installations coûteuses comme les réacteurs nucléaires sont requises.

Au sein du CCR, les travaux de recherche et de développement sur les matériaux sont principalement effectués à Ispra et à Petten et, en ce qui concerne le combustible nucléaire, à Karlsruhe. Ce domaine très vaste ne pouvant être approfondi ici, seuls quelques points précis seront abordés.

Les recherches portant sur les combustibles nucléaires concernent surtout le combustible destiné aux surgénérateurs rapides, qui est traité à Karlsruhe, et les particules de combustible enrobées, destinées aux réacteurs à haute température, qui sont étudiées à Ispra. Les activités de l'Institut des transuraniens ont déjà été décrites dans leurs grandes lignes. Nous ferons état ici des études concernant la tenue d'oxydes mixtes d'uranium-plutonium sous flux de neutrons rapides à des puissances nominales élevées. L'étude de l'influence de la teneur en oxygène et de la distribution de densité sur l'intégrale de conductivité, sur la ségrégation des produits de fission et la recristallisation ainsi que sur le gonflement des combustibles à base d'oxydes mixtes a donné d'intéressants résultats. Le gonflement de nitrures et de carbures mixtes a fait également l'objet de recherches. La détermination des constantes physiques, des diagrammes de phases et l'étude du processus de diffusion et de la recristallisation de composés de plutonium non irradiés permettront une meilleure compréhension des phénomènes d'irradiation. En outre, des travaux plus technologiques, tels que la fabrication de pastilles d'oxydes mixtes de faible densité ainsi que de microsphères de PuO_2 de densité très élevée, ont été exécutés à la demande de clients extérieurs.

A Ispra, les recherches relatives au combustible nucléaire se sont déplacées ces dernières années du domaine des carbures d'uranium à celui des particules de combustible enrobées. Une attention particulière est consacrée à la tenue sous irradiation et, notamment, à la libération de produits de fission et aux problèmes de compatibilité (entre noyaux et revêtements). L'étude des propriétés du revêtement et la mise au point de meilleures barrières en vue de la fabrication de particules capables de résister à des températures encore plus élevées s'inscrivent dans le cadre de ces recherches.

Les métaux de structure sont étudiés à Ispra et à Petten. A Ispra, l'accent a été mis sur la tenue à l'irradiation et sur la corrosion des alliages de zirconium connus, ainsi que sur la mise au point d'alliages nouveaux possédant de meilleures performances.

Les métaux réfractaires, intéressant les futurs réacteurs à haute température et leurs applications, sont étudiés à la fois à Ispra et à Petten. A Ispra, l'effort porte principalement sur les matériaux composites et, en particulier, sur les alliages renforcés par des fibres obtenus in situ par solidification unidirectionnelle des eutectiques, tandis que Petten se consacre au vanadium, étudié en tant que métal de structure en soi et en tant que modèle pour d'autres métaux cubiques centrés.

Les recherches sur les matériaux graphitiques et carbonés occupent une place importante dans les activités de Petten. On y procède, entre autres, à la détermination de la structure en fonction du procédé de préparation, à des études de compatibilité, à l'examen des propriétés mécaniques sous tension et sous irradiation, à l'élaboration de spécifications ainsi qu'à des contrôles de qualité.

L'utilisation de l'énergie nucléaire à d'autres fins que la production d'électricité fait partie des sujets d'étude à long terme susceptibles de fournir des résultats de la plus grande utilité. L'Etablissement d'Ispra s'attache tout particulièrement à produire de l'hydrogène à partir de l'eau, en utilisant la chaleur nucléaire aux températures atteintes dans les caloporteurs des réacteurs nucléaires, sans passer par le stade intermédiaire de la production d'électricité.

Des cycles de réactions chimiques, tels ceux illustrés notamment par les équations ci-dessous:

$CaBr_2 + 2H_2O$	$\rightarrow$	$Ca(OH)_2 + 2HBr$	à 730°C
$2HBr + Hg$	$\rightarrow$	$HgBr_2 + H_2$	à 250°C
$HgBr_2 + Ca(OH)_2$	$\rightarrow$	$CaBr_2 + H_2O + HgO$	à 100°C
HgO	$\rightarrow$	$Hg + 1/2\ O_2$	à 600°C

font actuellement l'objet d'investigations et sont considérés comme suffisamment prometteurs pour justifier la poursuite des travaux. En cas de bonne rentabilité, l'ensemble du secteur énergétique pourrait être ouvert à la technologie nucléaire, avec les conséquences importantes que cela pourrait entraîner pour l'environnement.

Bien que la sécurité offerte par l'énergie nucléaire ait toujours été remarquable, elle n'en constitue pas moins à bon droit un sujet de préoccupation pour les constructeurs de réacteurs, les autorités gouvernementales et l'opinion publique. Le problème se pose avec d'autant plus d'acuité qu'un grand nombre de réacteurs de puissance seront implantés dans le voisinage de vastes zones urbaines. Aussi le CCR étendra-t-il vraisemblablement son champ d'action dans ce domaine, déjà étudié depuis plusieurs années, dans des directions différentes.

Une synthèse telle que celle-ci doit être limitée à quelques exemples de recherches dont la plupart est réalisée en collaboration étroite avec les industries intéressées.

Le comportement des matériaux et des structures pendant les transitoires de caractère destructif, comme l'«accident maximal hypothétique», est étudié sous différents aspects comme par exemple la rupture des alliages de zirconium hydrurés sous l'effet de charges dynamiques, et la sollicitation par un choc explosif de modèles de structures de réacteurs. Les problèmes posés par la perte ou l'éjection soudaine de caloporteur du réacteur nécessitent des études de caractère général dans le domaine de l'échange thermique et de la thermo-hydraulique, comme par exemple dans le cas extrême d'une interaction entre l'UO_2 fondu et le Na dans un réacteur surgénérateur refroidi par métaux liquides.

Un effort remarquable a été consacré au développement de «barres de contrôle liquides», c'est-à-dire de systèmes remplaçant les barres d'absorption solides grâce auxquels des solutions absorbantes sont injectées dans des canalisations pénétrant dans le cœur du réacteur.

Les constructeurs de réacteurs ont manifesté de l'intérêt pour cette réalisation qui en est actuellement au stade des essais dans ESSOR.

Le programme de sécurité prévoit également des études de fiabilité des composants de réacteurs et de criticité, qui nécessitent l'élaboration de codes de calcul complexes.

Les études théoriques et expérimentales relatives au contrôle de sécurité des matières fissiles seront traitées dans un autre exposé.[2]

Les possibilités offertes par la conversion directe de l'énergie à l'aide de procédés thermo-ioniques et la rentabilité de cette technique sont toujours en discussion. A Ispra, ce sujet est à l'étude depuis plusieurs années tant sur le plan de la physique que de la technologie. Bien que l'avenir de cette activité reste un point d'interrogation, des résultats précieux ont été obtenus et sont utilisables dans d'autres domaines. Le développement de caloducs, en particulier, mérite d'être signalé, l'équipe d'Ispra jouant dans ce secteur un rôle d'avant-garde en Europe et l'industrie leur cherchant des applications dans des domaines très divers.

5. ACTIVITES PRESENTANT UN CARACTERE DE SERVICE PUBLIC

Le Bureau central des mesures nucléaires de Geel exerce essentiellement des fonctions de service public: production d'étalons, mesure de constantes et de paramètres neutroniques nécessaires à l'industrie nucléaire, détermination des caractéristiques de radionucléides. En outre, il accomplit, à la demande d'industries et d'autres clients, des travaux tels que des analyses isotopiques et la préparation d'échantillons de composition précise et homologuée.

Le BCMN est équipé d'un accélérateur d'électrons linéaire de 70 MeV à 11 tubes de trajectoire dont la longueur atteint jusqu'à 400 m, et d'un accélérateur Van de Graaff de 3 MeV; il a également accès au réacteur belge à haut flux BR2 situé à proximité. Cet institut participe à des programmes internationaux qui lui permettent de comparer ses résultats avec ceux d'autres bureaux de références importants.

Dans ses recherches sur les neutrons, le BCMN s'attache à établir un lien solide entre la science et la technologie nucléaires. Des sections efficaces de référence, telles que la section efficace à 2200 m/s de la réaction $^{10}B(n,\alpha)$, le rapport de branchement dans la désexcitation du ^{7}Li produit, ainsi que les sections efficaces de fission de ^{235}U et de ^{239}Pu, ont été déterminées avec précision. Des mesures ont également été effectuées dans le domaine des sections efficaces destinées aux détecteurs à seuil. On a mesuré les sections efficaces des réactions H(n, n') et C(n, n') afin de permettre la comparaison de différentes techniques de mesure de flux.

Des sections efficaces totales et différentielles de diffusion, de capture et de fission, nécessaires pour le développement et la conception de divers types de réacteurs, ont été établies et les travaux ont contribué à la compréhension des processus physiques fondamentaux, notamment la fission sous seuil de ^{240}Pu et la classification des spins pour les différentes résonances neutroniques dans ^{235}U.

[2] JACCHIA, E., FINZI, S., Ces Actes, mémoire 725, vol. 9.

Le groupe de mesures nucléaires du BCMN a pour principales activités:

- l'étude exacte des schémas de désintégration, la détermination des périodes, des rendements de fluorescence et des coefficients de conversion interne
- la préparation et la distribution d'étalons homologués (par exemple étalons isotopiques, sources de neutrons étalonnées)
- la prestation de services à l'industrie nucléaire et à d'autres centres de recherche (par exemple mesures isotopiques pour la fabrication et le contrôle de sécurité du combustible, déterminations de flux).

Diverses méthodes de comptage et de préparation des sources ont bénéficié d'améliorations apportées aux techniques expérimentales.

Le caractère de service public se retrouve dans les programmes susmentionnés de sécurité et de physique des réacteurs (par exemple l'«Integral Nuclear Data Centre», INDAC), dans certaines activités de l'Institut des transuraniens, dans les travaux du centre de calcul CETIS (Centre européen de traitement de l'information scientifique) d'Ispra sous la forme de bibliothèques de programmes et du développement de software, ainsi que dans le programme de biologie et de protection sanitaire, dont nous parlerons plus loin.

Le CETIS, qui traite les problèmes des différents départements du CCR, d'institutions étrangères et d'entreprises industrielles, à leur demande, s'occupe également du développement de software et d'analyse numérique. Un software a été conçu notamment pour la liaison d'un ordinateur avec des terminaux et la liaison entre ordinateurs, pour l'exécution automatique de séquences de programmes reliés, pour l'indexation et la recherche automatiques de documentation et pour des systèmes de gestion intégrés.

Le CETIS dispose de trois ordinateurs IBM numériques des types 360/65, 7090 et 360/30, utilisés suivant le principe du libre-accès (open shop). Récemment un système on-line a été mis en service avec différents laboratoires et la conversion du système de transmission off-line des données avec le BCMN en système on-line est en préparation.

Une bonne collaboration est établie avec la bibliothèque de programmes de l'ENEA qui expérimente ses nouveaux programmes sur les machines du CETIS. Le système de traduction automatique du russe en anglais, exploité par le CETIS pour des clients intra- et extra-communautaires, constitue également une activité à caractère de service public.

Le programme de recherche biologique de la Commission de la CEE est essentiellement mis en œuvre par le biais de contrats extérieurs. Le groupe de biologie d'Ispra est bien intégré dans ce contexte et réalise également des recherches sur place pour l'établissement.

Les recherches de ce groupe couvrent trois domaines principaux:

- la contamination du milieu par des substances radioactives et d'autres produits, y compris les mécanismes de transfert des agents de contamination par la chaîne alimentaire et les systèmes écologiques;
- l'interaction des radiations ionisantes et des agents chimiques avec les systèmes mammifères;
- la radiobiologie expérimentale et théorique.

Les études relatives à l'environnement présentent un intérêt particulier du fait que le Centre est situé au bord du Lac Majeur, qui irrigue une vaste zone de rizières et de pâturages. Une connaissance approfondie des transferts et des effets des produits libérés dans ce milieu est donc indispensable.

Les recherches engagées sur les effets des radiations ionisantes ou des produits chimiques (en particulier ceux qui sont utilisés dans le domaine de la technologie des réacteurs) sur les systèmes mammifères, notamment sur les cultures de cellules et les systèmes enzymatiques isolés intervenant dans la désintoxication ou la synthèse de l'ADN, fournissent une base appropriée de détection et d'appréciation des risques potentiels. Les techniques expérimentales sont également applicables aux problèmes posés par la pollution de l'environnement.

Il est nécessaire d'établir le rapport entre l'absorption d'énergie spectrale dans des modèles de structures biologiques et les lésions biologiques pour mieux connaître les mécanismes et évaluer les risques d'irradiation inhérents, notamment, aux neutrons rapides et épithermiques.

6. RECHERCHE FONDAMENTALE

Il est souhaitable que tout organisme de recherche consacre une partie de ses activités aux problèmes scientifiques de base, afin de préserver un niveau scientifique suffisamment élevé, de créer une atmosphère de travail stimulante, d'assurer des contacts avec les universités et d'autres institutions de recherche et d'attirer des éléments jeunes. Par ailleurs, les appareils coûteux et puissants installés dans les centres de recherche nucléaire et qui, d'habitude, n'existent pas dans les universités, offrent des moyens exceptionnels pour la recherche fondamentale. On peut même considérer qu'il appartient à de tels centres de mettre ces instruments à la disposition du monde scientifique extérieur.

Au CCR, la recherche fondamentale a été axée essentiellement sur la physique de l'état solide, au moyen des neutrons fournis par les divers réacteurs. Dans le contexte de cette expérience et de la compétence générale de l'établissement, une équipe d'Ispra propose depuis plusieurs années un réacteur rapide pulsé, SORA (SOrgente RApida), qui deviendrait un des instruments les plus puissants dans le domaine de la physique des neutrons et de l'état solide et attirerait des équipes de recherche d'un grand nombre de pays.

Ce réacteur a atteint le stade d'un projet industriel qui doit être terminé pour 1972 en vue d'une décision quant à sa construction. Bien qu'aucune information nouvelle ne puisse être donnée ici sur le projet, qui est déjà décrit dans la littérature, on peut rappeler que le passage d'un réflecteur de béryllium (fixé sur un bras mobile) à proximité du cœur du réacteur permettra d'obtenir 50 fois par seconde un flux neutronique de $4.15\ n/cm^2 \cdot s$ et d'une durée de $50\ \mu s$.

L'importance attachée au projet SORA ne signifie pas que la recherche fondamentale sera exclusivement centrée sur la physique de l'état solide, puisque tous les laboratoires devront se consacrer partiellement à des travaux fondamentaux ne se rapportant pas directement à des projets spécifiques. La collaboration avec les universités devra par conséquent s'étendre et intéresser un large éventail de disciplines.

7. REMARQUES FINALES

Dans le bref aperçu qui précède, certains aspects importants du CCR ont été obligatoirement laissés dans l'ombre. L'accent ayant été mis sur les principaux objectifs à poursuivre, l'attention du lecteur n'a pas suffisamment été attirée sur le fait que les établissements de recherche sont des organismes vivants dont les différentes branches scientifiques sont étroitement liées. Il va de soi notamment que toutes les activités évoquées ci-dessus doivent trouver un large support dans un grand nombre de domaines, allant des mathématiques à la chimie et à la physique, de la métallurgie et de l'électronique à l'ingéniérie, sans parler de l'infrastructure générale et des ateliers. C'est en fait ce support qui définit la physionomie réelle d'un centre de recherche et son potentiel pour l'avenir. Les compétences accumulées dans les divers laboratoires constituent, quant à elles, l'héritage de programmes antérieurs.

Ainsi, à Ispra, l'importance prise par la chimie organique est imputable au rôle qu'elle a joué dans la réalisation d'un réacteur à refroidissement organique. Les qualifications ainsi acquises, inhabituelles dans un centre de recherche nucléaire, peuvent maintenant être mises, avec celles de la division de biologie, au service d'un programme futur sur le contrôle de la pollution et l'environnement.

On peut affirmer que, d'une façon générale, la compétence acquise dans une discipline est une caractéristique plus durable des établissements de recherche que des applications spécifiques, ce qui tend également à expliquer le caractère artificiel d'une scission entre activités nucléaires et non nucléaires dans un certain nombre de cas.

Des considérations politiques et économiques ont amené les gouvernements de notre Communauté à associer leurs efforts et à créer le CCR. Les années passant, il a fallu réviser les objectifs spécifiques de cette entreprise pour les adapter au contexte industriel en constante évolution.

Les raisons primordiales de sa création et sa vocation essentielle n'en restent pas moins inchangés: améliorer les conditions de vie par le progrès technique et contribuer au processus d'intégration scientifique et humain des pays européens.

THE PLACE FOR COOPERATION ON A REGIONAL BASIS

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Abstract–Résumé–Аннотация–Resumen

THE PLACE FOR COOPERATION ON A REGIONAL BASIS.

Over the past 14 years, European countries of the OECD (formerly OEEC) have collaborated through the European Nuclear Energy Agency in joint activities for the development of nuclear energy for peaceful purposes. These activities have included technological and economic studies, the handling and diffusion of nuclear information and data, applications of radioisotopes, and the development of appropriate legal and regulatory measures to ensure the efficient and orderly exploitation of nuclear energy. But most particularly, they have included a number of practical cooperative projects concerned with the development of advanced reactors, with reprocessing technology and with other aspects of the fuel cycle (including radioactive-waste management). Thus ENEA has accumulated a wide range of first-hand experience of the problems involved in regional cooperation, and of the scope and limitations of such cooperation in areas of rapid technical advance and evolving relationships between governments, governmental institutions and industry. These factors are discussed with particular reference to their influence on the scope for regional cooperation, mainly between advanced countries, in the nuclear field in the 1970s.

ROLE DE LA COOPERATION SUR UNE BASE REGIONALE.

Durant ces 14 dernières années, les pays européens membres de l'OCDE (préalablement appelée OECE) ont collaboré, dans le cadre de l'Agence européenne pour l'énergie nucléaire, à des activités communes visant à promouvoir les utilisations de l'énergie nucléaire à des fins pacifiques. Ces activités ont porté sur la réalisation d'études techniques et économiques, sur le traitement et la diffusion d'informations et de données nucléaires, les applications des radioisotopes, et la mise au point de dispositions législatives et réglementaires visant à garantir une exploitation efficace et méthodique de l'énergie nucléaire. En outre, ces activités ont été orientées plus particulièrement vers un certain nombre de projets de coopération, à caractère pratique, portant sur la mise au point de réacteurs avancés, sur les techniques de retraitement et sur d'autres aspects du cycle du combustible (y compris la gestion des déchets radioactifs). Ainsi, l'ENEA a acquis une expérience directe et largement diversifiée des problèmes de coopération régionale, et notamment de la portée et des limites d'une telle coopération dans des domaines qui se caractérisent par une évolution rapide de la technologie et des relations entre les Gouvernements, les institutions gouvernementales et l'industrie. Ces facteurs sont passés en revue, en insistant particulièrement sur l'influence qu'ils peuvent exercer, au cours des années soixante-dix, sur la portée de la coopération régionale entre les pays généralement avancés dans le domaine nucléaire.

СОТРУДНИЧЕСТВО НА РЕГИОНАЛЬНОЙ ОСНОВЕ.

В течение последних 14 лет европейские страны – члены ОЭСР (ранее ОЕЭС) через Европейское агентство по ядерной энергии осуществляли сотрудничество по использованию ядерной энергии в мирных целях. Эта работа включала технические и экономические исследования, обработку и распространение ядерной информации и данных, применение радиоизотопов, а также разработку соответствующих мероприятий юридического и нормативного характера с целью добиться эффективного использования ядерной энергии. Исследования охватывали ряд практических совместных проектов, связанных с разработкой усовершенствованных реакторов, улучшением технологии переработки топлива и другими аспектами топливного цикла (включая обращение с радиоактивными отходами). Таким образом, ЕАЯЭ накопило большой опыт по вопросам регионального сотрудничества, с учетом его масштабов и возможностей в таких областях, где наблюдается бурный технический прогресс. Необходимы также совместные усилия со стороны правительств, правительственных учреждений и отраслей промышленности. Все эти факторы рассматриваются с точки зрения их влияния на масштабы регионального сотрудничества в области мирного использования атомной энергии между развитыми странами в 70-е годы.

IMPORTANCIA DE LA COOPERACION SOBRE UNA BASE REGIONAL.

Durante los 14 últimos años, los países europeos de la OCDE (anteriormente OECE) han colaborado a través de la Agencia Europea para la Energía Nuclear en actividades conjuntas para el desarrollo de la energía nuclear con fines pacíficos. Esas actividades incluyen estudios económicos y tecnológicos, la colección, registro y difusión de la información y de los datos nucleares, las aplicaciones de los radioisótopos, y el desarrollo de medidas legales adecuadas y de reglamentos para asegurar la eficaz y ordenada explotación de la energía nuclear. Más detalladamente, incluyen un cierto número de proyectos prácticos cooperativos relacionados con el desarrollo de los reactores avanzados, con la tecnología de la reelaboración y con otros aspectos del ciclo de combustible (incluida la gestión de desechos radiactivos). De este modo la AEEN ha acumulado amplia experiencia directa sobre los problemas implicados en la cooperación regional, así como de los propósitos y limitaciones de dicha cooperación en esferas de rápido avance técnico que entrañan relaciones de colaboración entre gobiernos, instituciones gubernamentales y la industria. Se estudian estos factores, considerando especialmente su influencia sobre los objetivos de la cooperación regional, principalmente entre los países más avanzados, que durante los años 70 se establezca en el campo nuclear.

During the last two decades few, if any, technological fields have received more widespread attention by Governments than the peaceful applications of nuclear energy. In addition to substantial national efforts to develop and control this new energy source, a considerable amount of international activity in a variety of forms and in a number of different frameworks has also emerged. The basic incentive has been the desire to pool resources and experience, in particular for costly development work, and the need to harmonise regulatory and protective measures to ensure for nuclear energy a safe and orderly growth.

International cooperative schemes have varied from simple bilateral arrangements to action on a worldwide scale. Regional cooperation could perhaps be defined as any multilateral cooperative scheme which is more narrow in scope than fully worldwide action. The notion "regional" need not then be taken necessarily in a strictly geographical sense: a region might also mean a group of countries which are close to each other in economic or political structure, or simply a number of countries having certain common economic or technical objectives which could be furthered through a joint effort.

Much of the work carried out in worldwide organisations like IAEA is in fact of regional nature, being limited to localised contexts, for instance assistance to a group of developing countries. On the other hand, cooperative action begun in a regional organisation may often lay a sound foundation for, and eventually become, action on a worldwide scale. At the other end of the spectrum, bilateral or trilateral agreements could, in many cases, be developed into regional schemes by the participation of additional countries.

The present paper will not attempt any general analysis of the many existing examples of international regional cooperation in nuclear energy. Details of a good number of these are being given in other Conference communications. The purpose of the present paper is rather to describe the principles adopted by one of the wider regional intergovernmental organisations, the European Nuclear Energy Agency of OECD, and to attempt to analyse its experience and the way in which, in the rapidly changing circumstances of today, this type of cooperation could continue to make practical contributions of value to Member nations.

The European Nuclear Energy Agency (ENEA) was set up nearly fourteen years ago by what was then the Organisation for European Economic Cooperation (OEEC). The mandate of the Agency, according to its Statute, was "... to further the development of the production and uses of nuclear energy for peaceful purposes by the participating countries, through cooperation between those countries and a harmonisation of measures taken at national level."

Although this mandate was intentionally wide and general, ENEA was also given specific initial instructions for its work. From the start it became an instrument for promoting cooperation on an optional basis between members, rather than a body for supranational planning and direction. A principal theme of the present paper will be that such a role is readily adaptable to changing needs and circumstances and that, where Governments wish to maintain a considerable degree of national independence in scientific (and other) affairs, its flexibility offers good prospects for success at regional or other levels. This is because successful international cooperation depends on the continuing will of participating countries (or non-governmental organisations, industrial consortia or commercial groups); and the best structure in the world will fail to produce results if its inability to adapt to changing needs destroys this willingness among the participants.

ENEA's role and activities over the past 14 years have therefore been highly selective, rather than the realisation of some comprehensive master plan for the development of nuclear energy in western Europe. This essentially pragmatic approach has been possible only because the Agency's Statute is itself an extremely flexible instrument, designed to encourage cooperation in whatever form may seem most appropriate for the particular objectives envisaged.

STRUCTURES FOR COOPERATION

Although the preceding paragraphs have implied that the organisational structure of a cooperative venture is of secondary importance compared with the willingness of those taking part to make it work, the form adopted for a joint activity can of course have a significant effect on its efficiency. In ENEA's various undertakings, from the major reactor projects Dragon and Halden to cooperative development programmes such as those on food irradiation and isotopic batteries, a wide variety of organisational forms has been employed.[1] Not all have been equally successful, but considered as an ensemble of practical experiments they provide guidelines to both the requirements and the pitfalls of international cooperation in scientific or technological fields.

It will perhaps be best to start with three basic similarities in the structure of ENEA's projects. Because these are common to all, it is reasonable to conclude that they probably represent necessary characteristics.

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[1] See Table I.

TABLE I. PRINCIPAL ACTIVITIES SPONSORED BY ENEA

ACTIVITIES	CURRENT TECHNICAL OBJECTIVES	ORGANISATIONAL STRUCTURE	PARTICIPATING COUNTRIES	OVERALL BUDGET MILLION EMA u/a (f)
DRAGON REACTOR PROJECT	HTGCR technology and fuel development	Projects with separate and autonomous international management. National "host organisations" performing legal acts on behalf of Projects	12 (c)	101.5 over 14 years (a)
HALDEN REACTOR PROJECT	Fuel testing, computerized reactor control		9 (d)	22.2 over 14½ years (a)
EUROCHEMIC FUEL REPROCESSING COMPANY	Reprocessing and development work	International shareholding company	13	65.5 over 15 years (a)
KARLSRUHE FOOD IRRADIATION PROJECT (b)	Development of wholesomeness testing methods	Project with separate and autonomous international management. National "host organisation" performing legal acts on behalf of Project. Work mainly through contracts	20	1.5 over 5 years (a)
ISOTOPIC BATTERY STUDY GROUP	Development of small isotopic batteries	Centralized management: work in national laboratories	7	Contributions entirely in kind
ATLANTIC WASTE OPERATIONS (1967, 1969 and 1971)	Disposal of packaged radioactive wastes in the deep ocean	Direction by special "ad hoc" committees	7, 5 and 4 respectively	
COMPUTER PROGRAMME LIBRARY (ISPRA)	Collection, testing and diffusion of computer programmes	Parts of ENEA Secretariat: supervised by special committees	13	1.6 over 7 years
NEUTRON DATA COMPILATION CENTRE (SACLAY)	Collection, classification and diffusion of neutron data		13	2.9 over 7 years (a)

HEALTH AND SAFETY COMMITTEE	Radiation protection, waste management	ENEA specialized committees or Groups of Experts	OECD countries, IAEA, Euratom	
EUROPEAN-AMERICAN NUCLEAR DATA COMMITTEE (EANDC)	Surveillance of current work and problems: proposals for new work		OECD countries (e)	
EUROPEAN-AMERICAN COMMITTEE ON REACTOR PHYSICS (EACRP)				
COMMITTEE ON REACTOR SAFETY TECHNOLOGY (CREST)			OECD countries, IAEA, Euratom	
GROUP OF EXPERTS ON PRODUCTION OF ENERGY FROM RADIOISOTOPES	Information exchange		OECD countries, Euratom	
WORKING GROUP ON GAS-COOLED FAST REACTORS	Information exchange			
STUDY GROUP ON LONG TERM ROLE OF NUCLEAR ENERGY	Forecasts of nuclear fuel demand, estimation of resources		OECD countries, IAEA, Euratom	
NUCLEAR LAW	Information and harmonization in the field of nuclear legislation			
MAGNETOHYDRODYNAMIC LIAISON GROUP (b)	Surveillance of current work and information exchange	Joint ENEA/IAEA specialized committees	OECD countries, IAEA, Euratom	
THERMIONIC CONVERSION LIAISON GROUP				

<u>NOTES</u>: (a) Until presently agreed date of termination
(b) Jointly with IAEA
(c) Including the 6 EEC countries, represented through the Commission
(d) 13 countries (including 6 EEC members) during first 6 years of Project
(e) Limited personal membership from certain countries; other countries represented through corresponding members and (for EANDC) a sub-committee
(f) EMA u/a = European Monetary Agreement units of account.

In the first place, all projects are supported financially only by those countries which are really interested - and in general it is only these countries which have direct access to the results of the work done. This voluntary participation, which results directly from the flexible nature of the ENEA Statute, has in recent years become known as "à la carte" participation. In certain cases it has been developed to the extent of enabling some countries to participate in different ways from others, for example by contributing work, or seconding staff, in addition to or even in place of direct budgetary contributions.

A second feature of all ENEA projects, and a consequence of the voluntary participation just described, is that each activity has its own, largely autonomous, management body. ENEA representation in these bodies is mainly advisory, the technical direction in particular being in the hands of the participants. It is those participants who pay, and it is right that they alone should decide how their money is spent.

Concerning finance, all the projects are financed on scales agreed in advance, and within budgetary limits agreed for fixed periods. Participants therefore know their precise commitments; and, although this may seem axiomatic, it may be noted that in one case where this simple rule was not observed, insoluble problems of management and control subsequently developed and the project had to be wound up. In cases where contributions in kind form part of a project budget, it is no less important than with direct financial contributions to agree in advance on the precise nature of the contribution and its equivalent monetary value.

The various ENEA projects have many individual and different characteristics. Among the most important of these are legal status and relations with the host country.

As a general rule, it has been found more convenient not to endow a project with its own legal personality. Thus, both for the Halden Reactor Project and for the "Dragon" High Temperature Reactor Project, all legal acts relating to the carrying out of the joint programmes are performed on behalf of the Signatories by the host organisations, the Norwegian Institutt for Atomenergi and the United Kingdom Atomic Energy Authority respectively. ENEA's "Common Services" on the other hand (the Computer Programme Library at Ispra, Italy, and the Neutron Data Compilation Centre at Saclay, France) are integral parts of ENEA itself, financed through the OECD budget.

Yet another approach has been adopted for the joint operations organised by ENEA for disposal of packaged solid wastes in the deep Atlantic. In this case the participant countries have themselves jointly contracted with shipowners and have observed operational procedures laid down and supervised by ENEA. Thus each problem or project has led to the development of an organisational and legal form suited to its particular circumstances.

One important exception to the practice of not giving projects their own legal personality is the Eurochemic Company. Under its Statute and Convention, signed in December 1957, the Company was established as an international organisation in its own right, benefiting from certain privileges, and subject to the laws of the host country (Belgium) only where its own Convention is silent. In practice this has meant that the Company has been deprived of the backing of a national host organisation, which in the case of other projects has been extremely helpful.

THE CHANGING RELATIONS BETWEEN GOVERNMENTS AND INDUSTRY

A factor of growing importance in ENEA's cooperative projects has been the increasing interest of industry. In the late 1950's and early 1960's, the involvement of industry was commonly achieved by the award of contracts, enabling industry to contribute to the realisation of a project but not to its planning or direction. The contract system also absolved industry of any real concern for the objectives of a project, and was not conducive to a relationship based on partnership. Such an arrangement may perhaps be satisfactory for projects of a purely research nature, but where - as for example with the Dragon Project - development work is expected to lead to commercial exploitation, it will be necessary at some stage to bring in industrial participation in a much more fundamental way.

This need for some form of governmental-industrial collaboration has gradually gained recognition, and it is probable that no project with essentially commercial objectives could now be considered other than in such a form. This raises an entirely new series of legal and administrative problems, to which ENEA has devoted some study. However, the evolution of both the Halden and Eurochemic projects has permitted the progressive direct involvement of industrial interests and this trend can be expected to continue. On the other hand, projects concerned with problems traditionally the prerogative of Governments are likely to continue to observe the precepts discussed earlier in this paper. A particular recent example has been the new ENEA/IAEA/FAO International Project in the field of Food Irradiation, involving governmental organisations in twenty countries, which came into being on 1st January 1971 to establish wholesomeness data concerning irradiated foodstuffs.

THE INCREASING IMPORTANCE OF LEGAL AND REGULATORY COOPERATION

Besides the promotion of research and development projects, specialised information services, and a number of scientific committees and liaison groups for exchange of information and planning of new work,[2] ENEA has, since its creation, been concerned with the development of special legal and regulatory regimes without which the progress of nuclear energy in Europe would have been greatly retarded.

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[2] For main examples see Table I.

This is a field where, unlike that of joint undertakings and common services, limited participation is undesirable, for to be effective the regime must be adopted by the largest possible number of countries. The clear implication is that nuclear law must in due course become world international law, and it appears that this objective will be attained more readily through coordination of regional efforts with those planned on a worldwide basis by IAEA. However, progress is necessarily slow because legal systems and principles differ substantially in different areas of the world, and the successful introduction of a sophisticated legal regime is not possible if the necessary executive machinery (system of advocacy, courts, judgment) does not exist.

The truth of this is emphasised by the fact that in the field of nuclear energy liability - which has received more attention than any other aspect of nuclear law - the only regime so far in operation internationally is that established for the ENEA area by the 1960 Paris Convention, which came into force in 1968. Even this Convention as yet applies in only seven countries, because Signatory countries have to adapt their own national legislation to the Convention's principles before they can ratify it. This often takes a very long time.

A further impediment to the rapid development of world nuclear law is the wide variation, in different countries, of the practical state of nuclear progress. As a result, although some countries have urgent need of a nuclear regime now, for others the matter remains academic.

THE FUTURE

In its early days the attention of Governments to nuclear energy derived to a large extent from political considerations and the importance of nuclear programmes (national, regional and international) was often measured in terms of investment rather than results. A contributing factor to this was the difficulty of measuring the real value of these results as long as they could not be applied in a normal competitive market situation.

For over a decade, however, political commitments to nuclear energy have been more and more subjected to economic analyses, with the principal objective of relating costs to expected benefits. This rigorous discipline, applying to nuclear power the same criteria as have long governed the exploitation of other energy resources, has naturally had its effect on current thinking about cooperation across frontiers. Recognising that such cooperation is not an end in itself, Governments are no longer willing to pledge their support until convinced that it may bring advantages unobtainable (or more expensive) at national level. This means that although nuclear cooperation still contains an element of solidarity between the participating countries and a recognition of their interdependence in this field, a clear practical benefit for every individual partner is being increasingly sought.

In this changing climate, regional and international organisations can no longer rely on idealistic support based on general political motivation, but must themselves demonstrate that their costs are justified by the benefits they can offer. This is especially true for large-scale development projects requiring substantial funds for investment and operation, and for which the expected benefits must be carefully assessed and compared with expected returns from alternative investments.

The difficulties of making cost/benefit analyses of research and development work are well known, and for obvious reasons they are even greater in the case of international projects yielding results to be exploited by a number of countries. Such studies of international undertakings would probably show that there are good and bad joint projects just as there are successful and less successful national projects. In the case of international projects, however, quite exceptional care is needed in assessing possibilities for the participants to make use of the jointly produced results, taking particular account of the complex patent and other legal problems which may evolve.

It must also be recognised that participating countries in a joint project might adopt changed policies during the project's life, and this might lead to a developing lack of interest, or even a conflict of interests in respect of the project. It is therefore important to build into any project Agreement provisions allowing for appropriate changes to be made, or even the project to be terminated, if it ceases to correspond to the common interests of the participants. In such circumstances termination of a joint project would not necessarily reflect on the quality of the project but rather the fact that the field had reached the competitive stage, and that continued collaboration between emerging competitors would be unrealistic.

It is often said when difficulties arise over multinational projects that these are due to Governments lacking the political will to cooperate. This might be true in some cases, since political support is normally essential for any large-scale project of this kind; in many other cases, however, what is interpreted as lack of political will may have its origins in fundamental divergencies over technical objectives, divergencies which must arise from time to time with the continuous evolution of both the project itself and the situation in the participating countries.

It is entirely natural that evolving circumstances may sometimes call for changes in existing cooperative activities, and even the ending of some. But it is also natural that the same evolution should bring into focus new possibilities and methods for cooperation, with the continuing overall objective of increasing efficiency, and effectiveness, of national efforts.

In the field of nuclear energy, these efforts have now enabled many countries to achieve a first goal, namely the development of economically competitive nuclear power stations. The next step, to which Governments are now gradually turning their attention, will be to ensure the rapid growth of installed nuclear generating capacity so that this may play its hoped-for role in meeting increasing electricity demands.

This introduces a number of new problems, from those of assuring adequate supplies of nuclear fuels, to the practical and psychological questions concerned with safety and siting of nuclear installations. Initially, of course, these problems will be of major interest to the more industrially advanced countries, most of which are now heavily committed to nuclear power. Since the problems are very similar - in some cases identical - from country to country, a multinational approach may well offer advantages, and on certain questions could lead to rationalised solutions. Indeed there are various policy problems (such as those of waste management, or of ensuring optimised use of basic resources) which by their nature are incapable of solution by individual nations in isolation. Here Governments have no choice but to adopt a cooperative approach which as a first step will include confrontation of national problems and policies. In general, such approaches may be expected initially at regional levels, among groups of countries where interests are inter-linked either geographically or by similar states of technological development.

The conclusion to be drawn is that, although the nature of cooperation in nuclear energy in future years may be expected to differ considerably from what it has been in the past, there will be an increasing need for such cooperation in many new directions. It will be the task of inter-governmental organisations like ENEA to define these directions, having in mind that the measure of success should not be quantity or size of activities launched, but their usefulness to participating countries.

NATIONAL NETWORK OF INIS IN JAPAN

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Abstract–Résumé–Аннотация–Resumen

NATIONAL NETWORK OF INIS IN JAPAN.

The INIS is an international information system based on national information systems. To establish an INIS in Japan, it is necessary to establish a national network in both input and output. The JAERI (Japan Atomic Energy Research Institute) was designated as the organization to carry out this project in Japan. For that purpose the JAERI obtains and scans non-conventional literature and core journals in atomic energy; the JICST (Japan Information Center for Science and Technology) is in charge of the peripheral fields, and the Keio Medical Library deals with biology and medicine. The JAERI checks inputs from these organizations, coordinating their activities. The Japanese Advisory Committee for INIS was organized in September 1970. The duties of the Committee are to advise the President of the JAERI concerning policies of the INIS management in Japan. A Technical Committee for Dissemination of Information in atomic energy was also set up in the Atomic Energy Society of Japan. In this initial stage of INIS, Japan is providing about 10% of the world's INIS input. In bibliographic descriptions, the language barrier is a problem in the functions of input. The standardization of bibliographic descriptions for Japan is being studied by the ISO National Documentation Committee, etc. It is desirable that Japan's input for world information systems be convertible. To effectively obtain information retrieval from magnetic tapes, the exchange of software, language control including a thesaurus, and the development of utilization techniques in related organizations are encouraged. The NIST (National Information System for Science and Technology) planned by the Japanese Government is expected to solve certain problems of the national INIS input and output network.

LE RESEAU NATIONAL D'INIS AU JAPON.

INIS est un système international de documentation basé sur les systèmes de documentation de chaque pays participant. En vue d'exploiter INIS au Japon, il est nécessaire d'établir un réseau national tant pour les données d'entrée que pour celles de sortie. Le JAERI (Japan Atomic Energy Research Institute) a été chargé de sa mise en pratique dans le pays. A cet effet, le JAERI se procure de la documentation non homologuée et la diffuse, et prépare également des extraits de périodiques dans le domaine de l'énergie atomique; le JICST (Japan Information Center for Science and Technology) s'occupe des disciplines générales et la bibliothèque médicale de l'Université de Keio de la biologie et de la médecine. Le JAERI vérifie les données d'entrée fournies par ces institutions et coordonne leurs activités. Le Comité consultatif japonais pour INIS a été organisé en septembre 1970. Il a pour mission de conseiller le président du JAERI en matière de politique de gestion d'INIS au Japon. Le Comité technique pour la diffusion de renseignements relatifs à l'énergie atomique a également été créé, au sein de l'Atomic Energy Society of Japan. A ce premier stade, le Japon fournit à INIS 10% environ des données d'entrée mondiales. Dans les descriptions bibliographiques, la barrière linguistique constitue un problème. Pour y faire face, on envisage actuellement, entre autres au sein du Comité de documentation nationale de l'ISO, la normalisation des descriptions bibliographiques pour le Japon. Il est souhaitable que les données d'entrée du Japon pour les systèmes de documentation mondiaux soient convertibles. Pour exploiter efficacement les informations fournies par les bandes magnétiques, on encourage l'échange des techniques du software, le contrôle linguistique, y compris le thésaurus, et le développement des techniques d'utilisation à travers les organismes concernés. Le NIST (National Information System for Science and Technology), dont la mise en place est envisagée par le Gouvernement, devra résoudre quelques problèmes relatifs aux données d'entrée et de sortie d'INIS dans le réseau national.

НАЦИОНАЛЬНАЯ СИСТЕМА ИНИС В ЯПОНИИ.

ИНИС является международной информационной системой, основанной на национальных системах информации. Для осуществления системы ИНИС в Японии необходимо организовать национальную систему, способную получать и выдавать информационные материалы в рамках ИНИС. Реализация этого проекта в Японии возложена на Исследовательский

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институт атомной энергии. Выполняя эту задачу, Институт получает и обрабатывает нестандартные публикации и периодические издания в области атомной энергии; Японский информационный центр по науке и технике проводит такую работу для периферии, Медицинская библиотека в Кейо занимается публикациями по биологии и медицине. Институт проверяет информацию, получаемую из этих организаций и координирует их деятельность. Японский консультативный комитет по системе ИНИС был организован в сентябре 1970 года. Комитет консультирует председателя Института по вопросам, связанным с организацией системы ИНИС в Японии. В структуре Общества по атомной энергии Японии был также создан Технический комитет по распространению информации. На начальном этапе работы системы ИНИС Япония будет давать около 10% всех информационных материалов, направляемых странами в эту систему. При составлении библиографических описаний материалов для ввода в эту систему проблемой будет языковой барьер. Национальный центр по документации Международной организации по стандартизации изучает вопрос стандартизации библиографических описаний для Японии. Желательно, чтобы материалы, передаваемые Японией в международные информационные системы, были бы конвертируемыми. Для эффективного поиска информации с магнитных лент применяется обмен средствами программирования, контроль языков, включая тезаурус, и разработка методов использования информации в соответствующих организациях. Ожидается, что NIST (Национальная информационная система по науке и технике), создание которой планируется правительством Японии, решит некоторые проблемы национальных входных и выходных данных в рамках ИНИС.

LA RED NACIONAL DEL INIS EN EL JAPON.

El INIS es un sistema de información internacional basado en los sistemas nacionales de información. Para utilizar los servicios del INIS en el Japón ha sido necesario establecer una red nacional con su sistema de entradas y salidas. Para tal fin se ha designado al JAERI que obtiene y examina literatura no convencional y prepara resúmenes de revistas especializadas en el campo de la energía atómica; el JICST (Japan Information Center for Science and Technology) se encarga de las publicaciones periféricas y la Biblioteca Médica de Keio de la biología y de la medicina. El JAERI comprueba las entradas procedentes de estas instituciones y coordina sus actividades. En septiembre de 1970 se organizó el Comité Consultivo Japonés para el INIS (Japanese Advisory Committee for INIS), que tiene como misión asesorar al Presidente del JAERI sobre la gestión del INIS en el Japón. Se ha establecido también un Comité Técnico para la Difusión de la Información sobre Energía Atómica, en el seno de la Atomic Energy Society of Japan. En esta fase inicial del INIS, el Japón suministra alrededor del 10% de las entradas mundiales. La barrera del idioma constituye un grave problema en las operaciones de entrada de descripciones bibliográficas. El Comité Japonés ISO de Documentación, junto con otras instituciones, está considerando la normalización de las descripciones bibliográficas japonesas, aspirándose a que las entradas preparadas en este país sean intercambiables con las de los demás sistemas mundiales de información. Con objeto de conseguir la más eficaz localización de la información acumulada, se estimulan entre las organizaciones afines los intercambios de programas (software), de listas terminológicas (incluido el Thesaurus) y de asesoramiento sobre técnicas de utilización del sistema. Se espera que el NIST (National Information System for Science and Technology), proyectado por el Gobierno japonés, resuelva algunos problemas de la red nacional, relacionados con los datos de entrada y de salida del INIS.

INTRODUCTION

INIS, one of the international systems of information service, is typical of its kind. Each member country provides input to the IAEA. In this operation, each country is to bear its share of the total costs involved according to the percentage of information in that country. This mechanism of operation is also quite common in similar international systems.

For INIS to be truly "user-oriented", it is necessary that the following procedures be standardized: bibliographic description, indexing, and output. Accompanied by these are the establishment at the IAEA of rules, personnel training, a check on inputs, etc. The proper world network of work, with individual countries as units, must be very well organized. Moreover, a similar network is also necessary in each country, including the input and output to terminal users.

In Japan, the Japan Atomic Energy Research Institute (JAERI) was designated as the national centre of INIS. In this nation, the project has certain problems, which include the special "mission-oriented" nature of nuclear energy, peculiarities of the Japanese language, etc. However, the entire set-up of INIS will be effectively conducted in Japan in the future through close cooperation with other organizations.

THE FIELD OF NUCLEAR SCIENCE AND TECHNOLOGY

Nuclear science and technology is not a so-called "disciplinary field" such as is chemistry or similar fields. It is therefore termed "mission-oriented" or otherwise "interdisciplinary". In other words, nuclear science and technology is distributed over the respective conventional academic fields.

In the JICST (Japan Information Center for Science and Technology), abstract journals entitled "Current Bibliography on Science and Technology" (for disciplinary fields) are prepared, totalling 400 000 abstracts annually.

These abstract journals concern "General and Mechanical Engineering", "Electrical Engineering", "Earth Science, Mining and Metallurgy", "Civil Engineering and Architecture", "Pure and Applied Physics", and a special issue on "Isotopes and Radiation Chemistry". There are no abstract journals for the life sciences and agriculture. Abstracts on nuclear science and technology are distributed among these abstract journals or their respective fields. Concerning the special issue on "Isotopes and Radiation Chemistry", there are overlapping entries with other "Current Bibliography on Science and Technology" issues. This is apparently a duplication of an information service which, although not desirable, is prepared because of considerations of the varied requirements of users. As in other countries, the field of nuclear science and technology in Japan has developed as mission-oriented. The total number of nuclear scientists and technologists in Japan, according to the INIS scope, is close to 10 000. The growth rate of nuclear personnel is larger than that of other fields [1]. Moreover, there are demands from other fields for information services in nuclear science and technology. Thus, the number of people engaged in nuclear research and technology is possibly several times larger than that indicated.

In Japan, the following journals are published especially for the nuclear fields: "Journal of Nuclear Science and Technology", "Journal of the Atomic Energy Society of Japan", "Nippon Acta Radiologica", and "Radioisotopes". Consequently, the field of nuclear science is firmly established in Japan, and it is parallel to or at the same level with chemistry and other broad fields. As a result, the information service can well be considered a singularly independent system for this particular field.

NETWORK OF ACQUISITION OF INPUT MATERIALS

In Japan, documents concerning the nuclear field appear as journal papers and non-conventional technical reports. The latter are restricted to a few institutions such as JAERI, while the journal articles are fairly extensive. The number of periodicals published in Japan covers about 5 000 titles [2]. A breakdown of these journals is listed in Table I.

TABLE I. NUMBER OF PERIODICALS PUBLISHED IN JAPAN

Fields	No. of periodicals	Percentage (%)
Natural Science	894	18.2
Engineering	2,138	43.6
Life Science	874	17.4
Agriculture	1,023	20.7
Total	4,929	(100)

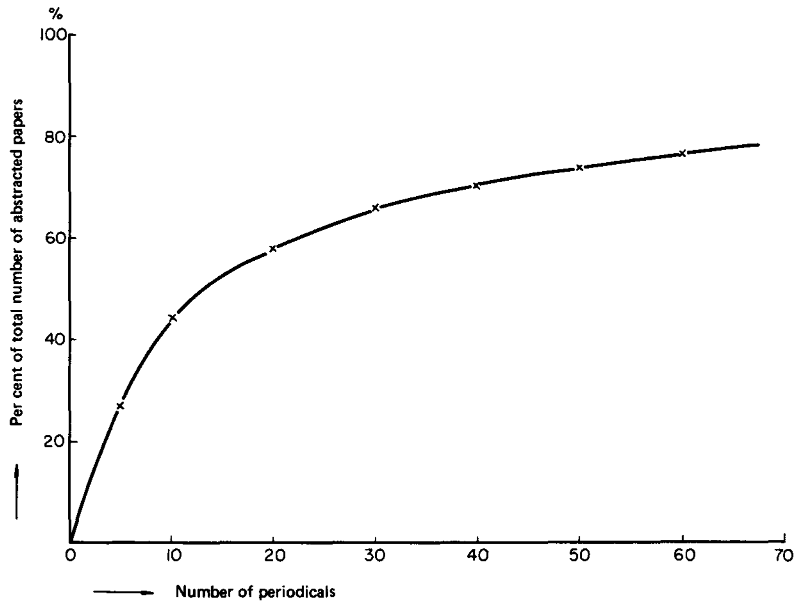

FIG. 1. Per cent of the total number of papers abstracted in the NSAJ compared with the number of periodicals. The curve shows that the rate of increase in the per cent of abstracted papers decreases rapidly beyond a certain number of periodicals.

The Nuclear Science Abstracts of Japan (NSAJ) was published for nine years until the beginning of 1970. The abstracted papers, which were published in the journals covered by the NSAJ, are widely distributed, as shown in Fig. 1.

In Table II a comparison is given for the abstract journals dealing with the literature in Japan, "Nippon Kagaku Soran (Complete Chemical Abstracts of Japan)", "Igaku Chuo Zasshi" (Japana centra revuo Medicina), and "Nuclear Science Abstracts of Japan". From this table it is evident that documents on nuclear science are spread over many fields, compared with the other two journals.

The research activities of JAERI include a fairly large part of the INIS scope. Those branches not undertaken by JAERI are the life sciences, agriculture, and mining. Regarding the network of acquisition for input,

TABLE II. DISTRIBUTION OF ABSTRACTS FOR THE THREE ABSTRACT JOURNALS

	No. of abstracts (A)	No. of periodicals (P)	P/A × 100
Nucl. Sci. Abstr. Japan	5 909	486	8.2
Chem. Abstr. Japan	37 000	(1 300)	3.5
Japana cent. Revuo med.	100 000	1 260	1.2

Note: The figure in brackets is an estimated one.

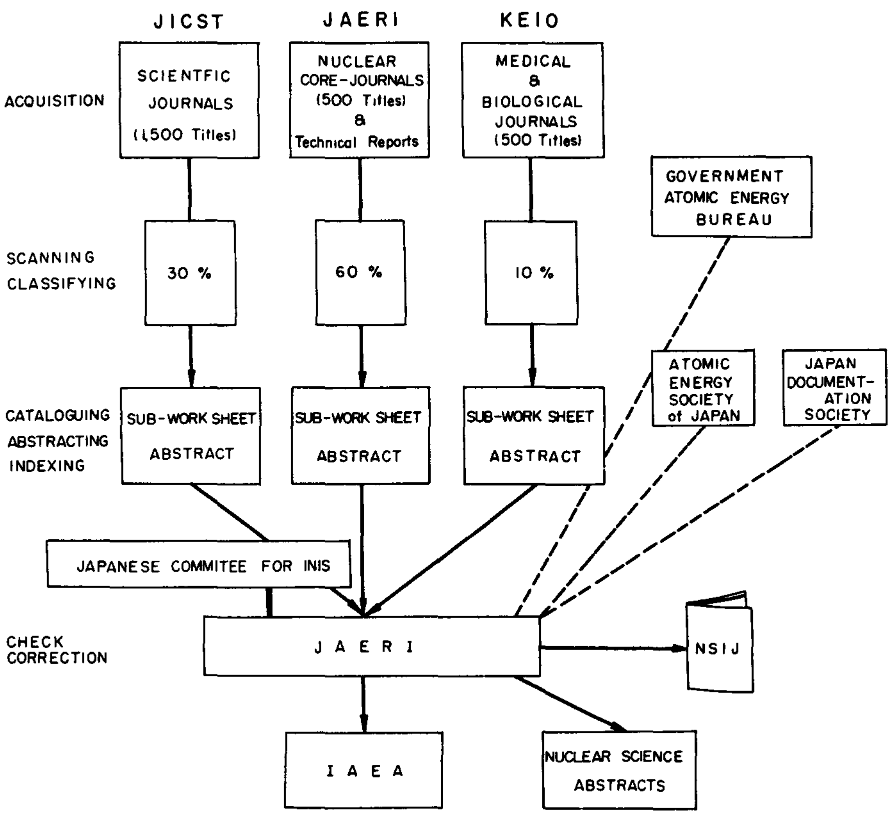

FIG 2. Network of INIS input in Japan.

JAERI takes care of core journals and non-conventional technical reports, the Keio University Medical Library is in charge of life sciences, and JICST is entrusted with other journals not covered by JAERI and JICST. The Keio University Medical Library is a service organ of the Medical Department of Keio University. In an international role, it also serves the MEDLARS by the input from Japan. The services by MEDLARS output are now being developed through collaboration with JICST, a central information centre in Japan related to the fields of science and technology. As already mentioned, it publishes abstract journals containing around 400 000 entries per year, and it also participates in other information services. The network of acquisition for INIS is shown in Fig. 2.

NETWORK OF BIBLIOGRAPHIC DESCRIPTION

INIS input consists of contributions from many countries, and thus there is a need for coordinating and standardizing rules. Regarding bibliographic descriptions, cataloguing standards were initially prepared, together with an Authority List. This Authority List has already been published under Corporate Entries and Journal Titles.

The Authority List can also be used in other information systems. It is desirable to prepare a list for Japan to be introduced into the Authority List by collaboration among similar information organizations and to steadily maintain this list in the future.

There is a variety of secondary literature in Japan. Among those based on Japanese periodicals are: Japana Centra Revuo Medicina, Complete Chemical Abstracts of Japan, Japanese Periodicals Index, Japanese Metallurgical Abstracts (in Japanese), Nuclear Science Information of Japan, Japan Science Review, and MEDLARS input (in English). For certain reasons, the Japan Science Review is now less active. In this connection, JAERI, engaged in INIS in Japan, is a pioneer in making bibliographic descriptions in English.

In Japan, bibliographic descriptions in English first involves the problem of the Japanese language. Personal and corporate names include Chinese characters in most cases, causing difficulty in identification. "Japan", for example, in Chinese characters may be read either as "Nippon" or "Nihon". Moreover, the Latin letters used here constitute several types, and in Japan conformity in the usage of any one type is very difficult to attain among various groups. For personal and corporate names, inquiries are often made by JAERI to authors and institutions. As a result, it is not easy to identify an author in English, unless his name is spelled in full [3].

These problems are common in Japan; thus, it is desirable to prepare an authority list by collaboration among the groups concerned.

The system of registering periodicals has been proposed by UNISIST. This is even more necessary for Japanese periodicals.

To deal with problems such as this, the Japanese Committee for INIS was recently established in JAERI. The duty of this Committee is to advise the President of JAERI concerning the policies of INIS management in Japan. Subcommittees can be established in the Committee, and an Expert Committee on INIS input has been formed.

The problems of standardization are "international". A Liaison Committee for the ISO (International Standard Committee) TC-46 Documentation was set up in the Japan Documentation Society. The subjects being discussed in this committee (the latinization of Japanese, journal abbreviations, input-tape format, and others) are also related to the INIS operation in Japan.

INDEXING NETWORK

The preparation of a thesaurus and its maintenance are effected collectively at IAEA. But the assignment of descriptors to the documents is performed by individual countries dispersed throughout the INIS network. In Japan, indexing is then done in JAERI, JICST, and KEIO. It is necessary to hold meetings among the indexers and to establish channels of communications among them. According to an investigation by Euratom on the stability of indexing, it is the most effective when performed by field specialists [4]. To realize an improvement in this respect, it is desirable to educate these scientists on the INIS and descriptor systems. A "Technical Committee for Dissemination of Information" was set up last year in the "Atomic Energy Society of Japan". This committee is composed of about twenty members specializing in nuclear science and concerned with information dissemination. One objective of this Committee is to foster information activities including a descriptor system among members who then transmit this knowledge to their colleagues.

OUTPUT NETWORK

The structure of input for INIS is now being formed in Japan; on the output side – that is, the use of magnetic tape for information retrieval – preparations are presently under way.

Various forms of the information system using a computer are being developed in Japan; however, both users and information service organizations are not yet familiar with such services. The use of magnetic tapes in MEDLARS is now being developed by collaboration between JICST and KEIO. On the other hand, an extensive information retrieval system in the Japanese language is progressing in the JICST. Such commercial magnetic tapes as Chemical Abstracts Services, ASCA, Ringdoc and others are being used in some enterprises, while input is also being prepared and the computer processed for internal use. In this situation in Japan, INIS will be one of the organizations in the field of mechanized information service.

Since there will be considerable software for computer systems in INIS, in IAEA, and also in individual countries, the expense involved is fairly large on both sides. In a public system such as INIS, it is of course desirable to use common softwares jointly; however, this is difficult to realize at present. In Japan, it is not certain yet whether output using magnetic tape should be made at more than one location. This especially concerns software.

Computers used in Japan comprise several types, including both domestic and foreign brands. In this respect, the employment of software conversion or a general-use program package is being investigated, but without any solution as yet in the field of information systems.

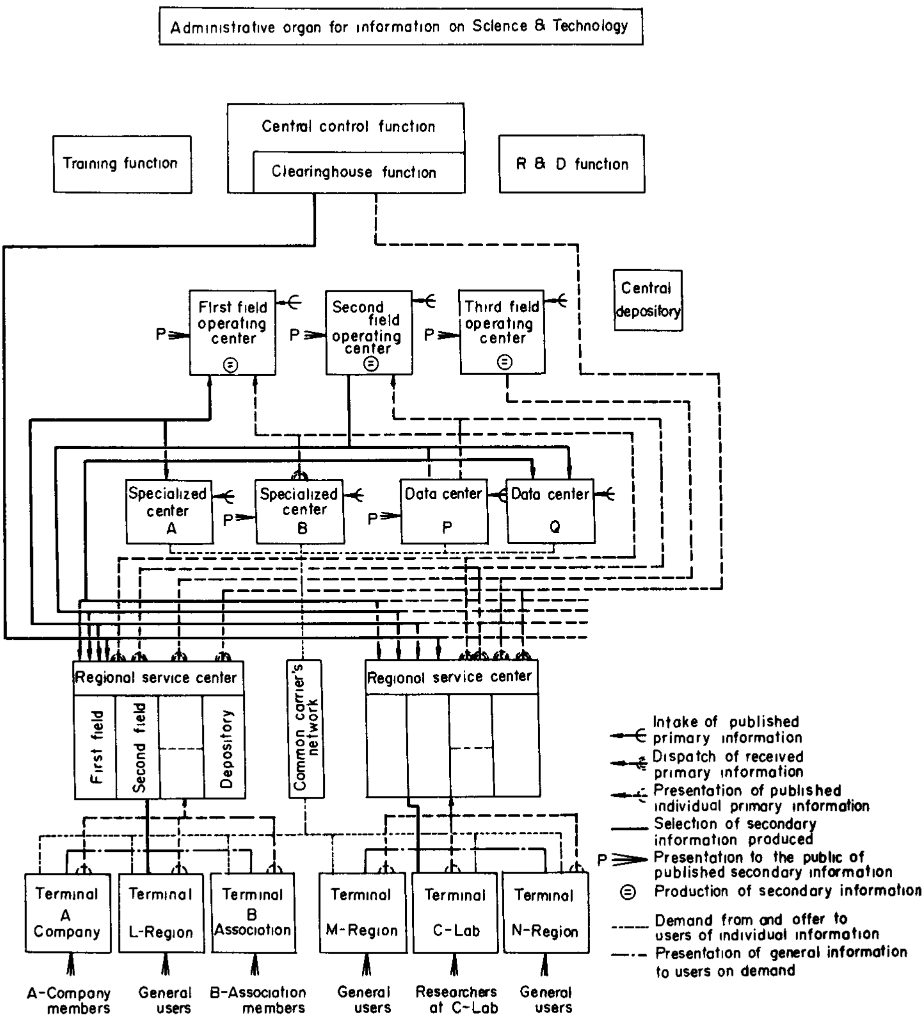

FIG.3. Functional chart of the NIST.

NATIONAL INFORMATION SYSTEM FOR SCIENCE AND TECHNOLOGY (NIST)

As already described, INIS in Japan is related to many other systems and schemes. A national project termed the "National Information Systems for Science and Technology" is presently being formulated to coordinate work regarding (1) information of international systems such as INIS, MEDLARS and CAS; (2) a national centre like JICST; (3) systems by associations, and so forth; and (4) other systems by foreign and domestic enterprises.

The Council for Science and Technology of the Japanese Government submitted a report to the Prime Minister who approved it in October 1969. It was entitled "A Basic Policy Concerning the Flow of Information Related to Science and Technology". According to this basic policy, concrete plans for the NIST are now being formed, and will be completed in 1972.

A chart of NIST is shown in Fig. 3. NIST consists of operating centres, specialized and data centres, regional service centres and terminals and a central depository. NIST is also involved in training, research and development. To control its overall activities, there are central coordination and clearing-house functions.

In the operation centres, primary literature is processed in major fields such as science and technology, life sciences, and agriculture. Then, in the specialized and data centres, processing into secondary information or evaluation of data collected takes place. JAERI, with its INIS and Nuclear Data Center, belongs to this category. The regional service centres, of which several will be established in Japan, are the sales outlets in NIST. The terminals in Fig. 3 are at the interface between NIST and the users such as educational institutions, societies, enterprises, and others.

The central coordination function assumes the following important roles: policy making, creating feedback systems from the users to NIST, acting as an agency for NIST in matters related to international cooperation, information, standardization, and so on.

Still in the stage of visualization, it will be more than several years before NIST goes into actual operation. The advance of INIS in Japan, of course, requires the support of IAEA, and also coordination with other organizations in Japan.

INIS in Japan will be positioned within NIST; thus the problems confronting INIS in Japan will be gradually solved with the growth of NIST.

ACKNOWLEDGEMENT

The authors are indebted to the staffs of the Division of Technical Information of JAERI.

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DISCUSSION ON AGENDA ITEM 5. 5

International cooperation in nuclear projects and exchange of information

DISCUSSION ON THE FOLLOWING PAPER:

P/102 USA Presented by M.B. Kratzer

M. SANDOVAL VALLARTA: Is any information available on the present employment and specialization of the hundreds of former students of the Institute of Nuclear Science and Engineering? Are their present activities still related to the peaceful uses of atomic energy?

M.B. KRATZER: This is a most interesting question and one on which we have attempted to obtain information for our own use. We have not had any formal follow-up program on the activities of the students of the Institute since the time it was discontinued, but we have tried to determine this informally. We know that many of them have gone on to become important members of their respective atomic energy programs and that, in general, a very high percentage of them have remained active in the nuclear field. Unfortunately, we do not have precise figures.

DISCUSSION ON THE FOLLOWING PAPER:

P/330 Poland Presented by R. Żelazny

There was no discussion on this paper.

DISCUSSION ON THE FOLLOWING PAPER:

P/007 Finland Presented by F.R. Marcus

N. PELZER: In 1963 the Scandinavian States and the IAEA concluded an agreement concerning mutual emergency assistance in cases of radiation accidents. I would like to ask whether, since the entry into force of this agreement in 1964, there have been any accidents which have brought this instrument into play. And if so, what were your experiences with the agreement?

F.R. MARCUS: I know that the system is in force, but to my knowledge it has not been used in practice.

DISCUSSION ON THE FOLLOWING PAPER:

P/341 Romania Presented by A. Georgescu

There was no discussion on this paper.

DISCUSSION ON THE FOLLOWING PAPER:

P/511 UK Presented by D.E.H. Peirson

N. PELZER: In connection with the possibility that the United Kingdom may become a member of the European Community, and more specifically of Euratom, what, in your personal opinion, will be the implications for your country? Do you think that the very elaborate provisions of the Euratom Treaty can be made to mesh with the legal and administrative system governing nuclear energy in the United Kingdom?

D. E. H. PEIRSON: We do not think that the assimilation of our system with that of Euratom will present any great difficulty (subject only to the consultation provided for in the United Kingdom-Euratom Treaty). The process will take some time but the problems should not be insuperable.

DISCUSSION ON THE FOLLOWING PAPER:

P/567 Argentina Presented by O.A. Quihillalt

There was no discussion on this paper.

DISCUSSION ON THE FOLLOWING PAPER:

P/743 USSR Presented by I.D. Morokhov

There was no discussion on this paper.

DISCUSSION ON THE FOLLOWING PAPER:

P/206 IAEA Presented by C.W. Pelzer

B. L. WOOD: Could Mr. Pelzer comment on the relationship between the INIS costs borne by the Agency and those borne by the participants.

C. W. PELZER: The costs to the Agency for 1970 are about $400 000; for 1971 and 1972 they will be $493 000 and $570 000, respectively. These are net costs and include the following: personnel, travel, supplies, full cost of equipment, computer time and programmers, and our share of common services (overheads); also, credit for income from sale of INIS products.

I do not have full information on participants' costs but at a meeting of a cross-section of INIS participants in July some countries indicated that their costs run about $15-30 per item – the high figure would include translations.

DISCUSSION ON THE FOLLOWING PAPER:

P/683 CMEA Presented by Z. Vadász

There was no discussion on this paper.

DISCUSSION ON THE FOLLOWING PAPER:

P/724 Euratom Presented by P. Caprioglio

M. A. ROLLIER: As Professor of Chemistry at Pavia University, where Alessandro Volta taught early in the nineteenth century, I should like to express thanks to the directors of the Joint Research Centre at Ispra for its assistance to the University in connection with the doctoral dissertations of many of its students.

DISCUSSION ON THE FOLLOWING PAPERS:

P/737 OECD Presented by E. Saeland
P/266 Japan

There was no discussion on these papers.

GOVERNMENTAL SCIENTIFIC EXHIBITION AND IAEA EXHIBIT

Scientific Secretaries

A.R. PALMER, IAEA
R. KRYMM, IAEA

Compiler

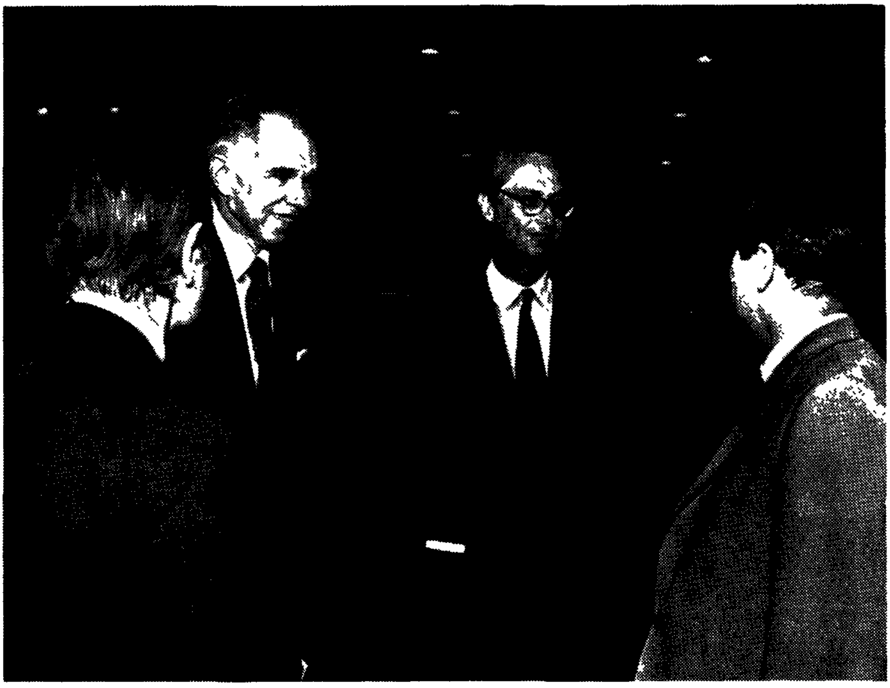
A.R. PALMER, IAEA

GOVERNMENTAL SCIENTIFIC EXHIBITION AND IAEA EXHIBIT

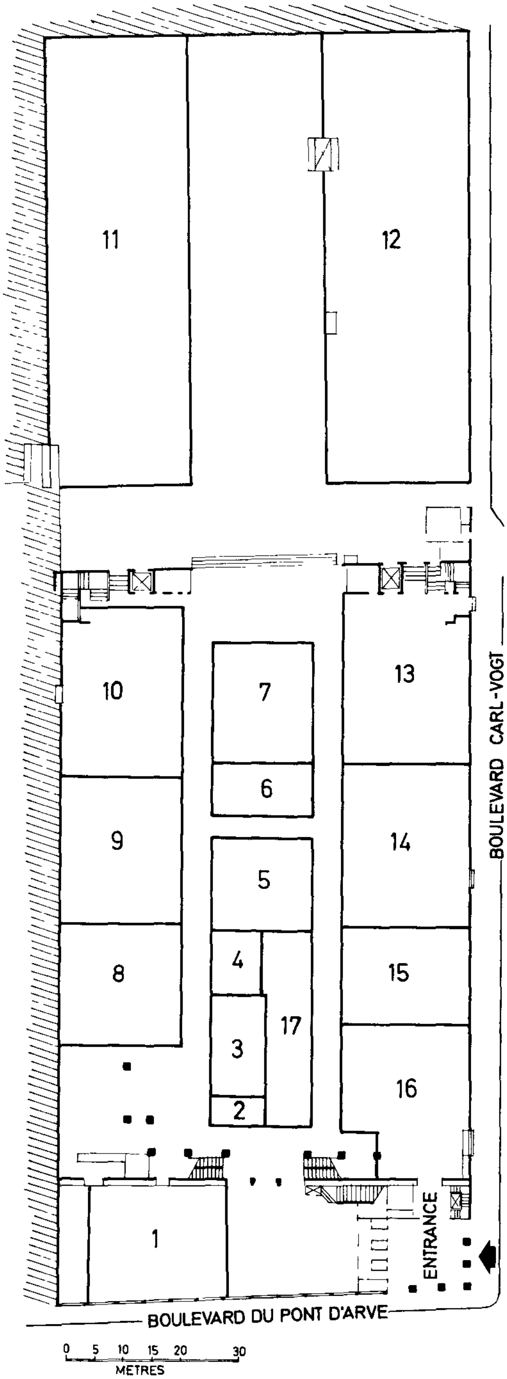
Narrative of the Exhibits

As with previous International Conferences on the Peaceful Uses of Atomic Energy, a Governmental Scientific Exhibition was held in the Palais des Expositions. This building, which is centrally situated in Geneva, was rented to house the seventeen exhibits and, by arrangement with the local authorities, was provided with a mobile fire picket, first aid post, catering and administrative facilities.

Nineteen Governments contributed seventeen exhibits, the arrangement of which is shown in the diagram of the floor plan. The exhibits varied in area from 47.50 to 1875 m^2 and occupied a total area of 9373 m^2. The cost of the hire of the building, common services and administration was met by the exhibiting governments in proportion to the surface occupied by each.



The President of the Conference, Mr. Glenn T. Seaborg, and Mr. Vittorio Winspeare Guicciardi, Director-General of the United Nations Office at Geneva, during the informal tour of the exhibits after the opening ceremony.



Floor plan of the Governmental Scientific Exhibition at the Palais des Expositions in Geneva

1. Canada
2. Liechtenstein
3. Switzerland
4. Romania
5. Netherlands
6. Debenelux
7. Belgium
8. India
9. Italy
10. United Kingdom
11. Union of Soviet Socialist Republics
12. United States of America
13 Federal Republic of Germany
14. France
15. Japan
16. Nordic Countries
17. Austria

As part of the Exhibition, the International Atomic Energy Agency set up a small exhibit in the Salle des Pas Perdus of the Palais des Nations. This exhibit illustrated the different aspects of the Agency's work and is described in greater detail later.

The Scientific Exhibition was opened to participants in the Conference on the afternoon of Sunday, 5 September, when the President of the Conference, Glenn T. Seaborg, accompanied by senior officers of the United Nations, members of the United Nations Scientific Advisory Committee, the Director General of the International Atomic Energy Agency and members of his staff and the Scientific Secretariat, civic dignitaries of the State of Geneva and representatives of Delegations made an informal tour of the exhibits. The Exhibition remained open until 16 September to Conference participants and members of the public.

The theme of the Exhibition was "Atoms for Development" and the National exhibits reflected this theme. No commercial exhibition was held as in 1958. National exhibits also reflected the papers presented at the Conference by the respective delegations.

AUSTRIA

Stand 17

Nuclear research and development in Austria is carried out mainly by the Österreichische Studiengesellschaft für Atomenergie GmbH (SGAE), universities and industry. The SGAE is jointly owned by the

A view of one of the stands in the exhibition hall.

Government of Austria, industries and utilities and has its own reactor centre at Seibersdorf, near Vienna. Close co-operation exists between all centres undertaking nuclear research and development, which has resulted in efficient working. The Austrian exhibit reflected this organizational structure and was divided into two main sections. One section of the exhibition stand illustrated a number of projects under development in the various research institutes and the other showed related industrial activities. International co-operation has made possible research and development on several reactor types.

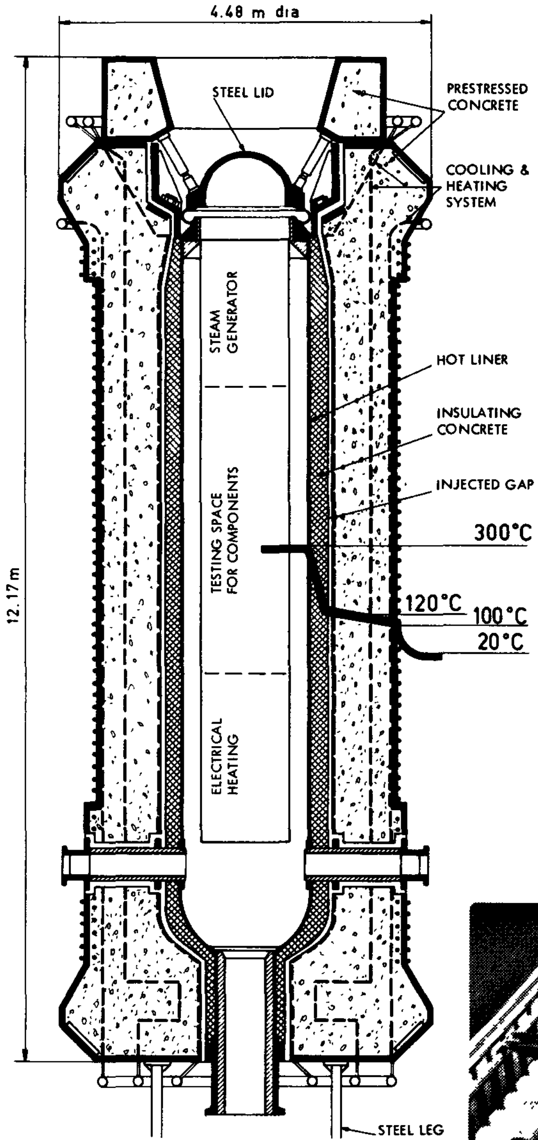
Much work in Austria is oriented towards reactor engineering and involves the use of liquid sodium, particularly at temperatures of 900°C and above. It is expected that this work will find application in fast breeder reactors and in liquid metal magnetohydrodynamic (MHD) power generating installations. A valve designed and tested for use in liquid sodium at temperatures up to 950°C was exhibited.

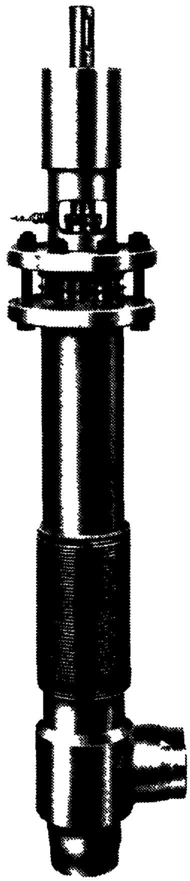
Special alloys developed for nuclear purposes were shown. These materials include special steels, and molybdenum and aluminium alloys. Seamless and welded stainless-steel tubes and pipes were displayed, together with associated welding techniques as appropriate.

Work on reactor systems was illustrated by means of scale models. A model of the 700 MW(e) nuclear power station which is to be built at Zwentendorf (near Vienna) on the Danube was displayed. Another scale model showed a nuclear power plant with integrated steam storage. Such a plant is suitable for load peaking. This development, which has not met with great success for conventional electricity generating plants, makes use of the fact that thermal storage, together with the low fuel cost of the nuclear plant, leads to low cost power for peak topping. It also enables a marked improvement in load factor to be obtained by allowing the plant to remain under full load during off-peak time whilst the steam accumulators are charged. The model shown featured a 1200 MW(e) base load plant with an additional load peaking unit of 400 MW(e). The peak load power is supplied by a separate turbine fed from the main accumulators. The steam supply for peak load power is superheated by means of superheat accumulators and superheaters, thus improving the efficiency and reducing the exhaust wetness in the auxiliary turbine. Cost optimization studies have shown that minimum peak power cost is achieved at a main steam accumulator pressure of about 20 bar and a superheat accumulator pressure of about 40 bar.

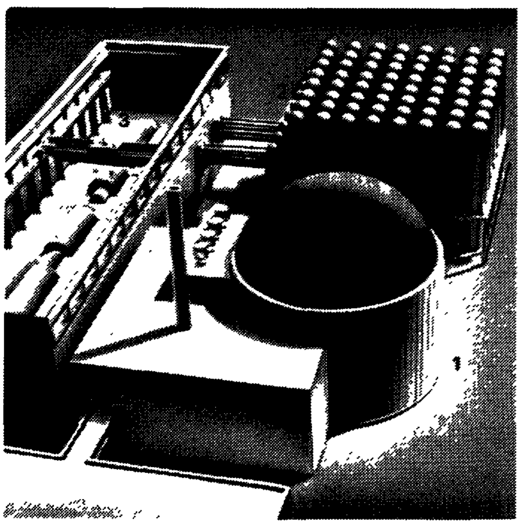
A particularly interesting exhibit illustrated work at the Reaktorzentrum Seibersdorf on a prestressed concrete reactor vessel (containing a hot liner) of advanced design. This work is a joint venture of the SGAE and several large industrial companies. A vessel 12 m high capable of withstanding an internal pressure of 100 bar and with a wall temperature of 300°C is under construction. The steel liner of the vessel will be located inside the thermal insulation and, furthermore, will be accessible for periodic inspection. A model section of the vessel wall was on display. Extensive development work is being undertaken on steel liners, heat resistant concrete and related engineering measurements. Initial experiments will use water as coolant under the working conditions of light water reactors. These will be followed by development work on the main components of a helium-cooled high temperature reactor, the core of which is to be simulated by means of an electric heater.

AUSTRIA





Reactor valve operating with liquid sodium at 950°C and 5 bar.



ABOVE: Prestressed concrete reactor pressure vessel of advanced design having a hot liner inside the thermal insulation accessible for periodic inspection.
RIGHT: Scale model of nuclear power plant with integrated steam storage for load peaking — 1. Reactor building; 2. Steam storage accumulators; 3. Turbine hall.

Work on plasma MHD was illustrated by means of a toroidal plasma storage ring suitable for fusion research.

The considerable export trade in main nuclear components such as core internals, pressure vessels and piping assemblies for the auxiliary systems of nuclear power plants was illustrated by means of photographs and models. Other reactor components such as coolant pumps and special sections were either on view or displayed pictorially.

A graphic display showed several processes developed for the quality control and post-irradiation examination of reactor fuels and, in particular, for coated particle fuels. A related display featured a remotely controlled research microscope (Telatom) for use with radioactive substances. It is located within a double enclosure fitted with lead shielding. The important parts, e. g. the illumination system, eye-piece body and photographic equipment are located outside the enclosure and the mechanical drives are provided with a system of remote controls.

An experimental rig for the concentration of liquid waste by evaporation was shown in order to illustrate the attention being devoted to the problems of waste disposal.

Several other items of scientific and industrial equipment were either exhibited or depicted. The triple axis neutron spectrometer for neutron diffraction studies developed jointly by the SGAE and the Institute for Nuclear Research at Swierk, Poland, was illustrated.

The use of radioisotopes for medical purposes, in agriculture and in industry was depicted. Newly developed labelled rheuma pharmaceuticals are being used to study their influence on human metabolism. Environmental pollution is being studied by determining the trace elements present in human organs by means of activation analysis. An instrument was shown which continuously measures the ash content in a running web of paper. This instrument, which is suitable for use in paper mills, does not involve any mechanical contact with the paper web and has an accuracy of better than $\pm$ 0.5%. Also depicted was a transmission type thickness gauge which measures the thickness of asbestos-cement sheets. With a measurement time of 2 seconds, an accuracy of $\pm$ 1% is obtained over a thickness range from 4 to 20 mm. An interesting graphic display showed numerous applications of radioisotopes in oil-field exploration and oil production. Wear measurements using tracer methods was also depicted.

Emergency training was displayed by means of a series of slides demonstrating the instructions given to the stand-by (and emergency) troops at the Reaktorzentrum Seibersdorf. Participants who successfully complete the course receive a diploma together with a Radiation Protection Competition Badge.

CONTRIBUTORS TO THE AUSTRIAN STAND

Austriatom, Vienna, a partnership of the following companies:
- Böhler & Co., Vienna,
- Maschinenfabrik Andritz Aktiengesellschaft, Graz-Andritz,
- Österreichische-Alpine Montangesellschaft, Vienna,
- Schoeller-Bleckmann Stahlwerke AG, Vienna,
- Simmering-Graz-Pauker AG, Vienna,
- Waagner-Biró AG, Vienna:

GKT-Gemeinschaftskernkraftwerk Tullnerfeld GmbH, Vienna;

Metallwerk Plansee AG & Co. KG., Reutte, Tyrol;

ÖMV - Österreichische Mineralölverwaltung AG, Vienna;

Österreichische Studiengesellschaft für Atomenergie GmbH (SGAE), Vienna;

Reaktorbau Forschungs- und Baugesellschaft mbH (RFB), Seibersdorf;

C. Reichert Optische Werke AG, Vienna;

Vereinigte Metallwerke Ranshofen-Berndorf AG, Braunau-Ranshofen;

VÖEST - Vereinigte Österreichische Eisen- und Stahlwerke AG, Linz.

BELGIUM

Stand 7

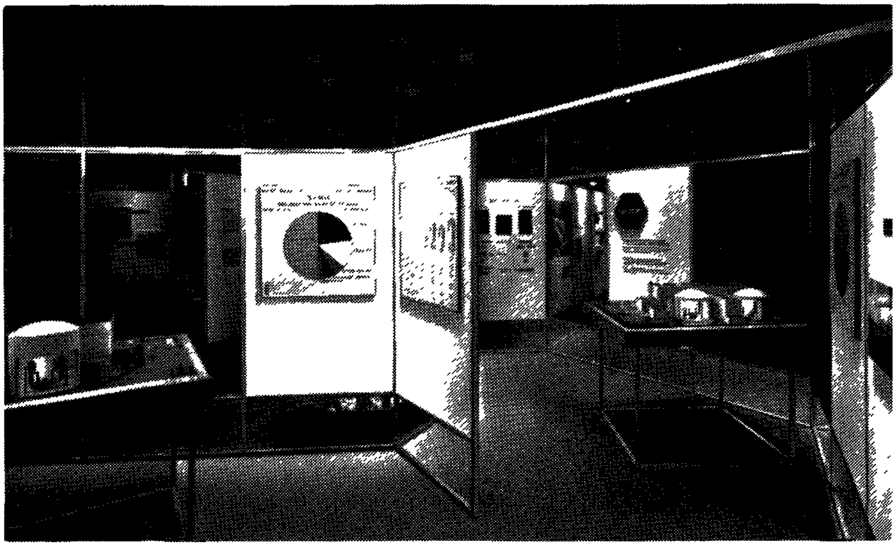
A visitor to the Belgian exhibition stand first saw a large map of Belgium showing the location of the nuclear plants and establishments within the country. This map revealed the closely connected, deeply integrated and highly specialized structure underlying nuclear development in this country and disclosed its varying aspects with respect to research, design, engineering, construction, fuel cycle and power production.

The Belgian stand was constructed on a honeycomb pattern. The arrangement was similar to the lattice assembly of the 300 MW(e) sodium cooled fast breeder prototype reactor which is to be constructed with considerable Belgian participation, and the stand's architect will have had this thought in mind when designing the exhibit.

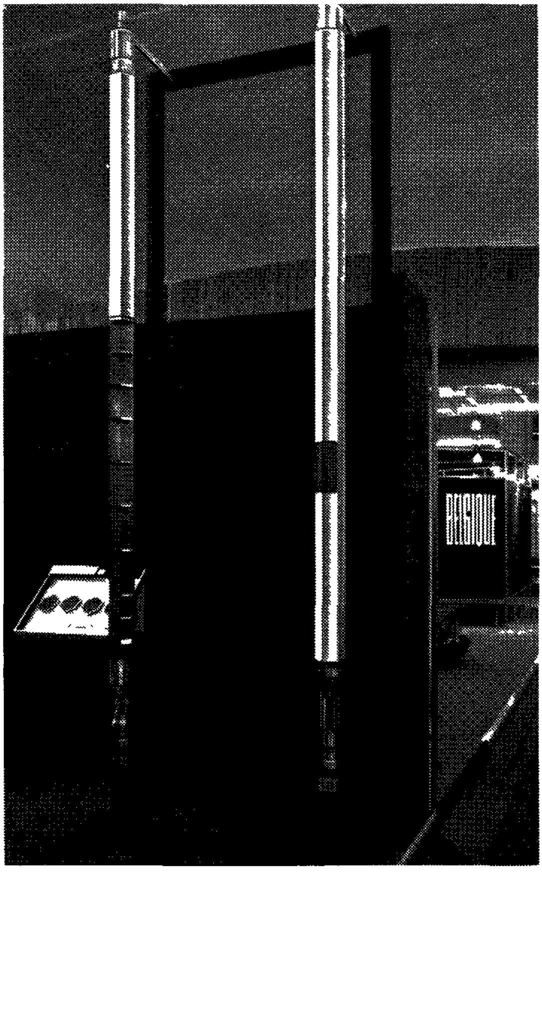
The first "cell" was occupied by the Centre d'étude de l'énergie nucléaire (SCK/CEN) of Mol whose display described the main projects carried out there, namely:

(a) Utilization of the materials testing reactor BR-2 as a tool for testing fast reactor materials;
(b) The use of the high performance sodium loop Na_3 for testing reactor components;
(c) The production of spherical fuel particles by means of high temperature coating equipment;
(d) The production of actinium-227 and thorium-228 for uses as neutron sources and of actinium-227 as a heat source;
(e) Reprocessing of fast reactor fuel of the UO_2/PuO_2/stainless steel type by liquid-metal decladding and subsequent disintegration using an oxidizing molten salt;
(f) Plutonium recycling in light water reactors;
(g) Production of radioisotopes.

The related activities of private industry were also displayed, the impression being gathered that Belgium's current effort is directed toward a quick extension of nuclear power generation and the corresponding creation of a strong fuel-cycle organization.



ABOVE: View of stand showing honeycomb arrangement of exhibits.



BELGIUM

LEFT: An SNR fast reactor prototype core and axial blanket subassembly to the left and, to the right, an SNR radial blanket subassembly.

The visitor was reminded that the picture given in the Belgian stand is by no means complete and he was referred to the 'Debenelux' stand for details of the work performed in Belgium — by the CEN as well as by industry — relating to fast reactors and the associated fuel.

Several industrial organizations contributed exhibits. One such exhibit showed advanced techniques for handling plutonium that can be applied in an industrial-scale production of plutonium bearing fuels. Some typical aspects of research and development laboratories were shown and a pilot line operation was shown pictorially. The pilot line was illustrated at several production steps, e. g. pressing, de-waxing, sintering, etc. A new full-scale plant that was under construction was also described. This plant is expected to be able to fabricate all types of plutonium fuels required for fast and thermal reactors.

Work performed on plutonium recycle in water reactors was shown, and irradiation results relating to fast and thermal reactors were displayed. HTR fuel development work has led to several types of kernels, coatings and compacts which were on display.

A fuel element of the type to be used in the 800 MW(e) power plant now under construction at Doel, north of Antwerp, was shown.

Alongside photographs of the Ardennes power plant, primary pumps and reactor vessel internals, one could see a PWR control rod drive mechanism of the Tihange type and a mock-up of a 600 MW(e) twin power plant. Other photographs presented concepts of major items such as turbo-generating sets, reactor vessels and steam generators.

The Gas Breeder Reactor Association displayed panels showing recent activities, and the aims and objectives of this Brussel's based international organization. The design characteristics of the system were given together with performance estimates for this type of reactor concept. Two potential fuel concepts were illustrated by means of pictures of fuel assemblies. These fuel assemblies use either stainless steel clad fuel pins or coated particles. The related basic research and development work required for successful commercial exploitation was also indicated.

A simplified flow-sheet of a patented electrolytic cutting and leaching head-end process was shown which illustrated some of the work being carried out in Belgium on the processing of fast and thermal reactor fuels. Other exhibits presented details of processes developed for disassembling fast reactor fuels, manufacture of nuclear materials, sample irradiation and transfer, and radioactive waste treatment.

The activities of the international venture, Eurochemic, were illustrated by means of several photographs: films of its activities were continuously screened in a nearby cubicle.

The stand also featured several models and photographs of reactor 'mock-ups'.

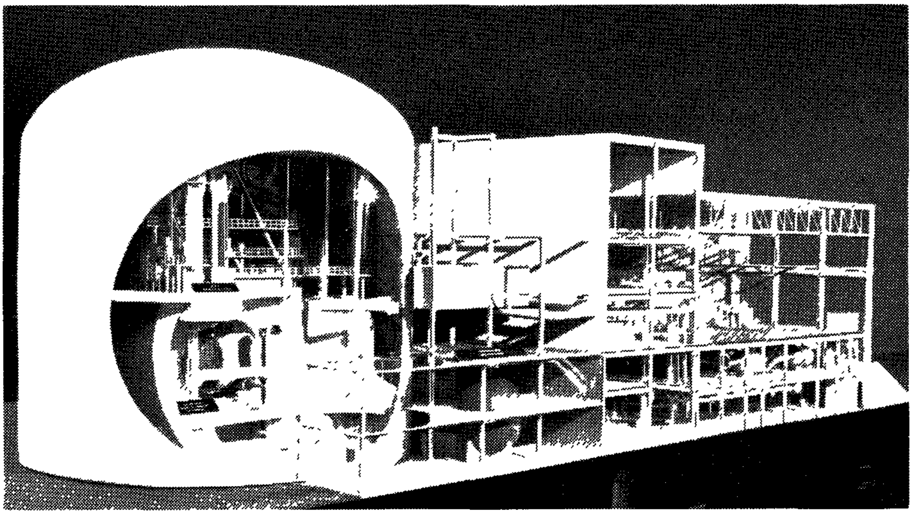
CONTRIBUTORS TO THE BELGIAN EXHIBIT

Studiecentrum voor kernenergie/Centre d'étude de l'énergie nucléaire (SCK/CEN), Mol;

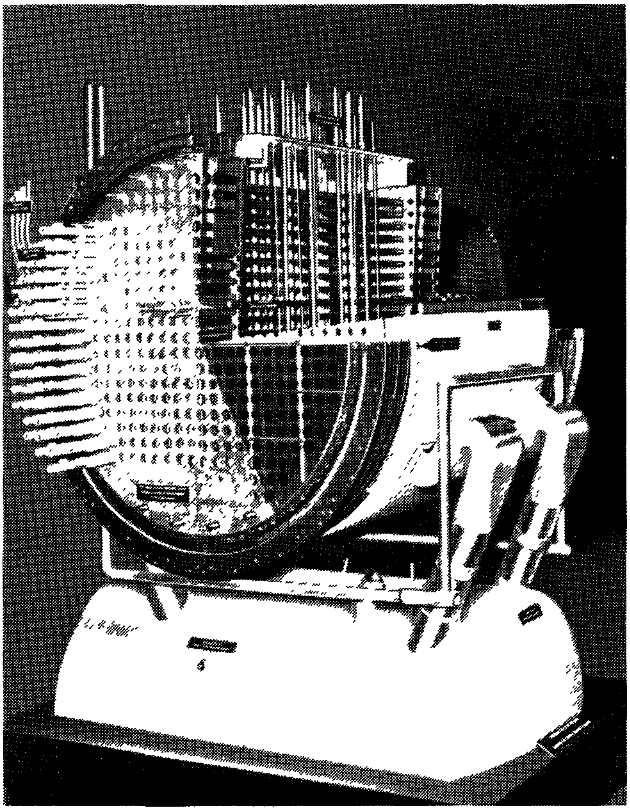
Belgonucléaire, Brussels;

Métallurgie et Mécanique Nucléaires (MMN), SA, Dessel;

Societé générale des Minerais, SA, Brussels;



Pickering Generating Station, Unit No. 1. The second CANDU-PHW reactor went into operation during the period of the Conference.



CANADA

The Pickering calandria.

Ateliers de constructions électriques de Charleroi (ACEC) SA, Charleroi;

SA Cockerill-Ougrée Providence and Espérance-Longdoz, Seraing;

The Gas Breeder Reactor Association (GBR), Brussels;

Synatom, Brussels;

ENI – L'Electro-navale et industrielle, Antwerp;

Eurochemic, Mol.

CANADA

Stand 1

Canada's national exhibit, occupying the area opposite the entrance to the exposition, highlighted the growth of nuclear power in Canada from the 22 MW(e) Nuclear Power Demonstration Station, which has been in operation since 1962, to a total of 11 heavy water-moderated reactors which will have a combined power output of 5512 MW(e) when the four units of the 3000 MW(e) Bruce Generating Station are in service.

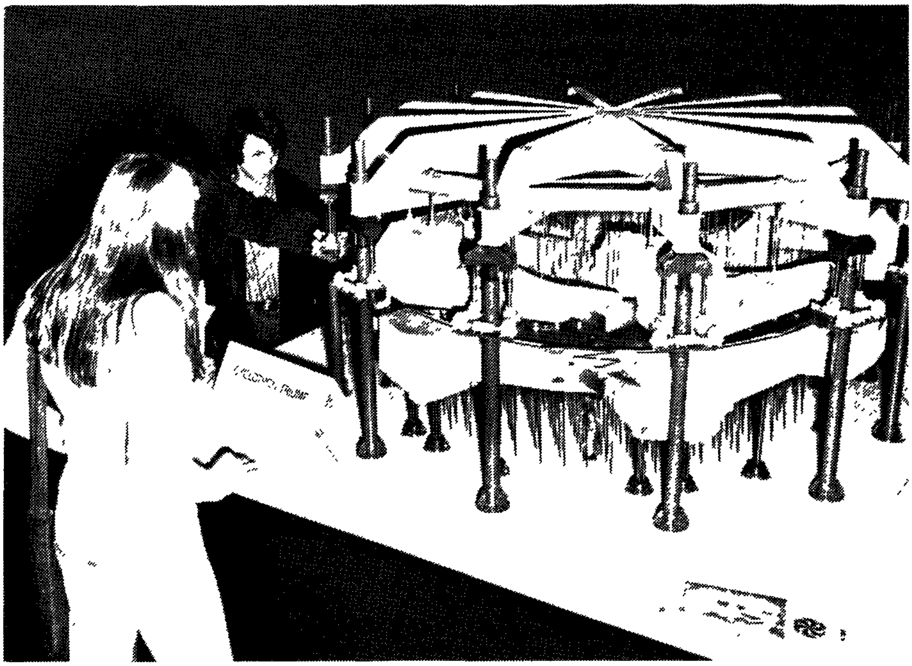
Particular emphasis was placed on Ontario Hydro's 2032 MW(e) Pickering Generating Station, whose first of four units went smoothly into operation in February 1971 and reached full power output in May of that year. The Canadians added a new graphic panel to their exhibit during the conference, to announce on the 15th of September that the second Pickering reactor had gone into operation. The third and fourth CANDU-PHW reactors in the station are scheduled for completion in 1972 and 1973.

Among the other topics in the exhibit were nuclear fuel and heavy water production; the manufacturing capabilities of Canadian industry; research reactors and other facilities at universities, at the Whiteshell Nuclear Research Establishment and at the Chalk River Nuclear Laboratories; international co-operation, including nuclear power stations of Canadian design in India and Pakistan; and applications of radioactive isotopes in medicine, industry and agriculture.

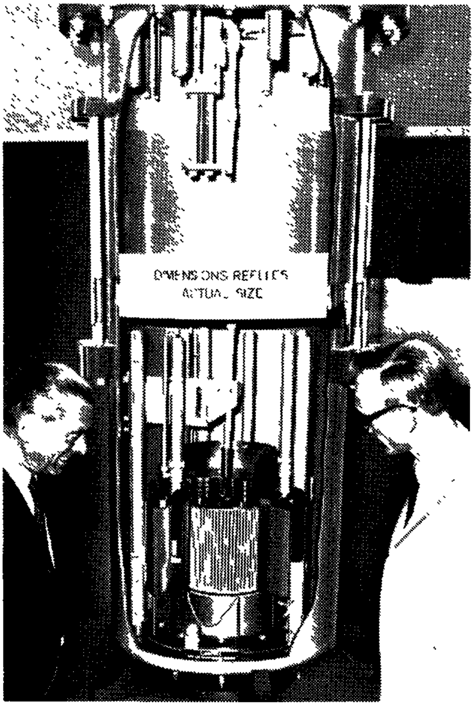
Around the circular exhibit at floor level were models of nuclear power stations, the TRIUMF accelerator, the SLOWPOKE research reactor, a medical products sterilization plant, a Gammabeam 650 irradiator, and the Taiwan Research Reactor.

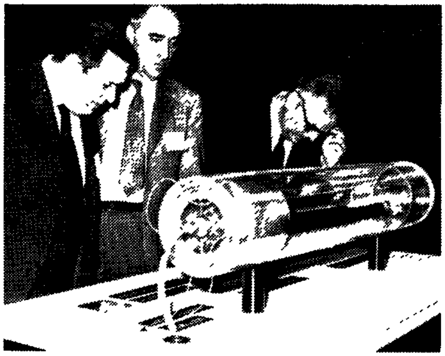
Also displayed were power reactor fuel bundles; equipment for gauging creep in Zircaloy pressure tubes; instrumentation of fuel elements to measure sheath temperatures, transverse vibrations, gas pressure and circumferential strain; the use of radioisotopes in entomology studies and in an ecosystem study of the productivity of natural grasslands; and a model of a neutron power monitor that simulated a tamper-resistant package for measuring reactor power. The latter is part of a United States of America-Canada co-operative research program, known as TRUST (Tamper Resistant Unattended Safeguards Techniques), that is aimed at developing and evaluating tamper-resistant and tamper-indicating instruments and techniques that might be used in safeguarding reactors and other nuclear facilities.

From a tower in the centre of the exhibit, five slide projectors and one film projector presented colourful views of Canadian research, power stations and radioisotope applications. While the slide projectors operated



Model of the TRIUMF cyclotron: scale is given by figures in the model.





ABOVE: Simulated neutron power monitor in TRUST display.
LEFT: Model of SLOWPOKE.

CANADA

continuously to provide a lively effect to the exhibit, seven different films, in English and French versions, were presented each day. Visitors to the exhibit could watch the films from seats at the front of a circular, raised platform surrounding the projection tower. On the opposite side of this platform was a technical information service where publications were displayed and distributed and a publication ordering service was operated.

The Canadian exhibit also showed a range of national activities directly related to informing the public of nuclear safety, the principles of operation of power stations and the "ABC's" of nuclear energy in general. In this area were photographs of a trailer exhibit that is sent to communities throughout Western Canada by the Whiteshell Nuclear Research Establishment, a truck that takes lecture demonstrations and films to high schools in Ontario, and an exhibit which travels to fairs and expositions throughout Quebec. This display also included racks of publications produced specifically for the general public.

In the nuclear power area of the Canadian exhibit the first display unit to be seen was an architectural model of the Bruce Nuclear Power Development on the shore of Lake Huron in Ontario. This model showed the 3000 MW(e) Bruce Generating Station being built by Ontario Hydro; the 800 t/a heavy water production plant being built by Atomic Energy of Canada Limited (AECL); an auxiliary steam plant; and the 208 MW(e) Douglas Point Nuclear Power Station.

The reactor vessels in the Douglas Point and the Pickering stations were represented by two cutaway engineering models, and a large model showed in considerable detail the reactor and turbine building of the first unit in the Pickering station, which has been producing electricity since May and operated at a capacity factor of 89% during July. Nuclear power development in Canada entered the commercial stage in 1964 with the commitment to build Pickering, which is expected to produce power at a cost slightly lower than that from conventional coal-fired units in the Ontario Hydro system. The on-power fuelling system in Pickering was shown by diagrams and photographs displayed behind a cutaway of an actual Pickering end fitting and sectioned portion of a fuel channel.

Another large model presented details of the 250 MW(e) Gentilly Nuclear Power Station, whose single reactor was brought into service in November 1970 and produced its first electricity in April 1971. The Gentilly station, known as a CANDU-BLW (Canada Deuterium Uranium — Boiling Light Water), is the first station with a reactor fuelled with natural uranium and cooled by light water. The moderator is heavy water. The station was built by AECL with the co-operation of Hydro-Quebec which operates it.

An engineering model depicted TRIUMF, a major nuclear physics research facility centred around a cyclotron. TRIUMF is a co-operative project of four Western Canadian universities; the University of Alberta, Simon Fraser University, the University of Victoria, and the University of British Columbia.

The cyclotron is designed to accelerate negative ions (H^-) to an energy of 500 MeV. Proton beams will be extracted from the machine; initially two of six planned proton beams will be extracted, one to be directed into a proton experiment area and one to be directed onto a succession of pi-meson production targets. The proton beam current and the secondary meson beams will be about 1000 times as intense as those now in existence. After passing through the meson targets, the proton beam will be dumped in a neutron target to generate neutron fluxes comparable to those produced in a nuclear reactor. These neutrons will be used to study the structure and vibrations of matter, to produce radioisotopes, and for the analysis of metallurgical and other specimens for industry and research.

A Radiotherapy and Radiobiology Annex will be part of the TRIUMF complex. Negative mesons are of great interest for radiotherapy. Their advantage over X-rays and cobalt-60 gamma rays lies in the fact that a very large fraction of their energy is deposited near the end of their range, making possible the destruction of malignant tissue with relatively little damage to skin and surrounding tissue.

Another exhibit item showing the results of nuclear research was a full-scale model of the SLOWPOKE reactor designed by the Chalk River Nuclear Laboratories and the Commercial Products group of AECL. A prototype of this 5 kW, pool-type, research reactor is now in operation at the University of Toronto. A low-cost reactor which can be operated for long periods of time without skilled operators, SLOWPOKE will produce radioisotopes and perform analyses useful to university, hospital and industrial laboratories. The reactor core is 22 cm in diameter and 22 cm high and is enclosed in a beryllium reflector. The fuel elements are small rods of enriched uranium-aluminium alloy with a thin aluminium sheath.

A graphic display illustrated the use of stable isotopes, radioisotopes and radiation in soil-plant nutrition and plant physiological investigations in the Matador Project, an ecosystem study of productivity of natural grasslands, and comparative cultivated systems, in the prairie region of Western Canada. The project was established in 1967 by the Canadian Committee for the International Biological Programme and is being carried out by the Department of Soil Science, University of Saskatchewan. Shown in the exhibit were the carbon, nitrogen, phosphorus and sulphur ion cycles, photosynthesis, respiration, and water budget assessments.

The applications of radiation in entomological research by the Chalk River Nuclear Laboratories were shown by enlarged colour photographs of eye mutations in insects, developed during the study and evaluation of genetic risks of radiation. Other illustrations showed the use of radioisotopes as tags in the study of the field ecology of insects. These procedures have been used with blood-sucking carriers of trypanosomes causing Chagas disease in South America, and with black flies in Ontario.

Canada was one of the first countries to enter the world market with cobalt-60. The Commercial Products group of AECL designed and manufactured the world's first commercial cobalt-60 cancer therapy unit, which began giving treatments in 1951. An AECL cancer therapy unit dominated the Canadian exhibit outside the main conference room at the first Geneva Conference in 1955.

By the fourth Conference, as the exhibit indicated, 900 Canadian cancer therapy units were in service in 62 countries and 279 irradiators were in use in 38 countries. In addition to illustrations of industrial-scale irradiation plants, Canada showed a model of a medical products sterilization plant. A full-scale animated model of a Gammabeam 650 was demonstrated to show how it could be used for both panoramic irradiation and production of high dose rates on its central platform. Visitors to the exhibit were shown how different dose rates could be obtained by altering the number of radioactive sources in the assembly of tubes above the shielded storage region at the bottom of the unit, or by changing the configuration of the tubes.

Canada has long had a program of international co-operation. Under the Colombo Plan it helped to provide India with the CIRUS reactor, a modified version of the NRX reactor at Chalk River. The exhibit listed Canadian co-operative agreements and showed the training of staff from India and other countries at Chalk River and at Power Projects; the Rajasthan Atomic Power Project being built by the Indian Department of Atomic Energy with AECL providing the nuclear design; and the Karachi Nuclear Power Project built for the Pakistan Atomic Energy Commission by Canadian General Electric Company Limited.

A scale model showed details of the Taiwan Research Reactor. In September 1969 the Atomic Energy Council of Taiwan signed an agreement with AECL for the purchase of a 40 MW(th) research reactor which is now in an advanced state of construction at Huaitzupu, about 20 miles south-west of Taipei, and will come into operation in 1973. Engineering responsibility for this NRX-type reactor is entrusted to the Canatom consortium and AECL has provided training for the Taiwanese staff that will operate the reactor. The reactor vessel, or calandria, is the first in the world to be fabricated entirely of Zircaloy.

The exhibit vividly portrayed the enormous growth of Canada's nuclear program since the 1955 exposition in which research reactors, laboratory-scale irradiators and cancer therapy units were the main topics in the small Canadian exhibit in a hallway of the Palais des Nations. In addition to new research facilities at universities and the growth of annual sales of isotopes and related equipment to about $10 million, Canadian utilities, engineering consultants and AECL are now engaged in a nuclear program involving the operation, design or construction of nuclear power stations representing an investment of nearly $2000 million.

DEBENELUX

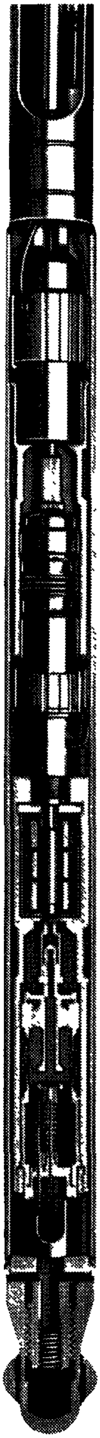
Stand 6

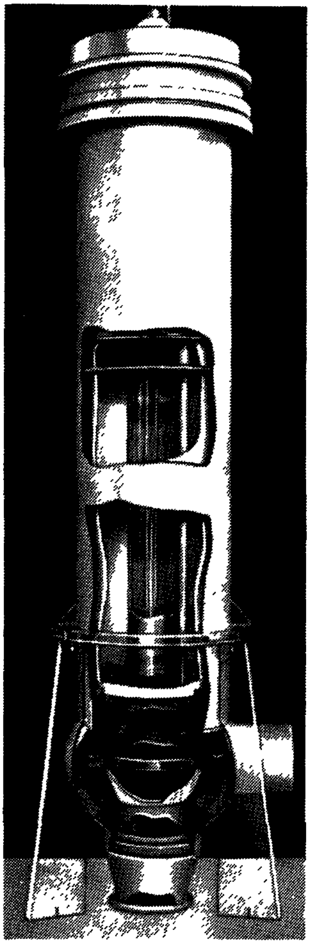
The Debenelux stand displayed the joint activities of the Federal Republic of Germany, Belgium, The Netherlands and Luxembourg. Since 1967 these four countries have merged their efforts on the development of fast breeder reactors. Governments, national research centres, industries and utilities of the Federal Republic of Germany, Belgium, the Netherlands and Luxembourg all co-operate in a Common Fast Breeder Project. Its first objective is the construction of a prototype sodium-cooled fast breeder reactor with an electrical output of 300 MW. Construction of this prototype reactor is planned to start in the spring of 1972.

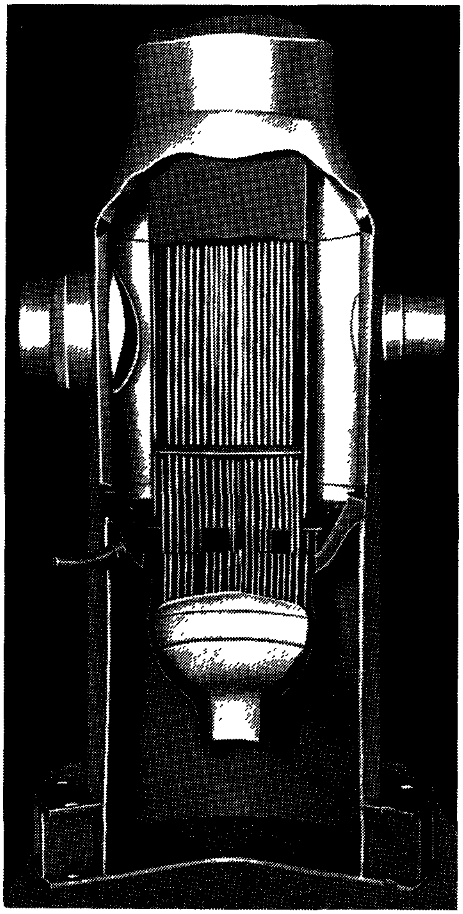
After this first phase, the four countries will continue their joint project in order to develop large commercially competitive fast breeder reactors. The costs of this development are estimated to be so high that co-operation with more countries is sought.

THE SNR 300 REACTOR

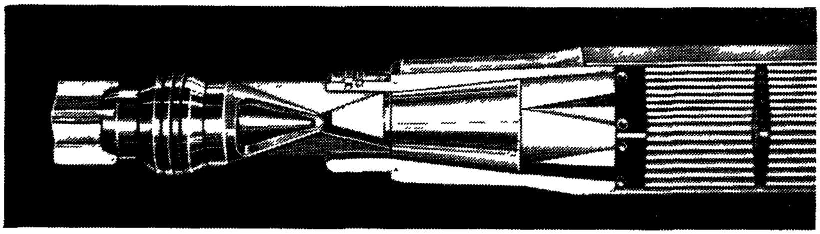
A model (scale 1 : 50) of this prototype reactor was the high-light of the Debenelux exhibit. This reactor is fuelled with prismatic-type fuel







DEBENELUX COMMON FAST BREEDER PROJECT, 300 MW(e) SNR
LEFT: Instrumented capsule for in-pile measurement of fuel creep.
TOP CENTRE: Model of 5000 m^3/h sodium pump.
TOP RIGHT: Evaporator of the 50 MW prototype steam generator.
BOTTOM: Bottom part of fuel assembly.



elements each of which contains 163 fuel pins of 6 mm diameter. A sectioned model (scale 1 : 1) showed the structure of the hexagonal fuel element. The fuel pins are filled with sintered pellets of mixed Pu-U oxide. A dummy fuel assembly and dummy blanket assembly were displayed. Another exhibit in this group gave information relating to the fabrication of fuel pins and spacers.

The core of this reactor is designed to produce 770 MW thermal and a detailed drawing of the core was displayed. Cooling of the core is by means of three primary loops which transfer their heat to secondary loops. A further (tertiary) loop is used to produce steam, which drives a turbo-generator of 300 MW(e) output. Reactor containment is by means of a prismatic building equipped with a steel liner.

One unique feature of the SNR reactor is the shut-down process. The reactor has, in fact, two independent shut-down systems. The functions, and construction of the SNR primary and secondary shut-down systems were explained on an illustrated panel.

Another working model displayed the techniques used for measuring the flow and level of liquid sodium in the SNR reactor and also gave details relating to fuel positioning. A further illustrated panel described the hot-cells currently being built in Luxembourg for the inspection and examination of irradiated fuel assemblies.

SUPPORTING RESEARCH AND DEVELOPMENT

Panels and diagrams gave an account of the research and development work being carried out in the four countries for the fast breeder reactor program. Much of the work is devoted to the development of specific components for the SNR 300 reactor. The construction of components for the SNR 300 reactor was also described.

One exhibit in this group was devoted to a description of work relating to the development of fuel elements. The work being undertaken varies in scale and complexity from small sized basic investigations up to the irradiation testing of whole bundles of fuel pins under power reactor conditions. A panel described the irradiation of one fuel bundle to a burn-up of more than 50 000 MWd/t. This particular fuel bundle was irradiated in the Dounreay Fast Reactor, Scotland. Within the joint project itself, irradiation facilities at Mol (BR 2) and Karlsruhe (FR 2) are available for parameter tests on fuels and cladding materials, and the study of the interaction of cladding materials with fuels. A number of panels with actual test capsules were on display, and sectioned, coloured drawings gave information on irradiation loops. Other panels gave examples of the data obtained from the irradiation experiments. A dummy fuel bundle, which is identical to the actual bundle currently being irradiated in Rapsodie Fortissimo, was exhibited.

REACTOR PHYSICS

Related work in the field of reactor physics was described. Theoretical studies are supported by experiments carried out in the large fast critical facility (SNEAK) at Karlsruhe and the fast thermal facility (STEK) at Petten.

View of Debenelux Stand showing, left to right, the impeller of the 5000 m^3/h sodium pump, the liquid sodium demonstration and the model of the 300 MW(e) SNR prototype.

The President of the Conference, Mr. Glenn T. Seaborg, looking at the liquid sodium demonstration during the tour of the exhibits.

Panels described this work. The SNEAK facility is used primarily for measuring the Doppler and sodium void coefficients and the spectra of fast reactors using plutonium (fissionable material) and ^{238}U (fertile material). The exhibit showed the cross-section of the two fuel arrangements. The STEK facility is used primarily to measure the neutron cross-sections of radioactive fission products. The exhibit described the testing methods used. A further panel gave details of the Belgian standard spectrum facility.

SODIUM TECHNOLOGY

A significant fraction of the exhibit was devoted to sodium technology. Pictures gave details of corrosion, wear and mass transport in sodium loops. Details were given of both smaller experimental facilities and the following large test rigs which are either under construction or in operation:

(a) The 50 MW(th) sodium facility built at Hengelo for testing SNR components under normal reactor conditions. This facility was illustrated by means of a model. As part of this exhibit, other models gave details of the steam generator and sodium heat exchanger also being tested at Hengelo;

(b) The sodium pump test facility and the SNR vessel with rotating top shield at Bensberg. These were illustrated by means of photographs. Also on display was a pump impeller which had been tested at the Bensberg facility for 1750 h. The sodium pumps to be used with the SNR reactor have a single impeller of the centrifugal type with a diameter of 880 mm and have a capacity of 5000 m^3/h for a speed of approx. 950 rev/min and a head of 85 m;

(c) The 20 MW(th) sodium cooled reactor KNK at Karlsruhe. An aerial photograph gave a view of this reactor, which will be equipped with a fast breeder core as the second fuel charge.

(d) The 5 MW sodium test loop at Bensberg. This loop, which is used for component testing, was shown by means of a photo. Other photos of the Bensberg installations showed the facilities for testing control rods and fuel elements. These components are tested with sodium flowing around them under conditions similar to those experienced during reactor service.

SAFETY EXPERIMENTS

Several exhibits dealt with the subject of reactor safety. Information was given relating to the loss of coolant tests which are being undertaken on fuel element pins as well as a photo of the test facility for safety experiments on sodium heated generators at Bensberg.

Other work on local and gross boiling tests on sodium were described. These tests are conducted in out-of-pile loops at Karlsruhe and Petten. Three panels gave details of the super prompt critical transient tests which were successfully carried out at the 20 MW SEFOR reactor project in the USA in August 1971. This reactor has contributions from the Debenelux countries. The main task of this reactor is to determine the Doppler coefficient of reactivity up to melt-down temperatures.

LIQUID SODIUM DEMONSTRATION

A special feature of the stand was a demonstration of the properties of liquid sodium in a vessel equipped with sight glasses. On pressing a button about 10 litres of liquid sodium were pumped into the demonstration vessel which was equipped with three windows. Behind each of these windows a different property of sodium was demonstrated: The compatibility of ferrous metals with sodium was shown by means of a "sodium wheel"; the high heat transfer coefficient of sodium was demonstrated by allowing the liquid metal to cool electrically heated wires; and the low specific gravity of sodium (less than that of aluminium) was shown by means of scales.

CONTRIBUTORS TO THE DEBENELUX STAND

Gesellschaft für Kernforschung, Karlsruhe, Federal Republic of Germany;

Centre d'Etude Nucléaires, Mol, Belgium;

Reactor centrum Nederland, Petten, The Netherlands;

Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek, The Hague, The Netherlands;

Interatom, Bensberg, Federal Republic of Germany;

Belgonucléaire, Brussels, Belgium;

Neratoom, The Hague, The Netherlands;

Luxatom, Luxembourg;

Alkem, Wolfgang/Hanau, Federal Republic of Germany.

FRANCE

Stand 14

The French exhibit was essentially oriented along two lines: (a) the nuclear fuel cycle, and (b) fast reactors. The section of the exhibit dealing with the fuel cycle consisted of displays relating to the apparatus and techniques used in ore prospecting, equipment for the extraction and enrichment of uranium, chemical reprocessing of nuclear fuels and the manufacture of nuclear fuels.

ORE: PROSPECTING, MINING, CONCENTRATION

The first portion of this section was related to the techniques used for ore prospecting including foot, car-borne and aerial surveys, geophysics, etc. Many of the techniques applied are based on the detection of radioactivity and involve the use of Geiger-Müller counters or scintillation detectors, whose principles of operation are well known.

A range of electronic instruments and equipment is used, each one tailored to its own particular task. French industry, in collaboration with the Commissariat à l'énergie atomique (CEA) and working from prototypes developed and proven by the CEA, produces reliable, sensitive equipment particularly suitable for arduous field use. On display were a radiation meter, a portable scintillation counter and a prospecting probe equipped with a semiconductor Ge(Li) detector.

The French nuclear fuel cycle industry is composed of private companies which co-operate closely with the CEA. Each of the companies specializes in one or more aspects of the fuel cycle. Information was given relating to French mining activities both within France and abroad. The fuel cycle organization has access to approximately 10% of the world's known reserves of uranium and possesses facilities for the conversion of fissile materials and fuel element production. Details were given of all of these activities together with accounts of current activities. On display were several samples of uranium ores and products derived therefrom.

The exhibit as a whole was notable for its display of several massive pieces of equipment which immediately attracted the attention of a visitor. This particular section featured a large size transport container for the shipment of uranium hexafluoride.

THE PRODUCTION OF ENRICHED URANIUM

This portion of the French exhibit reflected the current interest in the topic and supplemented the French papers presented at the Conference. Traditionally, enriched uranium for military purposes was prepared in France by gaseous diffusion in the Pierrelatte isotope separation complex. Slightly enriched uranium (2 to 3.5%) for power reactors is imported, in keeping with the practice followed by other nations in continental Europe.

In view of increasing demand for slightly enriched uranium, it is estimated that by 1980-1990 a total capacity of approx. 40 million separative work units will be necessary to satisfy the requirements of the Western world. This implies that decisions regarding the means to be provided to meet European demands will have to be taken by about 1973.

In view of this, the CEA and French industry are studying a major civil isotope separation project based on experience already acquired in the gaseous diffusion process. Simultaneously research and development work is being continued on other processes, particularly the ultra centrifuge process.

Several exhibits in this section demonstrated the developmental work in progress. Gasket testing equipment was on display. This equipment will accommodate gaskets of up to 3600 mm in diameter. Also included was an impressive display of valves designed for use with uranium hexafluoride. These valves ranged in diameter from 10 to 700 mm.

Several large compressors for uranium hexafluoride are being developed in France and a large compressor stator (type UFE-G) was on display. This particular compressor stator uses a light-alloy casting. In recent years, two loops of about 800 kW rating have been developed in France. These loops have been equipped with compressors of distinctive aerodynamic designs. Tests using these loops have confirmed the assumptions used as a basis for calculation and larger 3000 kW pilot systems are scheduled for commissioning before the end of 1971. Also shown in this section of the exhibit were two spirals of leak-proof volumetric pumps (600 m^3/h and 60 m^3/h capacity,

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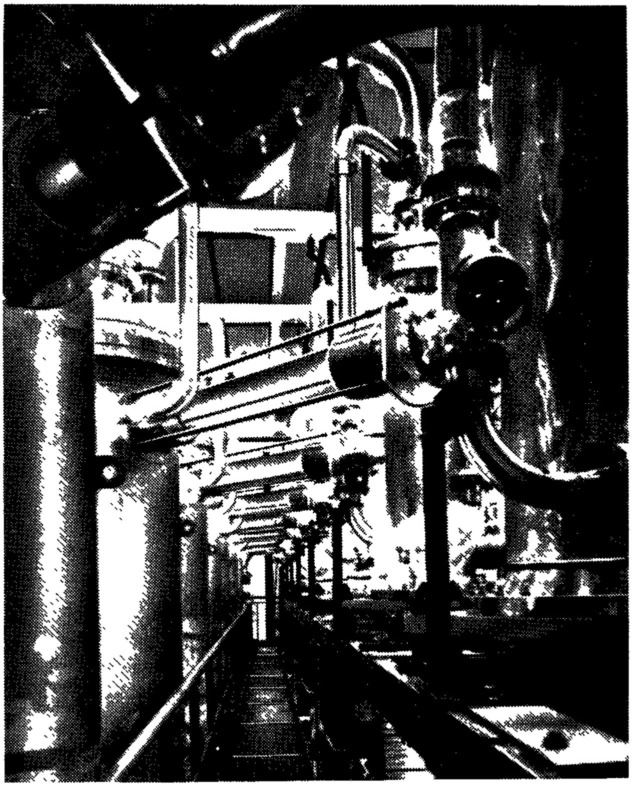
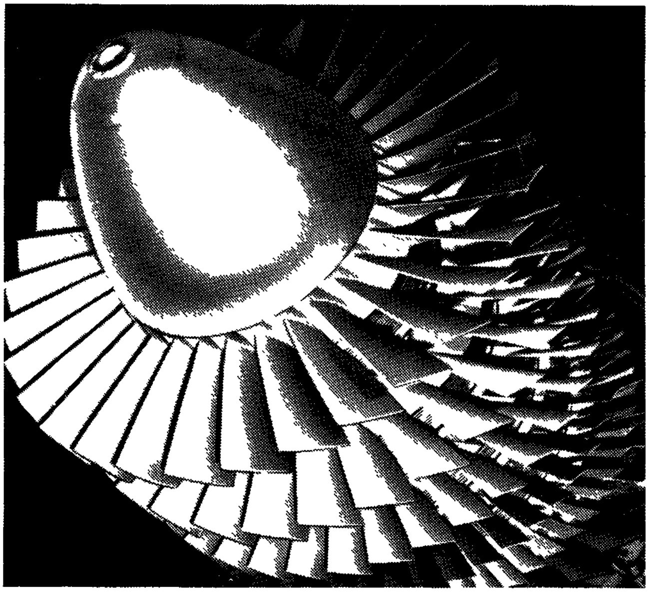


USSI Isotopic Separation Plant at Pierrelatte: UF_6 piping systems.



Large UF_6 compressor (UFE-G) rotor used with diffusion barrier systems. A two-loop pilot system, each loop of 800 kW, has been operating since 1969-70, and 3000 kW units were due for operation in 1971.

respectively) and a model of "the PP 300", a pilot plant designed for the testing of high power process stages which might be used in any large-scale gaseous diffusion isotope separation plant.

FUEL REPROCESSING

A general view was given of French capability in the area of fuel reprocessing. Wet processes are currently employed at Marcoule and La Hague. The uranium and plutonium are extracted with tributylphosphate and, at La Hague, the plutonium is purified by extraction with trilauryl-amine. Information was given relating to the dry process for fuel reprocessing developed jointly by the CEA and French industry that has now reached the pilot-plant stage. This process promises to be equally applicable to both metallic and ceramic fuels of high burn-up and short-cooling time.

The main emphasis of this section of the exhibit was on instrumentation suitable for use in fuel reprocessing plants. On display were several interesting examples of analytical instruments including an apparatus for the automatic measurement of the uranium and free acid content of solutions, and a computer-coupled nuclear spectrometer system.

The sequential solution analyser developed by the CEA uses physico-chemical analysis methods and modular concepts. The modules may be either hydraulic, electrical, optical or electronic and may be assembled according to requirements. The design described is particularly flexible and it is claimed that with the same instrumentation it is possible to determine:

(a) U(VI) in the concentration range 1 mg/l to 10 g/l;
(b) U(IV) in the concentration range 20 mg/l to 1 g/l;
(c) HNO_2 above the 5 mg/l level in solutions containing uranium and plutonium;
(d) hydrazine, iron, molybdenum, fluoride and phosphorus.

The nuclear spectrometer displayed was based on the well known CAMAC system (see Euratom report EUR 4100e). The complete system comprised a CAMAC chassis, instrumentation units including CAMAC controllers and branch drivers, special interface units, visualization units and a data processer. As signal detector, a 40 cm^3 Ge(Li) detector was used coupled to a low-noise charge sensitive pre-amplifier. For the 1.33 MeV ^{60}Co line, 2.5 keV FWHM resolution was obtained and a peak-to-Compton ratio of about 25. The efficiency obtained was about 8% (measured for a point source of ^{60}Co (1.33 MeV line) as compared with NaI(Tl) 3 in diam.×3 in (7.5 cm diam.×7.5 cm) detector and a common source-detector distance of 25 cm. The data storage-processing unit was provided with an 8K 19-bit store and programmed input/output and interrupt selectors. Data acquisition and processing programs provided for: Acquisition of data; determination of experimental parameters; testing and calibration; computing, e.g. peak abscissa (represented by brightened points in display), resolution, and peak activity with background subtraction; and data output to display (permanent spectrum display and to the printer computed results, tabulation or curve plotting).

Two related pieces of instrumentation were an instrument for measuring on-line the concentration of solutions containing fissile materials and a two

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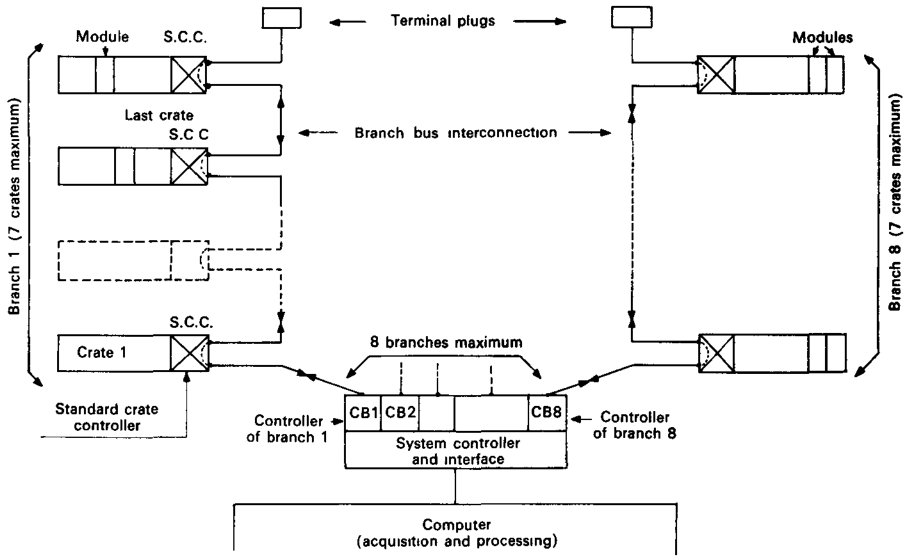


CAMAC system organization: general diagram. This is a modular instrumentation system for data handling, whose general specifications were laid down to ensure unit compatability with equipment from different manufacturers and countries.

Model of the sodium-cooled fast-neutron prototype reactor Phenix, designed for 250 MW(e) output at 563 MW(th) rating.

wave length differential photometric analyser. The on-line concentration meter utilizes a semi-conductor detector to measure the alpha emission from the sample which flows continuously through a sample cell. One wall of the cell is a thin, alpha-transparent window. The measuring head has the general form of a cylinder (70 mm diam. × 65 mm) and the chamber volume is about 1 cm^3. The detector has an effective life of more than 2 years and is suitable for operation in corrosive environments. The instrument is claimed to have a sensitivity of around 1 cycle/sec per mg(^{239}Pu)/1 and produces a signal suitable for monitoring the concentration of ^{241}Am-^{239}Pu in effluents. Both the on-line content meter and the differential photometer were developed by the CEA.

FUEL ASSEMBLIES

An interesting account was given of fuel assemblies. A model was shown of the Phenix reactor fuel assembly. This fuel element assembly has a "foot" for engagement with the sodium distributor plenum and a notched head to facilitate introduction and removal by the fuel handling grab. The fuel is comprised of 217 pins, consisting of a stack of sintered oxide pellets (UO_2-PuO_2 mixture, diameter 5.5 mm) in stainless steel cladding. The pins are assembled in clusters in a stainless steel outer shell of hexagonal cross-section which also contains the upper and lower fertile blanket pins (of depleted uranium oxide) and the upper neutron shield (the reader is referred to the paper by Dupouy et al. in Vol. 4, page 343 of these Proceedings).

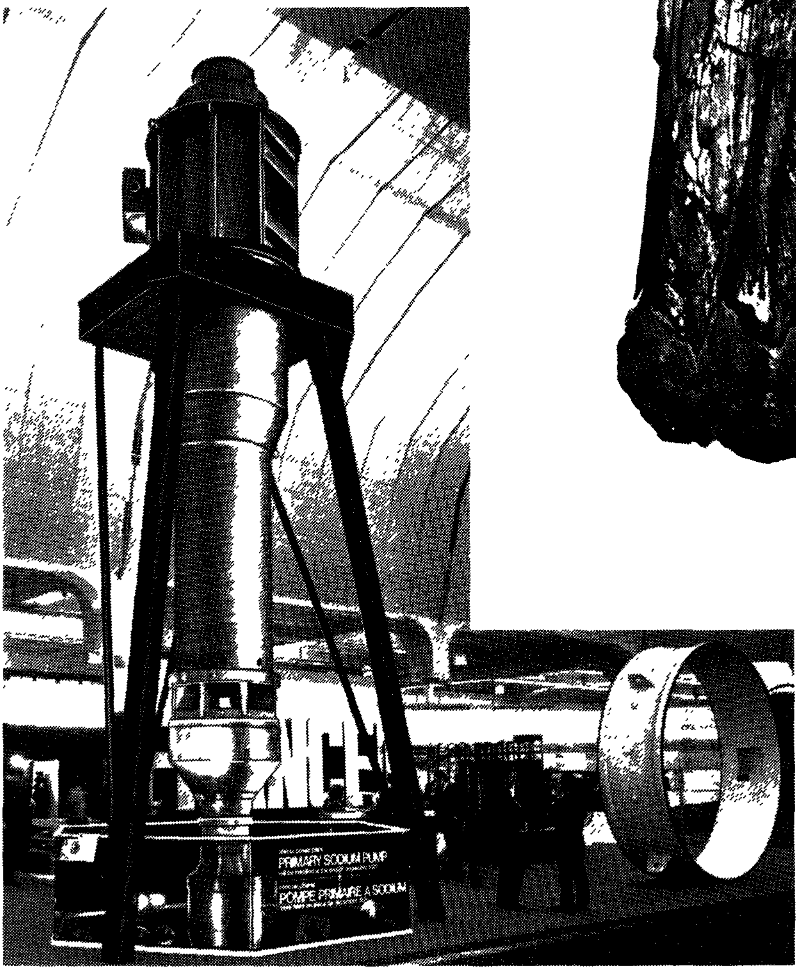
Pictures and graphical displays were given for other research and power reactor fuel elements. These included St. Laurent-des Eaux II, Bugey, EL 4, Tihange and Siloe. Several excellent fuel element models were displayed. The exhibit gave a comprehensive picture of the production of fuel elements in France, which embraces a wide variety of types. More than 3 million fuel elements have been produced to date.

The production of fuel elements requires adequate quality control and on display was an exhibit for the non-destructive inspection of stainless steel cladding tubes. This machine provided a permanent record of the tests conducted on the fuel cans and automatically sorted the cans into various grades.

CHEMICAL AND VACUUM TECHNOLOGY

A display showed a range of interchangeable valves and fittings for use in chemical and vacuum technology. The valves and fittings are constructed of polytrifluoromonochloroethylene and are designed to ensure that the working fluid is in contact solely with the resistant polymer. All the components are vacuum tight (leak rate $< 10^{-5}$ lusec) at normal operating temperature (room temperature) but may be operated at temperatures of up to 70°C subject to an accepted reduction in leak tightness. The range of components displayed included — straight and 90° valves; containers of various capacities; elbow, T and 4-way fittings; and flexible pipes. The components are particularly suitable for use with such materials as chlorine, fluorine, hydrogen fluoride and chlorine trifluoride.

RIGHT: A special feature of the exhibit was the 14th Century woodcarving of the Virgin with child which had been preserved by impregnation with monomer followed by radiation-induced polymerization.
BELOW: The largest single item exhibited at Geneva — the Phenix primary sodium pump (1 MW rating).



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FAST NEUTRON REACTORS

The other major section of the French exhibit dealt with fast reactors. Once again several massive pieces of hardware were featured.

THE PHENIX REACTOR

This reactor was described by means of a well constructed working model. Phenix is a sodium cooled fast neutron prototype reactor scheduled for service in 1973. The reactor is being built adjacent to the Marcoule establishment of the CEA about 30 km from Avignon. Mention has already been made in this narrative of the exhibits of the fuel element assemblies for this reactor. The exhibit described the reactor, its construction and purpose.

The Phenix reactor represents a logical development of the first fast neutron reactor experiment in France — Rapsodie. Rapsodie, of 40 MW thermal power, is essentially a testing facility for fast reactor fuel. Phenix represents the transition to electrical power production and has a designed output of 250 MW(e) for a rating of 563 MW(th). It is intended to provide the experience required for further development of 1000 MW(e) fast reactors.

PHENIX PRIMARY SODIUM PUMP

This item was the largest single item in the whole of the exhibition. The three primary circuit circulating pumps are variable speed units (150 to 970 rev/min) and deliver about 950 kg/s at 825 rev/min — their normal service speed. The sodium coolant enters the reactor core at about 400°C and leaves at about 560°C to six heat exchangers which are associated in pairs in three independent secondary circuits. Each primary sodium pump absorbs approximately 1 MW.

Also shown was an apparatus developed by the CEA for inspecting fillet welds. The welds are inspected ultrasonically and the apparatus is equipped with recording facilities.

NUCLEAR INSTRUMENTATION FOR THE PHENIX REACTOR

Several pieces of nuclear instrumentation for this reactor were on display. Included was an apparatus for the continuous measurement of the level of liquid sodium. The apparatus displayed is based on the variation of the mutual inductance of two coils when they are immersed in a conducting fluid such as sodium. The primary coil is excited by means of an amplitude and frequency stabilized a. c. supply. The voltage induced in the secondary coil is a linear function of the sodium level. By proper choice of excitation frequency, it is possible to compensate for variations in sodium temperature. The level probe is mounted in a pocket of stainless steel and is designed to withstand a sodium temperature of 600°C. The accuracy claimed for the gauge is ± 2% of full scale deflection.

A related display showed equipment (VISUS) for checking the position of a fuel assembly head. This apparatus provides a visual display of objects in a reactor vessel. It is designed to operate in liquid sodium and in the presence of intense neutron and gamma fluxes, and employs ultrasonic obstacle detection.

Ultrasonic wave trains are transmitted to a vertical waveguide which is filled with an auxiliary liquid possessing acoustic properties similar to those of sodium. At the lower end of the wave guide, the beam is deflected through 90° and passes out of the wave guide through an acoustic window. Echoes reflected by obstacles encountered in the scanned area are captured by an identical waveguide system which is terminated by a transducer connected to a receiver.

Movement of the scanning system is controlled and, from a knowledge of the position of the scanning unit, the intensity of the reflected signal and the time taken by the waves in transmission and reflection, the co-ordinates and shape of any obstacle encountered may be calculated. Visual display of the height and bearing of an object was provided by means of a cathode ray oscilloscope. The device displayed had a range of from 500 to 3500 mm, a vertical motion of 200 mm and a distance measuring sensitivity of ± 10 mm. Visualization is used whilst the fuel is being handled (i. e. with sodium at 250°C) but the system may remain in the Phenix reactor during normal operation of the latter.

Other instruments displayed in this section included flux measurement detectors, gamma chromatography equipment and a fast neutron spectrometer with a recoil proton proportional counter. The latter instrument is intended for spectral analysis of the fast neutrons in a reactor core with energies in the band 10 keV to 1. 4 MeV. It is suitable for plutonium fast neutron multiplying media and sub-critical assemblies possessing a multiplication coefficient of up to 0. 99. The method of data processing adopted makes it possible to attain counting rates as high as 15 000 counts/sec within the limit set by counter noise effects.

IRRADIATION FACILITIES

A large proportion of the facilities provided for research and development of fast reactors is located at the Cadarache Nuclear Research Centre. The major test facility at this centre is the fast reactor Rapsodie and this section of the French exhibit dealt with the irradiation facilities which have developed simultaneously with the use of Rapsodie.

A standard fuel assembly for Rapsodie was displayed. Rapsodie uses a mixed uranium-plutonium oxide fuel (70% UO_2-30% PuO_2), the uranium being enriched to the extent of 85%. Currently, the power level of Rapsodie is approximately 40 MW(th), the reactor core comprising three types of hexagonal fuel sub-assemblies, each of which has identical outer dimensions. A core sub-assembly is situated in the centre of the reactor and has a central region consisting of a bundle of 61 pins (length = 53. 1 cm, diameter 5. 1 mm) each pin containing a stack of 32 mixed-oxide pellets in a stainless steel sheath. The upper, neutron reflector region is simply a stainless steel rod and is provided with an axial coolant channel. The lower fertile region consists of seven pins (of 14.5 mm diam.) of natural uranium dioxide pellets in a stainless steel sheath. The full Rapsodie core comprises fuel, reflector and radial blanket sub-assemblies.

The essential tasks assigned to Rapsodie are to provide information relating to the behaviour of its own fuel and to provide a facility for the irradiation of experimental fuel pins in special irradiation assemblies. A display showed details of the main types of special irradiation facilities developed for use in Rapsodie and elsewhere.

Of the many irradiation rigs displayed, two were particularly interesting, namely the rigs "Esther" and "Banjo". "Esther" is an irradiation facility designed for conducting test irradiations of fast reactor fuel. "Banjo" is the name given to a sodium loop designed for the irradiation of fast reactor fuel elements in the Osiris research reactor. The "Banjo" loop is relatively conventional and includes a pump, heat exchanger, flow rate meter, the fuel pin, and a reduction vessel with its gas blanket. The loop will accept fuel pins of 5 to 10 mm external diameter, and the fissile length can be up to 600 mm and the total length as much as 1200 mm. This makes it possible, as an example, to study venting without reducing the "fuel" section of the pin. A total power dissipation of approximately 70 kW is possible.

An interesting model gave details of the Osiris neutron radiography system which is used for non-destructive studies of fuel irradiation capsules. The system installed in the Osiris pool type reactor has been in operation for three years. Details were given of the collimator used and the method used to exclude water from the zone subject to radiography.

A description was also given of a thermopump loop of novel design. Like the "Banjo" loop referred to above, this loop uses sodium as coolant — but a conventional electromagnetic pump is not utilized. The normal electromagnetic pump is replaced by a so-called thermal pump operating on the following principles: Electrical current is generated by a copper-constantan thermocouple, the hot source being the liquid sodium and the cold source being the coolant. The field is supplied by means of permanent magnets on either side of the sodium circuit and a driving force is produced by the interaction of field and current. The system requires no external power supply and is self-stabilizing for, as the sodium temperature rises, the pumping speed increases and the couple is more intensively cooled. The rig is claimed to have a power dissipation of from 60-70 kW. The test section is 20 mm in diameter and 1400 mm long. Sodium temperatures between 300 and 700°C can be handled and flow rates of from 2 to 6 m/sec achieved.

Two examples were given of continuous in-pile measurement technology. The first example described the continuous measurement in-pile of creep in samples subjected to either compressive or tensile stress. In this device, the specimen is surrounded by NaK and stress is provided by means of a push-tube and bellows. A highly accurate extensometer (a resonant cavity) is used which has a wide range of measurement and is capable of accommodating the displacement which occurs when load and heating are supplied. It also utilizes two independent methods of measurement thus offering the possibility of cross checks. It is claimed that this apparatus will work in a fast flux of 5×10^{14} n/cm^2 · sec (E > 1 MeV) and over the temperature range from 200 to 800°C.

The second example of "in-pile" measurement capability was a device for measuring continuously the variation in diameter of an object undergoing

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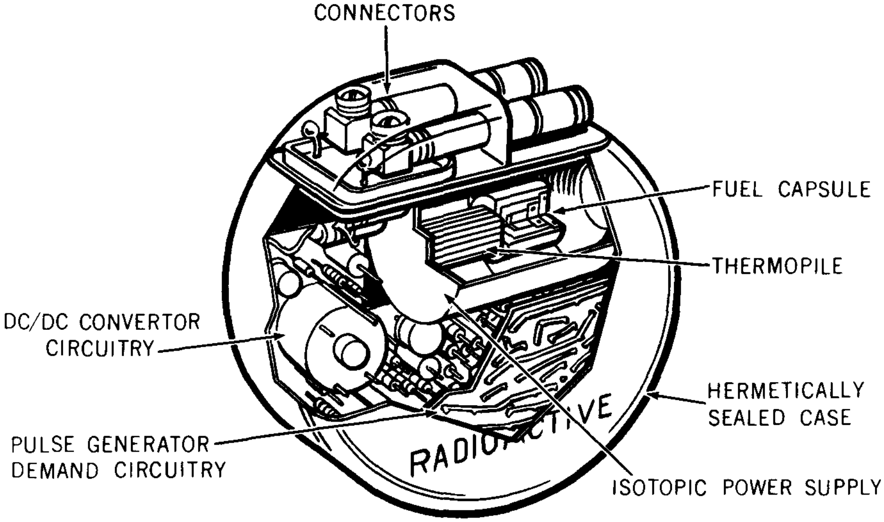

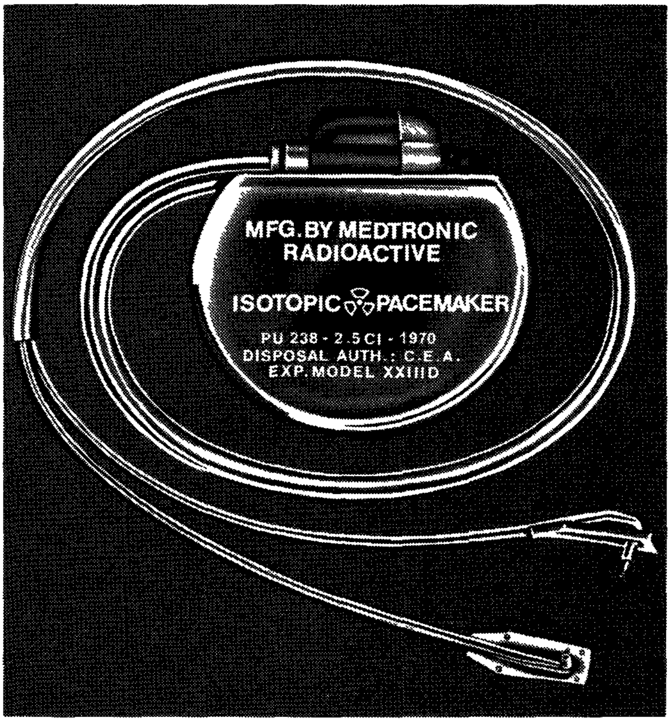

The Laurens-Alcatel nuclear-powered cardiac stimulator implant is being manufactured by Medtronic. The device will operate for at least 10 years on its loading of 150 mg of plutonium-238. The multi-layer capsule absorbs nearly all the radiation and, on the outside, radiation levels are less than those found for luminous dials of wrist watches. Such a device is inside the body of the recipient and the present system will reduce the problems of battery changing which on present devices must occur at about two-yearly intervals.

irradiation. Measurement of diameter variations is also made by means of a resonant cavity and wave guide.

The testing of reactor fuel for use in reactors usually involves the use of simulators to represent the fission heating of fuel pins. Such simulators are electrically heated and a description was given of high flux heating elements developed for use in this work. Electrically insulated wires are strung through the fuel pins and heated with single phase current. A heat flux of 300 $W \cdot cm^{-2}$ has been obtained and a maximum coolant temperature of 1000°C.

DIVERSE EXHIBITS

A further section of the French exhibit showed diverse examples of research and development activities. These included an implantable nuclear powered cardiac pacemaker. The pacemaker displayed utilizes ^{238}Pu as a heat source and is enclosed in a multi-layer capsule which, it is claimed, reduces radiation to insignificant levels. The power source and pacemaker are expected to have a useful life of at least 10 years and have already been implanted in humans. A related exhibit gave details of a heat source designed for undersea use.

The application of ionization radiation to produce wood-polymer composites was demonstrated in an unusual way. Displayed in this portion of the exhibit was a 14th century Madonna which had been preserved by impregnation with monomer followed by radiation polymerization. Though the technique leads to a significant weight increase, it is claimed that the colours remain unchanged. Other examples of the preservation of objects of art using this technique were described as well as other more conventional applications, e. g. fibre-resin composite production. An information office gave comprehensive information relating to radioisotopes and their production.

The remainder of this section of the French exhibit contained some excellent models of a sea-water desalination plant, models of the Bugey and Fessenheim nuclear power stations and the test loop at Les Renardières. The reactor at Fessenheim is of PWR type and is the first in the new French program based on light water reactors.

FRENCH-GERMAN HIGH FLUX REACTOR

The final area of the exhibit was devoted to the joint French-German project, the high flux reactor. Appropriately, this area of the exhibit linked the two national exhibits and a visitor could enter the German exhibit from the French exhibit (and vice versa) via this section.

The joint reactor project has been referred to elsewhere in the narrative. On display was a model of the core element which in fact comprises the whole core of the reactor. It comprises 9.2 kg of 93% enriched uranium deployed in the form of 280 curved plates arranged as an involuted circle. Two boron platelets are incorporated in each fuel plate and act as a burnable poison. Fuel canning material is an aluminium-iron-nickel-magnesium alloy. The 280 fuel plates are slid into parallel slots contained in two concentric tubes and comprise the whole annular fuel assembly which is finished by electron beam welding. Other features of the reactor were described.

Descriptions and exhibits displayed equipment to be used in conjunction with the high flux reactor. These included neutron guide tubes, a tritium removal system, new thermal neutron diffraction detectors (multidetectors) a hot source, a "multichopper" spectrometer and a "dancefloor" spectrometer. This latter instrument was constructed as a prototype and has been in use since July 1970. The multidetectors referred to above permit of the simultaneous analysis of neutron diffraction and inelastic scattering patterns and of better exploitation of available neutron beams.

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FEDERAL REPUBLIC OF GERMANY

Stand 13

The exhibit of the Federal Republic of Germany was designed to illustrate how nuclear energy was employed for peaceful purposes within the country. The activities shown not only dealt with the construction of large nuclear power stations using light-water reactors, the development of high-temperature reactors, fast breeders and thermonuclear reactors, but also the development of components and the entire fuel cycle. It was apparent that considerable work is being done on the development of measuring instruments for in-core instrumentation and radiation protection, and the uses of radiation sources in science, engineering and medicine were also outlined.

In addition, the exhibit drew attention to the international projects in which the Federal Republic of Germany is engaged and the visitor was referred to the work on the development of a fast breeder reactor as shown on the joint Debenelux stand. The United Kingdom, the Federal Republic of Germany and the Netherlands are participating in the development of the gas centrifuge for the enrichment of uranium. Exhibits concerning the gas centrifuge are mentioned elsewhere in this report on the scientific exhibition. The Federal Republic of Germany and France have jointly constructed the very high flux reactor at Grenoble and this bilateral co-operation was illustrated by means of a joint exhibit.

The exhibit of the Federal Republic of Germany had three main themes:

1. A report of current nuclear research and nuclear technology in the Federal Republic;
2. The trends in the development of nuclear research and nuclear technology in the Federal Republic;
3. The principles underlying German assistance to other nations in the nuclear field.

Approximately fifty items were on display.

NUCLEAR POWER STATIONS

The first group of exhibits was concerned with nuclear power stations and showed that, by 1976, 20 nuclear power stations will be operating in the Federal Republic of Germany. They will generate 10 600 MW(e), i.e. about 15% of the electricity needed in the country. Conservative estimates suggest that, by 1980, the share of power generated from nuclear sources will increase to about 33% of the total. At the turn of the century, 1200 TWh will be generated annually, being 76% of the total power, i.e. conventional primary sources of power will then only have a share amounting to approximately 24% of the total.

The items shown in this group were:

(a) A panel showing availability diagrams for German nuclear power stations;
(b) A plan showing the development of power generation in the country;
(c) A sectioned model of the Biblis Nuclear Power Station which is designed for a power output of 1150 MW(e) and will be equipped with a pressurized water reactor;
(d) A display which showed the 52 cruises made by N.S. Otto Hahn, the Federal Republic's first nuclear ship. A fuel element of its second core was on display, and data pertaining to the 1st and 2nd cores were compared;
(e) A full-scale model of a reactor coolant circulating pump to be used at the Biblis nuclear power station. Four such pumps are used each with a throughput of approximately 24 000 m^3/h of coolant water at an operating temperature of 284°C and a system pressure of 145 kg/cm^2.
(f) A model of the Brunsbüttel Nuclear Power Station. This nuclear power station is designed for a power output of 805 MW(e) and will be equipped with a boiling water reactor.
(g) A liquid scintillation test rack. This device serves for the automatic measurement of liquid scintillator samples which contain low-energy beta-emitters and alpha- or gamma-radioactive nuclides.
(h) A test stand for the simulation of pressure discharge in water-cooled reactors. The exhibit showed the test structure and the filmed pressure discharge.
(i) An exhibit showing the reactor pressure vessel with internal structures for the nuclear power station at Obrigheim. The pressure vessel for this reactor weighs approximately 218 t, has an outer diameter of 3.8 m and a total height of approximately 9.8 m. Construction took about two years.

URANIUM PROSPECTING AND THE FUEL CYCLE

The second group of exhibits dealt with the nuclear fuel cycle.

In the Federal Republic of Germany no uranium deposits have so far been found that would offer profitable mining and hence all is imported. The total demand for uranium in the Federal Republic up to 1980 will amount to some 40 000 short tons of U_3O_8. A map of the world was used to indicate where the Federal Republic is participating in prospecting in other countries. A portable radon monitor, used for long-term measurements of the concentration of ^{222}Rn decay products in the air of uranium and fluorspar mines, was on display.

Work on the separation nozzle method of ^{235}U-enrichment was described. By means of figures and diagrams descriptions were given of: a tube-shaped separation nozzle element for the enrichment of uranium-235; a technical separation nozzle stage used during performance tests on compressors; a ten-stage pilot plant to study the operation and control of separation nozzle cascades.

The Federal Republic of Germany has actively pursued work designed to use the plutonium produced in thermal reactors which contain both ^{238}U and fissile ^{235}U. The plutonium can be stockpiled until it is needed for the fast breeders. There is, however, a disadvantage in stockpiling: during storage, fairly large quantities of americium are built up, which have then to be isolated by a very costly process. In addition, storage over a prolonged period requires expensive safety precautions.

The second alternative is to recycle the plutonium into thermal reactors. By irradiating prototype elements, it was proved that such elements have a burn-up behaviour very similar to that of uranium fuel elements. Highly mechanized fabrication will therefore make it possible in the future for fuel elements containing plutonium to be profitably used in light-water reactors. The first exhibit in this group showed a number of fuel rod dummies which have proved their suitability for use in the reactor. Fuel rods of this kind are used, in particular, in the Kahl Experimental Nuclear Power Station and have displayed excellent operating behaviour. The plutonium rods for thermal reactors do not differ externally from uranium rods.

The next exhibit consisted of 11 pictures illustrating the fabrication of fuel elements.

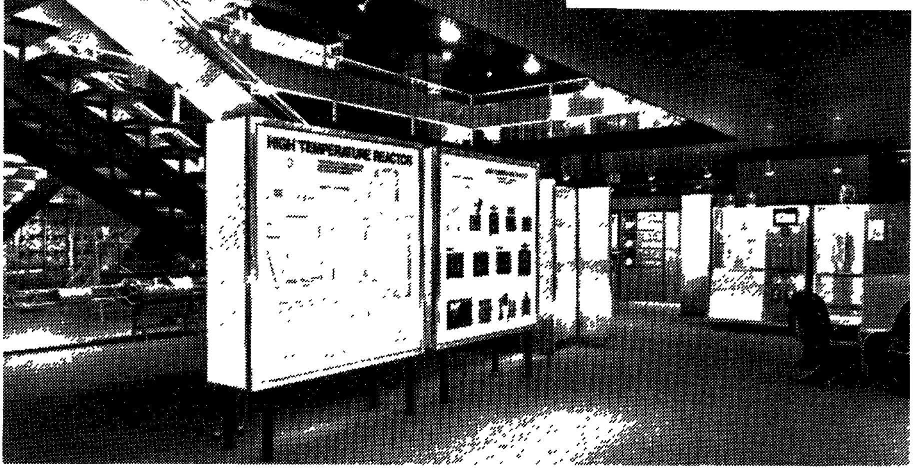
An eddy current testing device was shown which is designed as a standardized 19-inch module. A time-base oscilloscope was used for visual presentation of the results.

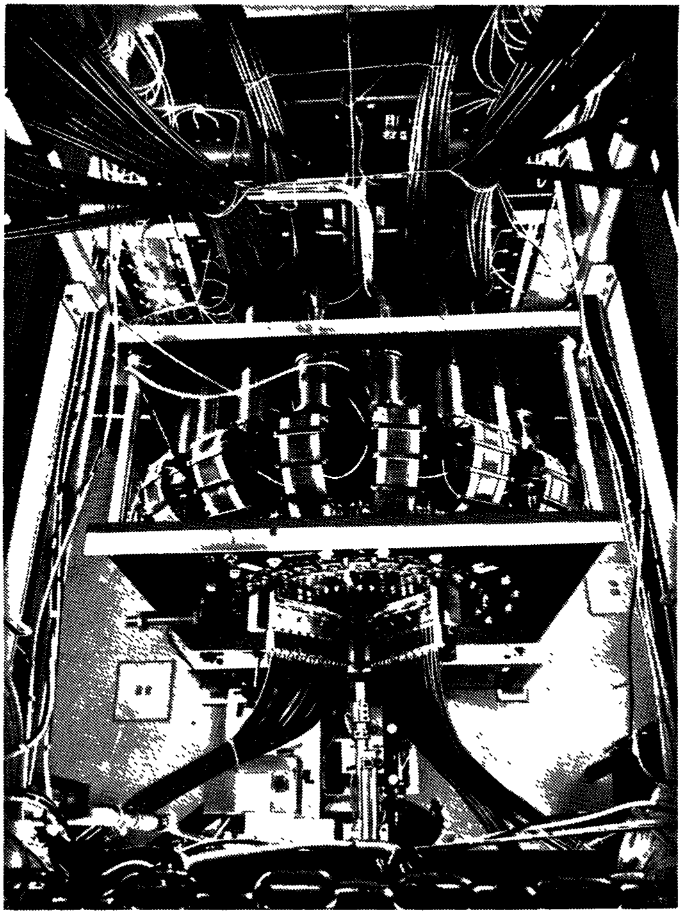
An ultrasonic rotation testing system was shown. This system is designed for testing pipes with an outside diameter in the range 5 to 35 mm.

RADIOACTIVE WASTE TREATMENT AND DISPOSAL

The development of nuclear technology is inseparably linked to the problems of treatment and removal of the radioactive wastes that are generated in practically every operation involving the processing of radioactive materials. Radioactive wastes in the Federal Republic of Germany are collected at the places of origin, concentrated in special plants, and converted into a form allowing of safe storage of the residues.

FEDERAL REPUBLIC OF GERMANY





ABOVE: A view of the Federal Republic's exhibit showing the display describing the production of the coated particles and moulding powder, and the fuel element spheres for the THTR reactor. LEFT: The "SPINNE", the toroidal theta pinch plasma device which operated throughout the period of the exhibition. Four operational configurations, θ-pinch, hexapole, screwpinch, and hexapole + screwpinch, were demonstrated, and the stability problems were explained to visitors by means of texts and photographs of the quality of the plasma confinement.

The first exhibit in this group showed the methods of treatment and removal of the main categories of radioactive waste. Also shown was a model of a test facility already under construction for the solidification of highly active waste (VERA).

A further interesting exhibit was a model of the Asse salt mine which will accommodate all the radioactive residues generated in the Federal Republic. The techniques of storage take into account the requirements of the different categories of waste.

SEPARATION OF URANIUM AND PLUTONIUM

Work on the continuous separation of U/Pu by means of counter-current ionic migration was depicted by means of a diagram of the separation apparatus. The electrolytical separation column, which is divided into chambers by nylon-gauze diaphragms, is separated from the cathode and divided into two compartments by means of a diaphragm. This diaphragm permits the electric transport of ions, but no liquid flow to occur. By suitable arrangement of the flow rates of weak acid, the complexing agent solution and the U/Pu mixture to be separated, the uranyl ions travelling into the separation column are prevented from reaching the cathode. By the proper choice of the electrolysis conditions, a steady state is soon established in which the uranium and the plutonium can be produced continuously at separate points along the column and in a pure state. The exhibit showed the qualitative distribution of the components in the steady state.

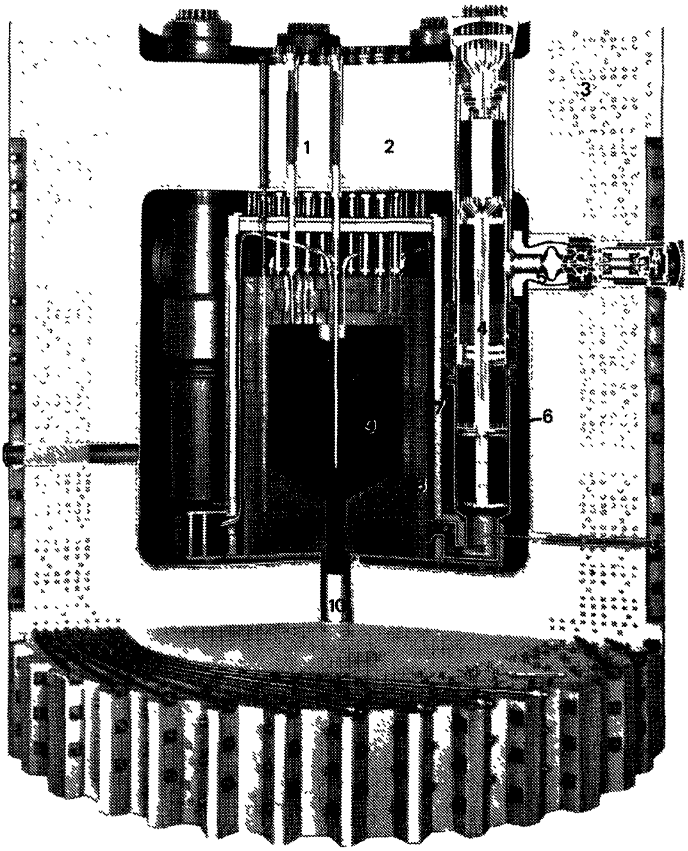
The process described also lends itself to the separation of Am/Pu mixtures, so that a simple separation of ^{241}Am formed by radioactive decay of ^{241}Pu can be achieved. Optimal throughput is claimed to be obtained with a column with 50 W/cm^3 of cooling capacity and a 1000 cm^2 cross-section, with an output of approximately 1 mole per hour in the migration direction. The exhibit simulated the separation of uranium and plutonium by means of a mixture of Ni(II) and Fe(III). With the aid of these coloured ions, the electrolytical extraction process was clearly demonstrated.

DEVELOPMENT OF REACTOR FUELS

Work on the development of fuel for high temperature gas-cooled reactors was also shown. The fuel is composed of fissile and fertile material in the form of coated particles, which include a spherical uranium/thorium or a uranium nucleus in the form of the carbide or oxide.

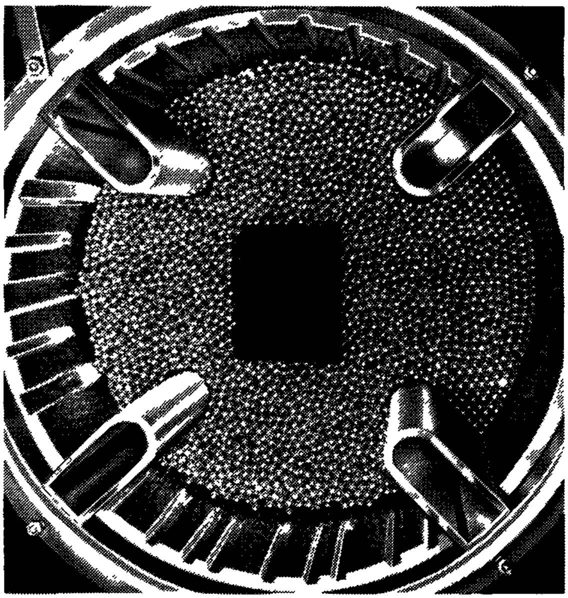
The first exhibit of this group showed a wet chemical method for the production of nuclear fuel particles which is based on the solidification of spherical droplets from a heavy-metal solution. Solidification is accomplished by a chemical reaction in the interior of the droplet, which is brought about by increasing the temperature. The heavy metal is either in the form of an aqueous colloidal suspension of uranium dioxide or a highly concentrated solution of complex stabilized uranyl nitrate. The aqueous heavy-metal suspension is dispersed by means of cooled paraffin oil which flows through a double nozzle into hot paraffin oil. The particles which solidify in the

FEDERAL REPUBLIC OF GERMANY



Model of the prestressed concrete pressure vessel of the THTR power plant.

1. Shutdown rod
2. Prestressed concrete vessel
3. Hoop reinforcement
4. Steam generator
5. Blowers
6. Thermal insulation
7. Thermal shield
8. Side reflector
9. Core
10. Sphere removal tube



The fuel element spheres of the THTR must move freely in a state of ideal disorder like the particles of a fluid. Alignments of spheres that correspond to "crystallizing" are dangerous since they inhibit free circulation. The right-hand segment of the model core shows such a situation. In order to preserve "disorder", various patterns of grooves, cut into the wall, were tested.

column are washed, dried and sintered. This process permits of the production of fuel particles with a variety of densities, porosities and diameters (in the range 100 to 1000 μm). The subsequent coating uses materials which are deposited from the gaseous phase onto the particles in fluidized beds at temperatures between 1200 and 2100°C by pyrolytic decomposition of different hydrocarbons or chloromethyl silanes. Since such coating procedures are carried out at very high temperatures and the movement of phases in the fluidized bed cannot be observed directly, the operations and different stages in the hot fluidized bed are simulated by means of transparent models.

Another model exhibited demonstrated the production of fuel elements for the thorium high temperature reactor.

A scavenging control circuit for HTR irradiation tests was demonstrated in a special exhibit. Its essential components are:

(a) A gas purification system using charcoal traps cooled by liquid nitrogen, and separation of helium and neon;
(b) A gas mixture regulation system controlled by the fuel temperature, the total throughput remaining constant;
(c) A continuous activity measuring point equipped with a Ge(Li) detector by which the activity of a particular isotope is checked;
(d) A fission gas measuring device with a Ge(Li) detector for the sporadic measurement of the fission gas spectrum. This measuring station is connected to a computer, which automatically controls the measuring operation and prints out R/B-values;
(e) A gas analysis unit to determine impurities in the gas of the scavenging system in the front and at the rear of the rig;
(f) A gas purification section for activity control before the gas is passed to the exhaust.

In the mock-up (1/6 scale) of the THTR-core shown, the loads to be considered in designing the core are directly measured. The parameters relevant for the degree of loading are varied by selecting various prototype spherical elements. Similar investigations on core models of different size will permit of extrapolation to reactor conditions.

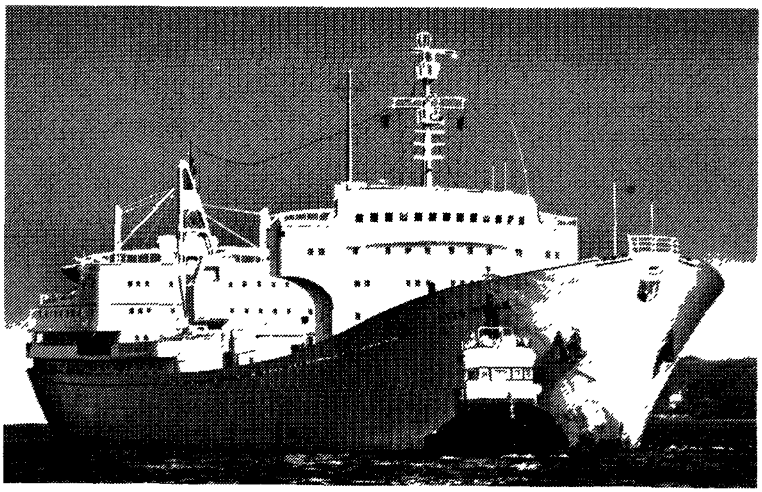
Another exhibit showed a process diagram and flow chart for reprocessing high temperature gas-cooled reactor fuel and comprised the following steps: burning of the graphite matrix and off-gas treatment; dissolution (using fluoride catalyst) of the oxide residue in nitric acid; feed adjustment with acid recycling; and TBP solvent extraction.

SAFEGUARDS

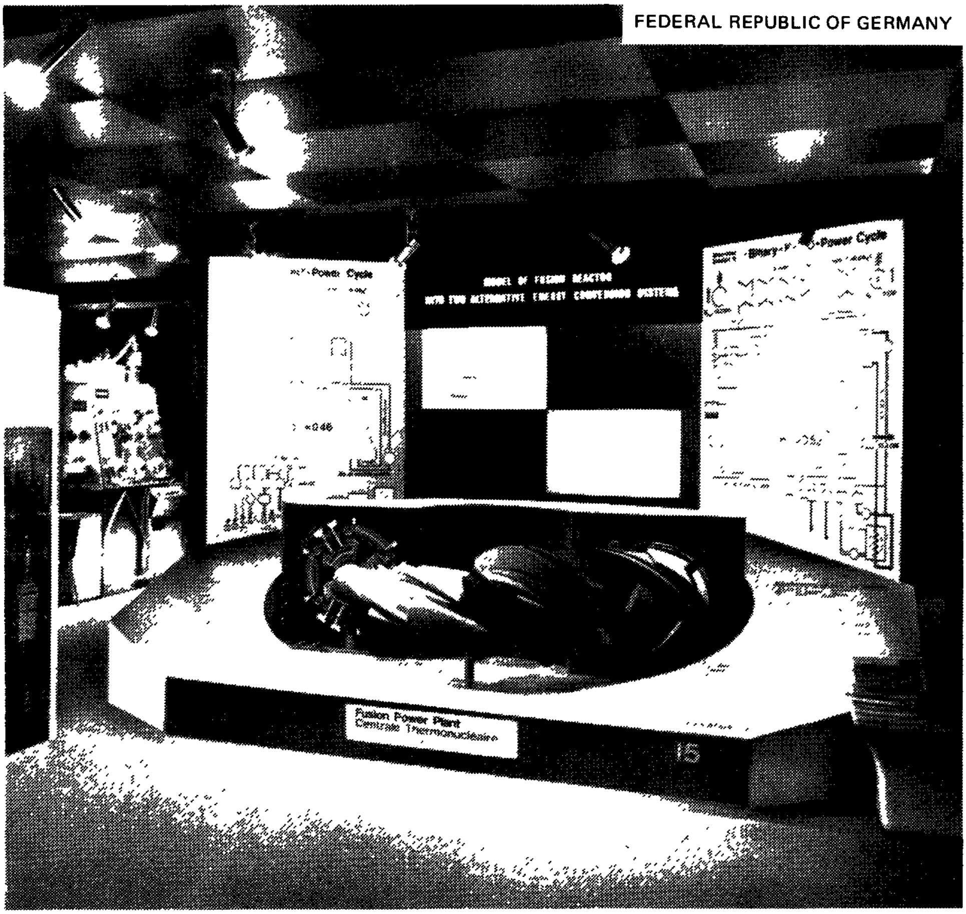
The growth of the use of nuclear energy requires that more importance be attached to the control of fissile materials. The availability of large quantities of fissile material will enhance the risk of their diversion for non-peaceful purposes. In 1967, a research and development program was started in the Federal Republic to lay the foundation for an instrumented nuclear safeguards system. The exhibits in this group demonstrated the principles of instrumented nuclear safeguards.

A first exhibit depicted the fuel cycle. A second exhibit showed the floor plan of a reprocessing plant. A further exhibit showed an automatic


MHD DIRECT ENERGY CONVERSION
TEST LOOP "ARGAS"
MHD Channel of the Argas Test Loop
Canal du générateur MHD du cycle Argas



FEDERAL REPUBLIC OF GERMANY



ABOVE (from left to right): 1. The inert gas experimental MHD duct from the ARGAS test loop at the Jülich Nuclear Research Centre. It was the largest closed-cycle MHD system in operation, and enabled MHD power generation parameters to be studied under realistic conditions; 2. Rare-gas MHD test-rig used for studies at the Max-Planck Institute for Plasma Physics at Garching. One side wall was replaced by a ground-glass screen onto which an image of a typical discharge was projected; 3. Large model of a toroidal 6 GW(e) fusion reactor as it is at present envisaged. The plasma is confined by means of a variation of the stellarator principle termed the 'Torsatron', proposed by French physicists.

LEFT: The nuclear-reactor powered ship, the NS Otto Hahn.

X-ray fluorescence spectrometer with programmed sample preparation for nuclear safeguards purposes. The automatic system consists of an automatic sample preparation stage, an automatic spectrometer, and a computer for data processing.

The last exhibit of this group was the "Gamma-lock". This device is intended to demonstrate that an unauthorized withdrawal of fissile material from reactor plants can effectively be prevented.

PLASMA PHYSICS

A further group of exhibits was devoted to an account of German work on plasmas.

The first exhibit of this group was the SPINNE toroidal theta pinch which was in operation throughout the period of the exhibition. This experimental device aims to confine a hot plasma in a torus by means of magnetic fields. Corresponding experiments have shown that the confinement time in linear geometries is limited by end losses, so that a fusion reactor would have to have a length of 1 km or more to achieve a suitable confinement time. A torus, though not subject to end losses, entails other problems that are no less serious. In a pure, smooth torus the plasma is not in equilibrium, but drifts to the outer wall in a very short time. This is due to the necessarily non-uniform magnetic field in such a torus. Theoretically, there are various possible ways of eliminating the "torus drift", e. g. by means of the so-called'M-and-S configuration', 'screw pinch' or 'stellarator' principles. The aim of the M-and-S configuration is to make the magnetic field lines in the torus of about the same length everywhere by appropriately shaping the torus surface in order to equalize the magnetic field strength, thus eliminating torus drift. The screw pinch principle utilizes the fact that opposite currents repel one another, and maintains the plasma in equilibrium by inducing electric currents in the plasma all the way round the torus. Finally, the stellarator uses currents in supplementary wires wound around the torus or a suitably shaped coil surface to vary the torus' magnetic field in such a way as to produce an equilibrium configuration. THE SPINNE device has previously been used to conduct studies of the said magnetic field configurations, but so far no geometry has been found which would clearly permit the construction of a fusion reactor. At present the SPINNE can be operated in the following configurations: a toroidal theta pinch without any supplementary fields — the plasma is not in equilibrium, but drifts to the outer wall in about 1 μsec; a toroidal theta pinch with superposed, non-helical hexapole field — the plasma is in equilibrium, but can reach the wall of the vessel along the magnetic field lines in a relatively short time; a screw pinch (= toroidal theta pinch + toroidal Z-pinch) — the plasma is in equilibrium, but becomes unstable after a time, and reaches the vessel wall; a screw pinch with a superposed non-helical hexapole field — the plasma is in equilibrium, and the screw pinch instabilities are suppressed by the hexapole field.

The next exhibit of this group showed a vacuum-tank and the coil system of an experiment which had been set up to study the equilibrium and stability properties of axially symmetric toroidal plasmas at high temperatures.

Another exhibit showed the MHD test rig at Garching full-size. A portion of the picture containing the generator duct had been replaced by the original duct and a side wall was removed to expose the interior of the duct, which had been provided with a ground-glass screen onto which a film of the discharge in an MHD duct could be projected.

A small exhibit showed an experiment on dynamic stabilization. High frequencies are used to prevent liquid with a given viscosity from escaping from an inverted beaker.

A large model of a fusion reactor was displayed in the next exhibit. The model shown represented a toroidal fusion reactor of a design realizable at the present time.

The last exhibit of this group was the original ARGAS MHD generator channel. It consists of 98 pairs of molybdenum electrodes and insulators made from ultrapure and temperature-shock-proof alumina. The inner cross-section of 8 cm × 8 cm is designed for an energy flux of 4 MW.

NUCLEAR MEDICINE

The first exhibit of a group devoted to nuclear medicine showed a spongiograph. The early diagnosis of osteoporosis and other diseases of the skeleton is still a matter of great difficulty: both radiological methods and other techniques of measuring radiation absorption in the extremities have proved unsatisfactory. An advance in this direction is a profile scanner, using a ^{125}Sb radiation source, for measuring the radiation absorbed by a finger bone; the device, which includes a new method of evaluation, was shown.

The next exhibit of this group dealt with the determination of blood volume. Examinations using radionuclides have already become an integral part of routine clinical treatment. The exhibit showed an apparatus for the semi-automatic determination of blood volume. This can be carried out either with erythrocytes labelled with ^{51}Cr or with human albumin labelled with ^{131}I. The apparatus, with 'peripheral' computer, can also be used for other measurements in nuclear medicine, as for example the T_3 test, the T_4 test, the Schilling test, and the determination of the liver function and the life-time of erythrocytes.

A $^{14}CO_2$ exhalation measuring instrument was shown which continuously analyses $^{14}CO_2$. It is suitable for respiration studies in human and veterinary medicine and for biological research.

The last exhibit of this group demonstrated equipment for radiation protection measurements and showed various designs of large-area proportional counters.

FOOD AND AGRICULTURE

The majority of the world's population draw two-thirds or more of their protein supply from plant sources. However, these food plants have a low protein content and lack certain essential amino acids, a deficiency which make them unsuitable as the main source of nutrition. The aims of raising the content of protein and improving its quality in useful plants are, therefore, of the greatest importance, particularly for developing countries.

The induction of new gene combinations through treatment with ionizing radiation or chemical mutagens has proved an excellent method of improving the quality, and increasing the quantity, of protein in useful plants (e.g. corn, rice, millet, wheat, soya beans). The first exhibit of this group showed work on barley. Both untreated plants and irradiated plants were shown. It was clear that, as a result of irradiation, one characteristic (the shape of the ears) has been visibly modified.

The next exhibit of this group showed apparatus for the determination of soil humidity. It combines a classical technique with a nuclear method.

Another exhibit showed a model food irradiation plant on board ship intended to preserve a catch of fish. A radiation dose of 100 krad used directly after the catch will preserve fish kept on ice in perfect condition for 10 to 15 days longer than was previously possible.

TRANSPORT PROCESSES IN OCEANS AND LAKES

An interesting group of exhibits dealt with the subject of environmental pollution.

One exhibit showed a method for examining transport processes based on tritium and ^{14}C. In addition, measuring instruments were displayed which can be used for demonstrations.

Another exhibit showed the principle of determining mean depth, a parameter important in sand migration studies. With a multichannel analyser, the spectrum of undisturbed activity (plane source) is recorded and plotted, followed by the spectrum of disturbed activity. At the same time, the counting rate in both areas is ascertained using digital counting. By means of a calibration plot the thickness of a buried layer of sand can be ascertained.

INTERNATIONAL COOPERATION

Assistance by the Federal Republic of Germany to other countries interested in developing some aspect of nuclear technology was shown in a special exhibit. This aimed to present an idea of the time that elapses from the first contacts between two countries to the point at which industrial projects amenable to collaborative solution are put in hand.

In general, first contacts are established directly between scientists at conferences or by visiting delegates. This is followed by an exchange of guest scientists and the granting of fellowships. In those cases requiring a specific state of knowledge in the partner country, official contacts at government level may be established and a basic agreement on collaboration in research and development may be concluded in addition to any exchange of knowledge and personnel. Such agreements have already been signed with Argentina, Chile, and Spain. Negotiations with other countries are being pursued.

These basic agreements constitute the foundation of individual agreements concluded in the field of nuclear research between the German nuclear research centres and the atomic energy commission in the partner country. The individual agreements cover not only the exchange of personnel and information but also the execution of joint projects, which have the purpose of promoting basic research in and industrial application of nuclear technology. On the basis of such individual agreements a number of joint projects have been embarked upon, e. g. a large multi-purpose sodium loop, the irradiation of test fuel elements and the development of structural materials for advanced reactors.

The long-term objective of this collaboration is not only to gain the ability to participate in large-scale international projects, but also to establish an independent nuclear industry. This will benefit both countries in the long-term by helping to raise the standards of living.

BASIC RESEARCH

The first exhibit of this group showed a cold neutron source with various arrangements for scattering-experiments. The exhibit showed the end of a beam tube where the cold source, one-litre of liquid hydrogen, is mounted. The cold source is cooled by helium at 14°K, where, due to nuclear heating and line losses, a cooling capacity of 1 kW is required.

A view of cold neutron source, refrigerator and neutron beam tunnelling through guide tubes, together with the installed spectrometers (1/50 scale), was shown. All experiments can be carried out simultaneously. For two experiments, a time-of-flight spectrometry and the high-velocity Doppler drive system, transit time dispersion is used for neutron energy analysis. The underlying principles of their functions were demonstrated with an optical analog read-out. The energy resolution of the individual instruments is very different. Maximum resolution is obtained with a back-scattering spectrometer with 4×10^{-4} meV. Silicon crystals with a Bragg angle of 90° are used as analysers. The high-speed Doppler drive exhibited (having a maximum speed of 15 m/sec) operates equally well with backward reflection. The special design ensures, over the entire crystal, an equal instantaneous velocity each time.

The second exhibit of this group simulated an experiment in which the reactor beam is no longer pulsed periodically, as has been the custom hitherto, but modulated pseudostatically with the aid of a neutron chopper. This technique makes it possible to raise the utilization time to 50%. The pseudostatistic time-of-flight method shown for scattering experiments with slow neutrons made it possible, in some instances, to reduce the measuring time by a factor of more than 20 as compared with the conventional time-of-flight method.

PUBLIC INFORMATION

In addition to the exhibits a large-scale projection system gave visitors a cross-section of all activities in the field of nuclear research and technology in the Federal Republic of Germany. A special section within the stand showed all publications relating to nuclear research and technology published in the Federal Republic of Germany within the last five years.

Two books were published especially for the 4th International Conference on the Peaceful Uses of Atomic Energy, viz. Nuclear Power Today and Tomorrow by Robert Gerwin (dva Stuttgart), and Nuclear Education and Training in the Federal Republic of Germany, compiled by Alfred Rottler and Kurt Hogrebe (Federal Ministry for Education and Science).

The first book (available in English, French and German) covers aspects of nuclear technology of interest in developing countries.

INDIA

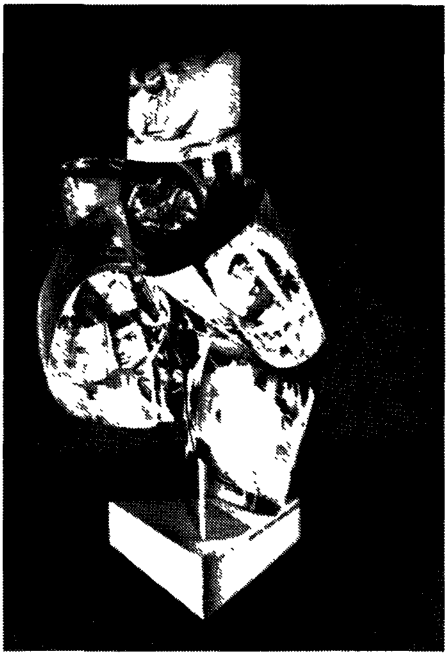
Stand 8

The problem of mounting a representative exhibit in a far-distant country was solved by India in an attractive, imaginative but inexpensive way. On a built-in screen 21 m long and 3 m wide, an audio-visual display was presented. The presentation showed how "Shiva and Shakti" — knowledge and power — are synthesized by atomic energy in India. A battery of projectors linked to music and commentary colourfully brought to the screen the dance of creation; the twelfth century idol of Lord Nataraja used is from the National Museum at New Delhi. On the same multi-image screen appeared juxtaposed several pictures of research and power reactors, applications of atomic energy in different fields, and views of the Bhabha Atomic Research Centre and other places in India where research and developmental work are being pursued. The visitor was kept entranced for some five minutes by this synthesis of mythology and modern technology.

In addition, four main themes of interest for India were additionally represented: Atoms for Power, Atoms for Health, Atoms for Food and Atoms for Industry.

ATOMS FOR POWER

This section illustrated the role of power, more specifically of nuclear power, in India's development. A 20 ft (6 m) high photo-sculpture laid stress on the fact that production of more power would create more jobs,



ABOVE: Interior of the Indian pavilion
RIGHT: One of the interesting graphic displays showing applications of atomic energy.

increase productivity and thereby stimulate national prosperity. A graph linking per capita national income with per capita energy consumption emphasized the fact that energy is the sine qua non of development. The anticipated growth of power in India during the three decades up to 2000 AD was shown on a chart which illustrated how nuclear power was expected to play an increasing role in India's power development program. An animated panel demonstrated the comparative costs of power production between coal-fired and nuclear power stations. In particular in India, large regions of the country are more than 500 km away from coal fields. These regions constitute 35% of the country by area and 30% by population. With the exception of the eastern zone, they include the principal communities engaged in activities needing energy in rapidly increasing quantities for industry and agriculture. The transport of coal to these areas involves major investments in the transport system. Pictures of the already operational Tarapur Atomic Power Station and the power stations under construction at Rajasthan and Madras were displayed.

The program for the utilization of thorium in future power stations and the setting up of a Fast Breeder Test Reactor and a Reactor Research Centre were explained with the aid of charts and texts.

ATOMS FOR HEALTH

The impact of nuclear medicine in the diagnosis and the treatment of different diseases, on which work is now being carried out by the Radiation Medicine Centre of the Department of Atomic Energy in Bombay, was demonstrated by giving details of typical diseased organs with the corresponding data-scans appearing on an adjoining screen. Samples of radiopharmaceuticals manufactured by the Isotope Division of the Bhabha Atomic Research Centre were displayed.

ATOMS FOR FOOD

In this section, the development of promising radiation preservation procedures for perishable foods tuffs was illustrated by means of samples of irradiated and unirradiated fresh foods. Disinfestation of wheat by irradiation and the development of new mutants of the groundnut evolved at the Bhabha Atomic Research Centre were on display. These, together with slides, underscored the mammoth problem of nourishing a population already over 550 million.

A good example of the role that nuclear power can play is related to a study that has been carried out on the feasibility of setting up an agro-industrial complex in the western Uttar Pradesh region of northern India, which has a population of 24 million. The studies revealed that a return of 54% can be achieved on an incremental investment of approximately 110 million Rupees with 1200 MW(e) of nuclear power supplying energy for 25 800 additional tubewells, and simultaneously producing phosphate fertilizers using an electrolytic process. The program would generate year-round direct employment on farms for 1.4 million persons, resulting in an additional agricultural production of 9.4 million tonnes of food grains, 1.8 million tonnes of potatoes and 11.2 million tonnes of sugar-cane. An artist's impression of the proposed complex was displayed.

ATOMS FOR INDUSTRY

The infra-structure of industrial growth in the self-supporting program of atomic energy in India was represented by a selection of nuclear electronic instruments produced and marketed by the Electronic Corporation of India, a public sector undertaking of the Government of India. Pictures showed the control consoles manufactured by the corporation for power plants.

A panel on the outer wall of the pavilion showed a cross-section of the facilities set up during the last two decades and the programs envisaged for the future.

The keynote of the pavilion was on the relevance of the development of atomic energy for peaceful applications in India and the major programs and activities that are currently under way. Broadly these are: construction of nuclear power stations of a total of 2700 MW(e) during the current decade; design and construction of advanced thermal reactors of about 500 MW(e) unit size; completion of a fast breeder test reactor; increased heavy water production to about 400 t per year to back up the program for the use of natural uranium in Indian power reactors; design and construction of a large 500 MW(e) prototype fast breeder test reactor; development of gas centrifuge technology for ^{235}U isotope enrichment; development of the Narwapahar Uranium Mines; completion and development of the Nuclear Fuel Complex at Hyderabad; creation of adequate facilities for reprocessing of irradiated fuel and recovery of essential by-products; and a more widespread application of isotopes in industrial processing, food preservation, medicine, research and the sterilization of medical products.

ITALY

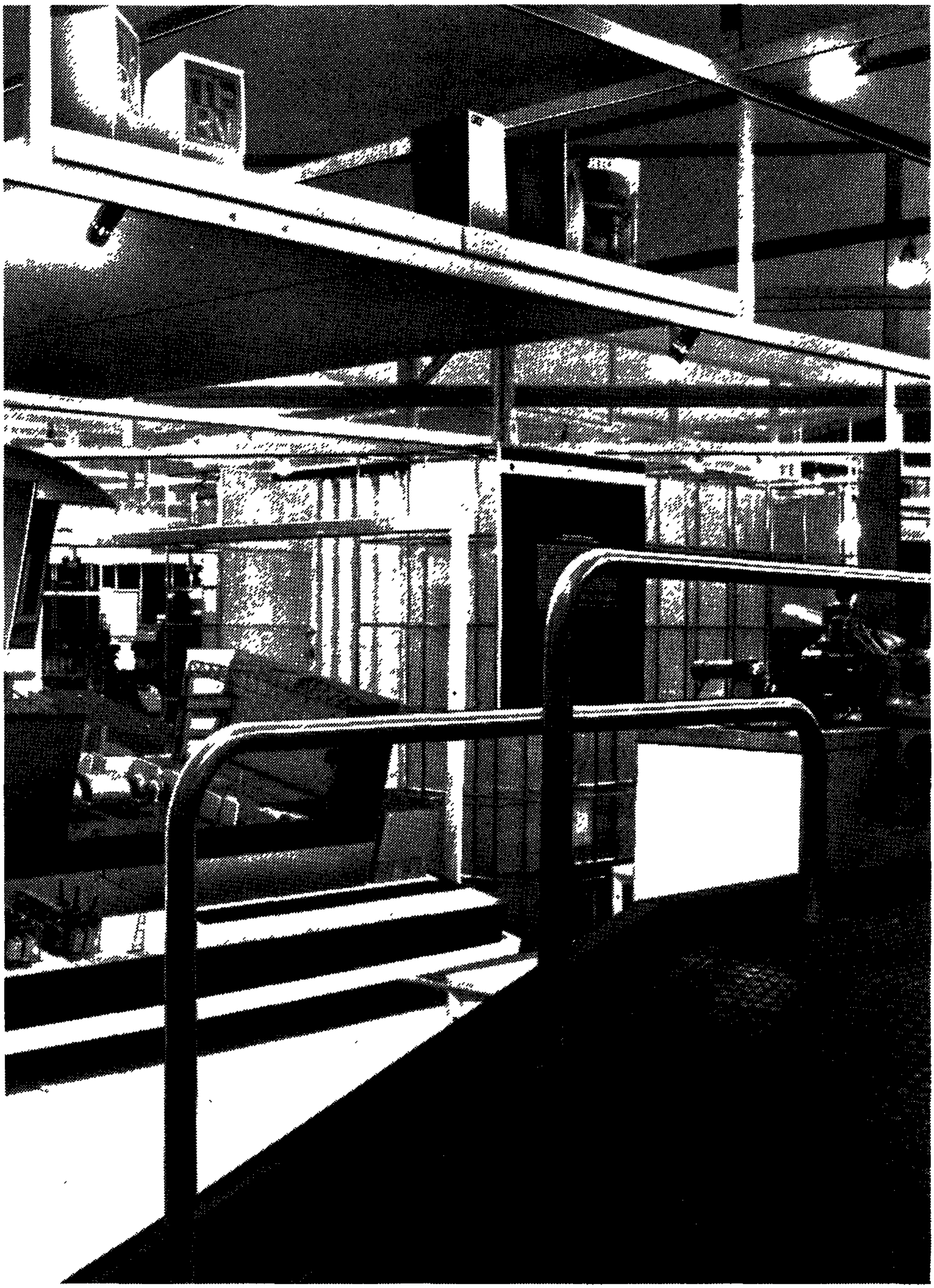
Stand 9

The exhibit summarized the recent major nuclear activities carried out in Italy by the Government's Comitato Nazionale per l'Energia Nucleare (CNEN) and by the main Italian industries operating in the field.

The exhibit showed clearly that Italy is expanding its activities in research and development, and in the industrial production of nuclear energy. It was laid out in such a way as to present to the visitor, in turn, the various sectors into which activities in the nuclear field may be divided. It high-lighted the nation's effort and the achievements in: prospecting for uranium; uranium enrichment; construction of established reactors; research and development on advanced-type reactors; special purpose reactors; irradiated fuel reprocessing; development of instrumentation and special technologies; and basic research.

The material was exhibited in such a way as to form a kind of "frozen picture" to a visitor passing through the exhibit along a route indicated by four raised platforms. Visitors had a number of subsidiary routes available to them where they could stop and look at individual exhibits and examine them in detail.

ITALY



The Italian pavilion showing some of the impressive models

THE EXHIBIT

In the field of uranium prospecting, which formed the first section of the stand, prospecting already carried out had shown that it was unrealistic to expect to find a sufficient amount of uranium in Italy to cover its needs. These activities have, therefore, been developed outside Italy as well. Searches for deposits within the country continue, with the aim of meeting part of the demand and of locating resources for special situations. Activities outside the country were illustrated on a planisphere, whilst a geological map showed the main deposits identified in Italy. These were also represented by models of the areas and by samples of the ores.

Work on uranium enrichment is coordinated by an organization involving all the industries concerned, together with the CNEN. Research is carried out on both the gaseous diffusion and the ultracentrifuge processes. Some of the more interesting components employed were exhibited in the Pavilion. The exhibits of barrier materials and glass-fibre reinforced centrifuge rotors attracted considerable attention.

For several years now Italy has had three power reactors in operation. These are of the gas-cooled graphite-moderated, pressurized water and boiling water types and have a total rating of 615 MW(e). A fourth plant was ordered in 1969 (BWR/800 MW(e)) to be built by Italian industry. This plant was illustrated by means of a model and large detailed diagrams.

Illustrations of the activities involving the production of fuels for the three nuclear power plants already in operation were given. An important part of the information displayed in the exhibit was related to the design and construction of power stations, their components and the fuel elements used. One particular section was devoted to the production of special steels needed in nuclear plant construction. Two other sections concerned the construction of pressure vessels for power stations and internal mechanical components, fields in which Italian industry has achieved a marked success in foreign as well as local markets.

Also displayed were research and development activities on advanced converter reactors (heavy water and high-temperature gas-cooled) and fast reactors. Activities in the heavy water reactor field are co-ordinated under a special program (CIRENE), a joint enterprise carried out by the CNEN and the Ente Nazionale per l'Energia Elettrica (ENEN), with the partnership of the Italian nuclear industries. Research on fluid dynamics, neutronics, fuel element development and the development of various other components was illustrated.

High temperature gas-cooled reactor development is being pursued within a framework of international collaboration.

As far as fast reactors are concerned, the most important aspect is the construction of a fuel element testing (PEC) reactor. For that purpose, an industrial consortium has been formed, with the participation of Italian public industries. Models of the PEC reactor and of its fuel elements were exhibited. The apparatus, installations and instrumentation developed in the course of research on fast reactors were presented.

Illustrations were also given of research and construction work in the marine propulsion sector for the Italian nuclear ship "Enrico Fermi". A bundle of fuel elements for a reactor to be used for naval propulsion was shown and reactor control structures could also be seen in an illustration.

An industrial consortium formed in Italy is now engaged on the ROVI project, a water desalting project. A ROVI reactor has been designed to drive a sea-water distillation plant. The organic-moderated reactor illustrated was developed under this project.

Italian activities in the field of reprocessing of irradiated fuels comprise research and the operation of two pilot plants, EUREX-1 and ITREC, and an industrial plant, EUREX-2, which is at the design stage. The pilot plants were illustrated, as were also the major achievements of the research conducted to date. In particular, plant control and the use of new solvents developed by the CNEN were displayed.

Progress in the use of the atom for development calls for corresponding progress in instrumentation and other advanced technologies likely to find important applications outside as well as within the nuclear field. Certain examples of these were shown: a servomanipulator named MASCOT-III for operations in enclosures inaccessible to man (e. g. hot cells); the development, from nuclear instrumentation, of a small-sized computer with related control apparatus for hospital use; semi-conductors; microwelding; advanced ceramic techniques; atomic absorption analysis; systems engineering (statistical processing of random signals); a gel precipitation method for the production of dense ceramic elements; and a method of control for steel pressing.

Finally a description was given of Italy's major achievements in the field of basic research. A 1500 MeV accelerator (ADONE) designed by Italian physicists and built by Italian industry was illustrated, together with interesting examples of special applications emerging from this fundamental research, which may be useful in many conventional industrial sectors. Thus, mention was made of a highly compact electron accelerator (MICROTRONE) developed in Italy, an apparatus for neutronic event recording, research on superconduction, the application of explosives to the plastic deformation of metals, and studies of high-intensity magnetic fields — used in the plasma research program.

CONTRIBUTORS TO THE ITALIAN STAND

Breda Termomeccanica, Milan;

Comitato Nazionale per l'Energia Nucleare (CNEN), Rome;

COGNE, Turin;

Ente Nazionale per l'Energia Elettrica (ENEL), Rome;

Ente Nazionale Idrocarburi (ENI), Rome;

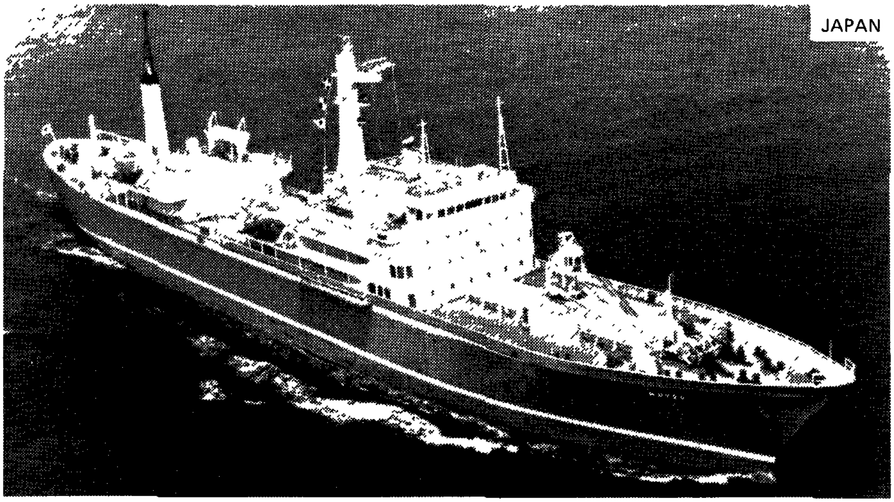
FIAT, Turin;

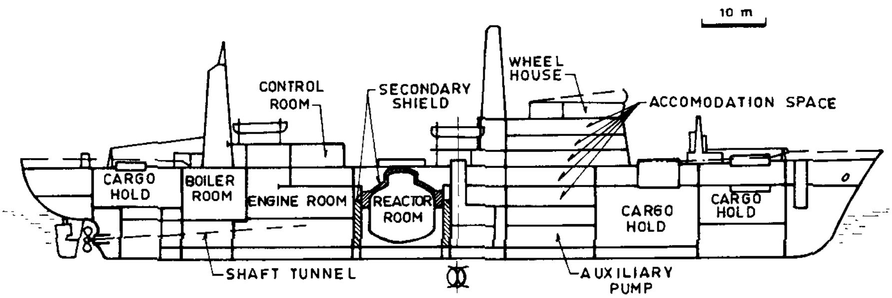
IRI-FINMECCANICA, Rome;

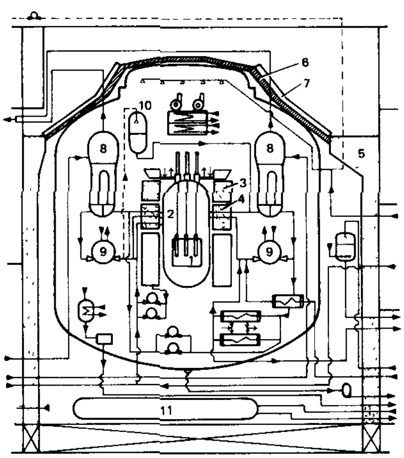
Montecatini-Edison Elettronica, Milan;

SNIA Viscosa, Milan;

TERNI, Terni and Rome.







The NS Mutsu.

TOP: The hull under trial propelled by an auxiliary boiler.

CENTRE: Position of the reactor room in the hull.

LEFT: The steam-generating nuclear reactor and the reactor room.

1. Reactor core;
2. Pressure vessel;
3. Upper shield;
4. Intermediate shield;
5. Secondary shield (concrete);
6. Secondary shield (lead);
7. Sec. shield (polyethylene);
8. Steam generators;
9. Main coolant pumps;
10. Pressurizers;
11. Medium level waste tank

JAPAN

Stand 15

The Japanese exhibit was arranged so as to present an overall view of the development of nuclear science and technology in Japan. The stand was divided into five main sections and, in view of the distance between Japan and Geneva, relied heavily on photographs. On entering the exhibit visitors received a small brochure which indicated a logical inspection order and directed them to the first section of the exhibit. A Japanese atmosphere was given by the decor and the background of Koto music.

The first section, which served as an introduction to the whole exhibit, showed how Japan was fast becoming an urbanized society requiring, in consequence, large quantities of industrial power. Attractive panels showed pictures of the five newly completed nuclear power plants and underlined the necessity for further nuclear development. Further panels displayed the seven nuclear power plants under construction and drew attention to the way in which the safety of these plants is ensured and the quality of the environment preserved. Excluding some aspects of the production of nuclear fuels, more than 90% of the nuclear equipment of the power stations under construction is being supplied by domestic industry. Of particular interest was the description of the new PNC process for the production of uranium tetrafluoride directly from concentrate, thus eliminating the necessity to make yellow cake.

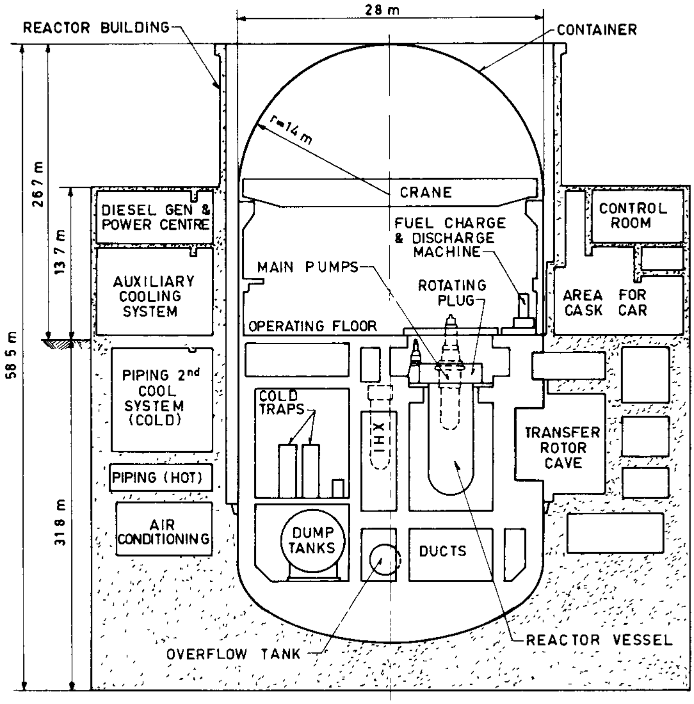
The second section of the exhibit gave a view of power reactors and nuclear fuels in Japan. After a description of the basic policy and development program, a further panel showed the developmental facilities. Pictures gave a good view of the Japan Materials Testing Reactor and the Fast Critical Assembly. A further series of photographs showed the work on sodium and described the sodium-flow test facility, the sodium component test facility and sodium technology test facility. At all of these facilities, extensive research and development work in connection with fast reactors is under way. Also displayed were the modern hot cells which have been constructed to enable post-irradiation examination of components and fuels to be made.

An interesting feature of this second section was a description of the experimental fast reactor "JOYO", and an account of the names used for new types of reactors. An artist's impression was given of the prototype heavy water reactor "FUGEN".

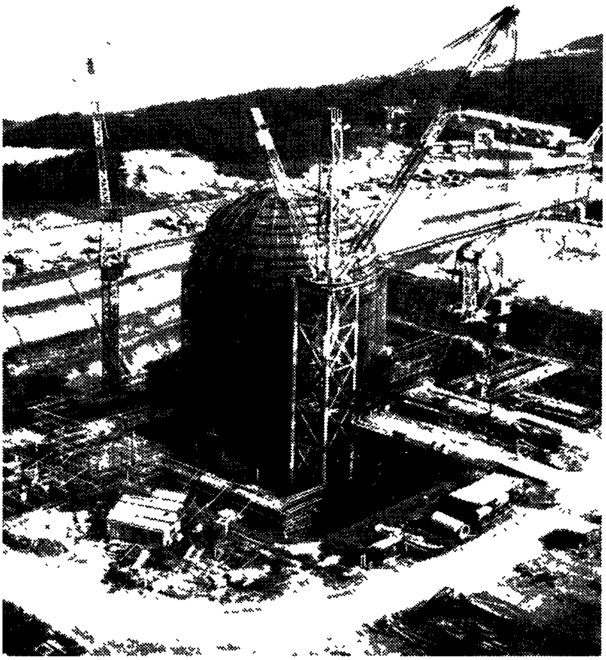
Further evidence of the scale of engineering development in Japan was provided in a series of photographs showing the full-scale safety experimental facility which was described in a paper presented at Conference, the component test loop, the heat transfer test loop and the deuterium critical assembly.

Other panels gave an account of Japanese work on nuclear fusion, nuclear fuels manufacture, inspection analysis, the development of plutonium fuels, fuel assembly and fuel reprocessing.

Among the prominent features of the second section of the exhibit was the "JOYO" experimental fast reactor which has developed from a preliminary design study carried out in 1964 and 1965. It utilizes liquid sodium as coolant and mixed oxide as fuel. As refined and developed,

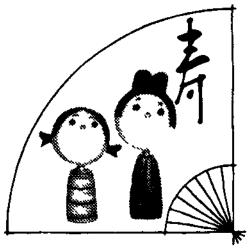


Vertical cross-section of JOYO reactor building. Experience needed for constructing the Prototype Fast Reactor MONJU will be obtained on the JOYO sodium-cooled fast reactor. It is rated initially at 50 MW(th).



JOYO under construction on the site of the O-arai Engineering Centre in Ibaraki-ken.

JAPAN



this reactor will develop, initially, 50 MW(th) (ultimately 100 MW(th)) and has a blanket fuel region using depleted uranium surrounding the inner core, the reflector region and the six boron carbide control rods. The reactor is designed to be as simple and rigid as possible. The sodium outlet temperature will be 435°C for 50 MW(th) output. The prototype reactor features a double rotating plug system for fuel handling, a loop for the reactor proper: it can also be used as a fuel test facility.

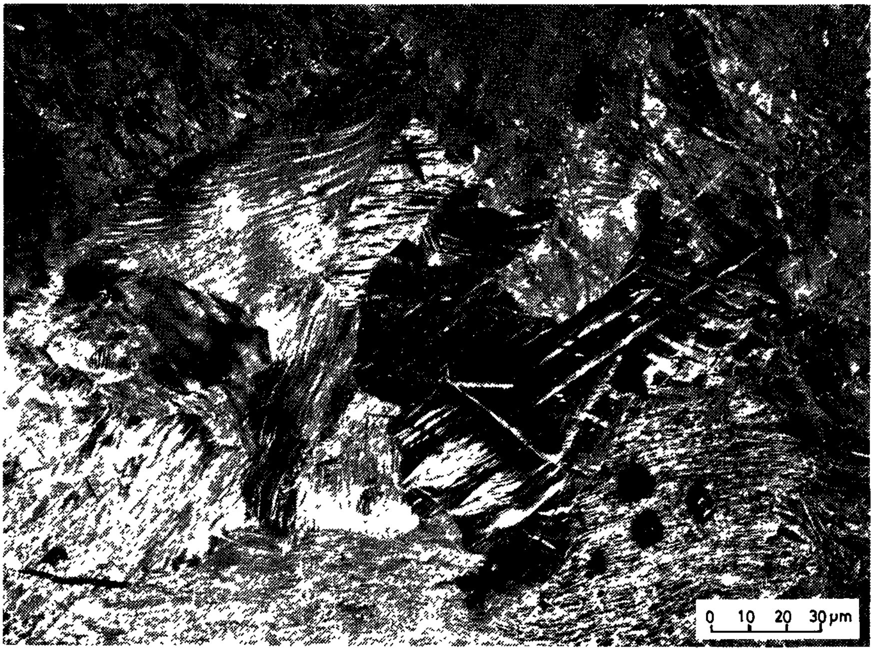
Also of considerable interest was the account of the prototype fast breeder reactor "MONJU". This reactor is intended to demonstrate through the processes of design, manufacture and operation that, in Japan, the performance, reliability, safety and economics of a large fast breeder reactor would be competitive with those of more conventional power plants. The design is based on existing technology plus research and development that will be completed in time for construction to commence in 1974. The core of this reactor will be divided into two radial regions with respect to plutonium content, the cladding material will be stainless steel and the Pu/U mixed-oxide fuel will have the low density of 85% theoretical. The sodium reactivity void coefficient allowed will be partially positive whilst the overall void reactivity coefficient will be negative. The reactor structure features a core supported from a hanging device riding on the upper part of the coolant vessel. This design feature is claimed to result in smaller vessel size and ample space for fuel handling.

The third section of the Japanese exhibit highlighted the development of nuclear powered ships in Japan. The main feature of this section was a large model of the nuclear ship "Mutsu" (gross registered tonnage 8350 tons, speed 16.5 knots) which is scheduled to be completed by the beginning of 1973. The general arrangement of the N.S. Mutsu was shown by means of photographs and diagrams and a detailed account was given of its layout, design philosophy and construction. This ship, with built-in protection against stranding and collision, will be powered by a reactor with a thermal output of 36 MW. The reactor core comprises 32 fuel bundles, 20 of which have uranium enriched to 3.24 wt%, the remainder being enriched to 4.4 wt%. Each fuel bundle consists of 121 rods arranged in a square (11 rods per side) with each bundle containing nine rods of boron silicate as burnable poison. Cladding is stainless steel and each fuel rod contains 53 dished pellets of sintered uranium dioxide. Control rods are of cruciform type (silver, indium, cadmium alloy) with a follower of Zircaloy.

Burn-up will be 5500 MWd/t corresponding to a core life of approximately 2 years (60% load factor) without fuel shuffling. The main engine is a cross-compound saturated steam turbine equipped with double reduction gears. Power output is 10 000 h.p. under continuous rating. As a constant average primary water temperature system is adopted, steam pressure varies between 62.5 kgf/cm^2 (no-load) and 39.5 kgf/cm^2 (full-load). Stand-by power is by means of an auxiliary boiler.

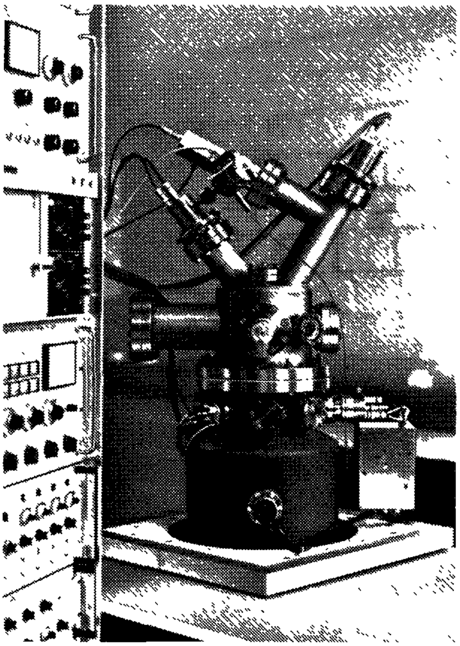
Illustrated panels gave details of development work being conducted for the ship's reactor core and a full size bundle was exhibited.

The fourth section of the exhibit gave an account of developments in the applications of radiation and radioisotopes in Japan and complemented work presented at the Conference. Extensive work in radiation chemistry is being carried out in Japan and this was illustrated by means of photographs. Other panels described work on neutron activation analysis for



Uranium-0.2% vanadium alloy under photoemission electron microscope Metroskop KE-3 (original magnification was X1000).

LIECHTENSTEIN



Secondary-ion mass spectrometer for chemical analysis of surfaces using argon ion bombardment.

the control of steel production, research and development on food irradiation and applications of radiation in nuclear medicine.

The final section of the Japanese exhibit gave a wide ranging view of the technical competence of the national industry. The panels covered such diverse subjects as turbine generators, containment vessels, pressurized water reactor evaporators and scientific instruments. A steel plate from a containment vessel was exhibited, as was a large diameter stainless steel pipe. An interesting model of a moisture separator was also on display, together with nuclear turbine blades and a thermoluminescent dosimeter. A much studied exhibit from this section showed a remote-controlled in-service inspection technique based on a resistance probe method.

CONTRIBUTORS TO THE JAPANESE STAND

Atomic Energy Commission of Japan, Tokyo;

Japan Atomic Energy Research Institute, Tokyo;

Power Reactor & Nuclear Fuel Development Corp., Tokyo;

Japan Nuclear Ship Development Agency, Tokyo;

National Institute of Radiological Sciences, Chiba City;

Federation of Electric Power Companies, Tokyo;

Electric Power Development Company, Tokyo;

Japan Atomic Power Company, Tokyo;

Japan Iron & Steel Federation, Tokyo;

Japan Federation of Construction Contractors Inc. Tokyo;

First Atomic Power Industry Group, Tokyo, comprising:
- Ebara Manufacturing Co. Ltd., Tokyo,
- Fuji Denki Seizo K.K., Tokyo,
- Furukawa Electric Co. Ltd., Tokyo,
- Kawasaki Heavy Industries Co. Ltd., Kobe City;

Mitsubishi Atomic Power Industry Group, Tokyo, comprising:
- Mitsubishi Atomic Power Industries, Inc.
- Mitsubishi Electric Corp.
- Mitsubishi Heavy Industries Co. Ltd.
- Mitsubishi Shoji Kaisha Ltd.

Nippon Atomic Industry Group, Tokyo, comprising:
- Ishikawajima-Harima Heavy Industries Ltd.
- Mitsui & Co. Ltd.
- Mitsui Shipbuilding & Engineering Co. Ltd.
- Nippon Atomic Industry Group Co. Ltd.
- Tokyo Shibaura Electric Co. Ltd.
- Toray Industries, Inc.

Sumitomo Atomic Energy Industries Ltd., Osaka;

Tokyo Atomic Industrial Consortium, Tokyo, comprising:
- Hitachi Co. Ltd., Tokyo,
- Hitachi Shipbuilding & Engineering Co. Ltd., Osaka,
- Marubeni-Iida Co. Ltd., Osaka,
- Showa Denko K.K., Tokyo;

Japan Atomic Industrial Forum, Tokyo.

LIECHTENSTEIN

Stand 2

The Principality of Liechtenstein has contributed to the development of the peaceful uses of atomic energy mainly through its development of specialized scientific equipment.

The exhibit showed scientific apparatus suitable for materials research, isotope separation, surface studies and radiation research on biological systems. A particularly interesting exhibit was a photo-emission electron microscope for the structural examination of reactor materials over the temperature range 20 to 2000°C. This instrument can produce magnifications of up to × 50 000. Also on display were secondary ion mass spectrometers and Auger electron spectrometers which may be used for micro-studies of surfaces. Devices such as these give a deeper insight into the processes occurring at solid-liquid and solid-gas interfaces both before and after irradiation.

A considerable portion of the exhibit was devoted to equipment suitable for producing and studying nuclear materials. Included were vacuum metallurgical furnaces and automatic analysers for the rapid determination of gases such as oxygen, nitrogen and hydrogen in metals, e. g. in uranium, zirconium or stainless steel.

High vacuum components and measuring equipment were also displayed, as were high vacuum pumps of a wide range of types. A related display gave details of preparation techniques suitable for electron microscope studies of tissue. These techniques use a vacuum-freeze/etch process and permit an unobstructed view into cells, thus disclosing alterations due to radiation damage.

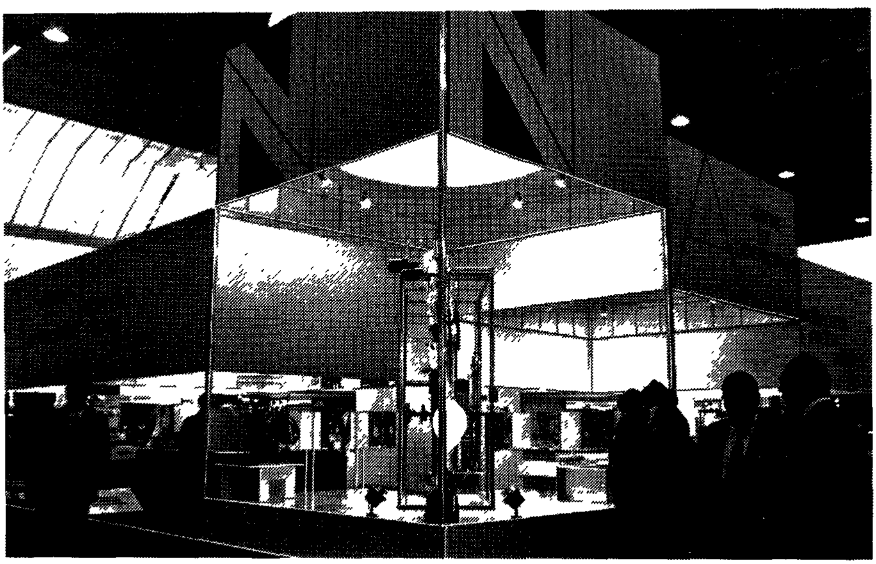
CONTRIBUTORS TO THE LIECHTENSTEIN STAND

Balzers Ltd., Liechtenstein.

THE NETHERLANDS

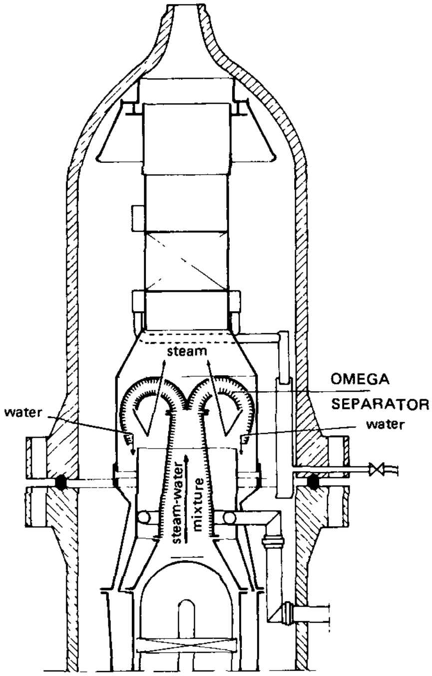
Stand 5

The Netherlands' stand gave an overall survey of national research and industrial activities in the nuclear field. These activities are aimed at the development of several types of nuclear reactor and are carried out partly in collaboration with foreign research institutes and/or industrial organizations.



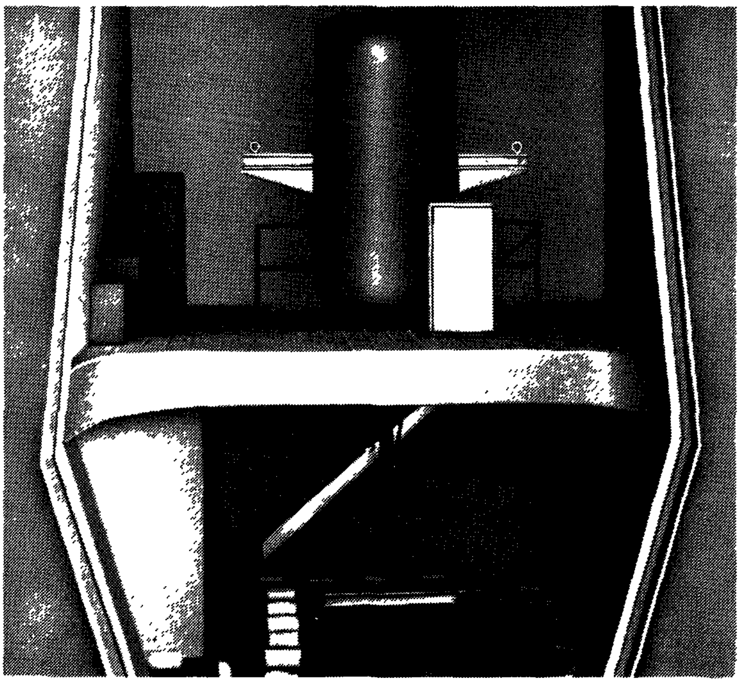
The Netherlands stand theme was 'Atoms for Development'.

NETHERLANDS



RIGHT: In natural recirculating steam generators, as commonly used on PWRs, the first stage of the separation of steam from water is a mechanical device such as a cyclone type or a swirl or radial vane separator. The OMEGA separator is inherently simpler and uses a flow-field rotating about a vertical axis to obtain separation.

BELOW: The 'Pilot-plant for Food Irradiation Association' is a non-profit making group that aims at carrying out research on and collecting data for commercial application of the radiation process to food preservation. Shown is the γ-irradiation plant, near Wageningen, which uses a 180 kCi ^{60}Co source and has a throughput of about 1.5 t/h for a dose of 250 krad.



A visitor to this stand was referred to the Debenelux stand where work on the fast breeder reactor was displayed. Essential work in the Netherlands is concerned with the fast breeder reactor which is planned for construction in the near future. A working model of the fast-thermal coupled facility (STEK) was on display. This facility is designed to provide integral data on fission products and the model showed clearly the operation of the facility.

Work on the development of fuel elements for water cooled reactors was shown and covered the complete field of the design and manufacture of reliable and guaranteed fuel elements. Also on display was a prototype fuel element for the N. S. Otto Hahn and a fuel element loaded with vibro-compacted fuel which will be tested in the Dodewaard nuclear power station.

For some years work in the Netherlands has been carried out on graphite irradiations in connection with the high temperature reactor project 'Dragon'. A dilatometer, capable of examining six graphite specimens simultaneously, was on display. This dilatometer measures the residual strain in graphite creep specimens.

Thermal breeders are actively under consideration by Dutch electricity producers because of the anticipated increase in the cost of uranium and problems which might possibly arise in the development of fast reactors. An experimental facility for work on thermal breeder reactors was completed in 1971 and was illustrated by means of a model.

A special section of the Dutch exhibit provided a glimpse of work on uranium enrichment by means of ultracentrifuges. This work, as part of a co-operative project with the United Kingdom and the Federal Republic of Germany, was illustrated by models of the pilot plants in the various countries and some interior photographs at these plants. Also exhibited was a stylized centrifuge model. Although not particularly revealing, this section of the Dutch exhibit attracted much attention.

In keeping with the large amount of work performed in the Netherlands, food preservation occupied a prominent part of the exhibit. Potatoes, laboratory animal food and special food for hospital clean room patients were on display. A further exhibit described work in the Netherlands on environmental pollution. Details were given of environmental studies by means of activation analysis. A map displayed results of the determination of heavy metal pollution of water, silt and grain throughout the Netherlands. As in other countries, attention has been paid to the problem of mercury pollution.

One interesting exhibit featured a model of a fully instrumented (BWR) pressure vessel used for stress analysis. This vessel (1/4 scale) was used for determining the stress at critical points prior to design and manufacture of the vessel supplied for the Dodewaard reactor. Other scale models of reactor pressure vessels were shown.

Several interesting industrial exhibits were also present in the Netherlands stand. These included a weld thermal cycle simulator, a sealed tube neutron generator , visdo seals for free-surface sodium pumps and ultrasonic scanning and testing of butt welds and brazed joints. Noteworthy was a display showing the radiographic examination of small defects (< 0.5 mm) by means of a specially constructed microfocus X-ray tube equipped with a long rod anode.

Other interesting exhibits included a model of a steam/water separator, a radiation monitor and width monitor and a Perspex model of an aqueous suspension thermal breeder reactor. Irradiation facilities were also shown, in particular the various facilities at the High Flux Reactor. One particularly interesting facility consists of a camera for neutron radiography which is permanently installed in the reactor pool.

CONTRIBUTORS TO THE NETHERLANDS EXHIBIT

Reactor Centrum Nederland, Petten;

N.V. Kema, Arnhem;

Interuniversity Reactor Institute, Delft;

Royal Engineering Works Stork N.V., Hengelo, Overysel;

Metal Research Institute TNO, Delft;

Proefbedrijf Voedselbestraling N.V., Wageningen;

The Rotterdam Dockyard Company, Rotterdam;

Radiobiological Institute TNO, Ryswyle, Zuid Holland;

Philips Research Laboratories, Eindhoven;

Smit Nijmegen Electrotechnische Fabrieken N.V., Nymegen;

Institute TNO for Mechanical Constructions, Delft;

ITAL, Wageningen;

Röntgen Technische Dienst N.V., Rotterdam;

Central Laboratory TNO, Delft;

Ultra-Centrifuge Netherlands Ltd., den Haag;

Institute for Plasma Physics (FOM), Utrecht.

THE NORDIC COUNTRIES

Stand 16

The long standing tradition of co-operation which exists between the Nordic Countries was further exemplified by the joint exhibit of Denmark, Finland, Norway and Sweden which was entitled "Nuclear Scandinavia". The exhibit was but one of the tasks of a special co-ordination committee which has been created by the nuclear research centres in Denmark, Finland, Norway and Sweden to take the initiative in joint ventures. A visitor to "Nuclear Scandinavia" rapidly became aware that, within a common framework, ample room had been created for both joint undertakings and national exhibits.

The front entrance to the combined stand was dominated by a large map of the four Nordic countries. This map showed the interconnected electricity grids of the countries and the nuclear power plants both planned and under construction. By 1980 it is envisaged that 10 000 MW(e) of nuclear plant will be installed, 7000 MW(e) of which will be sited in Sweden. The optimization of the combined electricity supply systems is accomplished by means of a

The entry to the NordicCountries'stand, whose theme was Scandinavian cooperation.

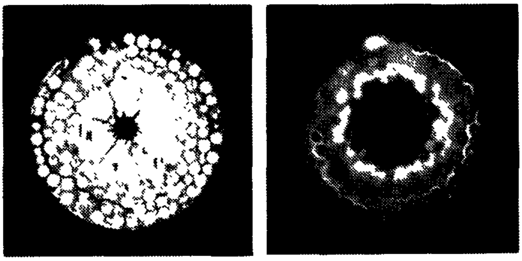
planning committee of Nordel, an advisory body comprised of leading members from the power utilities in the four countries. This planning committee also recommends additional links between the countries. The day-to-day exchange of power is handled through an operational committee.

The second joint exhibit displayed the industrial irradiation plants used for the sterilization of medical supplies, and other irradiation plants in the Nordic countries. Information was given about the major applications, capacity and design of each plant. Close co-operation exists between the Scandinavian countries for the development of bacteriological control systems. Danish and Swedish test pieces used for the control of the efficiency of radiation sterilization plants were on display.

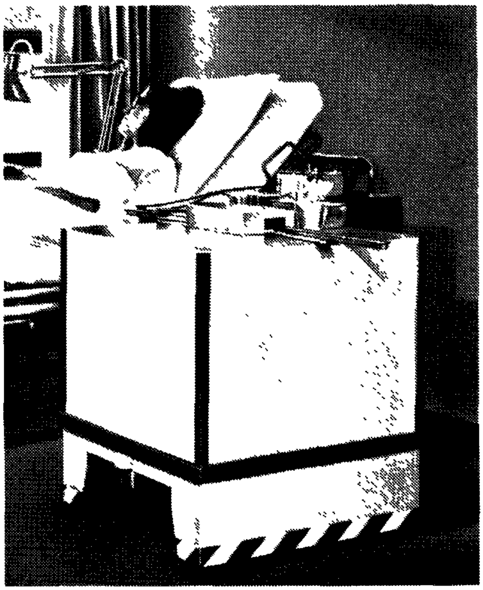
A further joint exhibit dealt with the development of a prestressed concrete vessel which has been constructed and tested as a joint project at Studsvik. A model of this pressure vessel was on display. The experiments on this concrete vessel have been jointly planned and financed and represent an important step in the development of prestressed concrete reactor vessels for light water reactors. The model clearly showed a section through the vessel and gave details of the removable lid and the removable steel insulation.

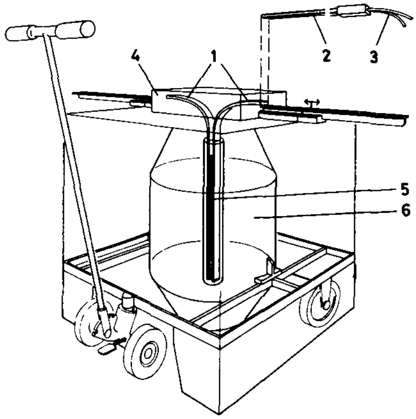
The last joint stand dealt with the production of isotopes and their application in medicine. The Nordic countries have a long tradition in the production of radioisotopes and their medical applications. The exhibit comprised stationary and portable blood irradiators, a novel bone density meter and other specialized equipment, as well as samples of isotopes and labelled compounds for diagnostic use.

DENMARK



Work done at Risø on fuel examination. The autoradiographs are from the same transverse section of an irradiated fuel pin which contained 2% PuO_2 in natural UO_2. The left-hand one uses α-autoradiography to show plutonium distribution, the right-hand one $\beta\gamma$-autoradiography to show migration of $\beta\gamma$-emitting fission products.





Risø mobile gamma therapy unit for extra-corporeal irradiation of blood: 1 - irradiation channels; 2 - flexible insert with blood tube; 3 - extra-corporeal shunt; 4 - top shield; 5 - ^{137}Cs source; 6 - steel encased main lead shield.

DENMARK

The Danish display was designed to demonstrate the achievements in the nuclear field of the Danish Atomic Energy Commission both alone and in collaboration with Danish industry and other Danish organizations.

Danish work in the field of reactor irradiation and post-irradiation examination was displayed. Complete reactor irradiation programs in such diverse fields as materials testing, physics experiments, isotope production etc., can be carried out in Denmark. Information was presented which described the high flux research reactor DR-3 and the major rig installations at Risö, near Copenhagen. Post irradiation examinations are performed on a contract basis for foreign institutes utilizing the alpha, beta and gamma-hot cell facilities installed at Risö. Examples were given of the different types of examination which can be undertaken, together with a survey of past work and experience in this field.

In view of the current interest in the subject of environmental pollution, the exhibit describing Danish work on the rational location of sewer outfalls was particularly topical. The model on display complemented the work described during the Conference. Studies of the type described have been carried out at many locations throughout the world, the experimental work being conducted by a non-profit-making organization founded by the Danish Academy of Technical Sciences.

Since 1968 extra-corporeal irradiation of blood has been used in Denmark for pre-transplantation, immuno-suppressive treatment. By March 1971, a total of 78 patients had been treated. The irradiation equipment shown was developed as a result of a collaborative effort and consisted of both high intensity, mobile gamma irradiation units (maximum dose being 20 krad/24 h per 5 litres of blood) and prototype, portable beta irradiation units. The portable beta units are intended for clinical research on the effects of prolonged low-dose therapy.

Denmark has for some years devoted much effort to the development of irradiation facilities of all types. Amongst the many developments, a versatile high-intensity gamma cell was described. This cell can conveniently be located in existing laboratories and requires no additional shielding, access restrictions or special training. The cell features a rotating source – an arrangement which ensures a high degree of gamma-field homogeneity even when a limited number of source capsules of different strengths are used. The maximum dose rate at the centre of the irradiation chamber is 0.3 Mrad/h for a source loading of 3 kCi of ^{60}Co.

Work on mutation breeding in plants was displayed. Ionizing radiation has long been used to induce mutations suitable for plant breeding, and Danish work in this field, e.g. on barley seeds and carnation cuttings, was described. Plants whose properties have been usefully altered, for example for disease resistance, increased growth rate or new, attractive flowers, are being utilized by plant breeders to create new varieties.

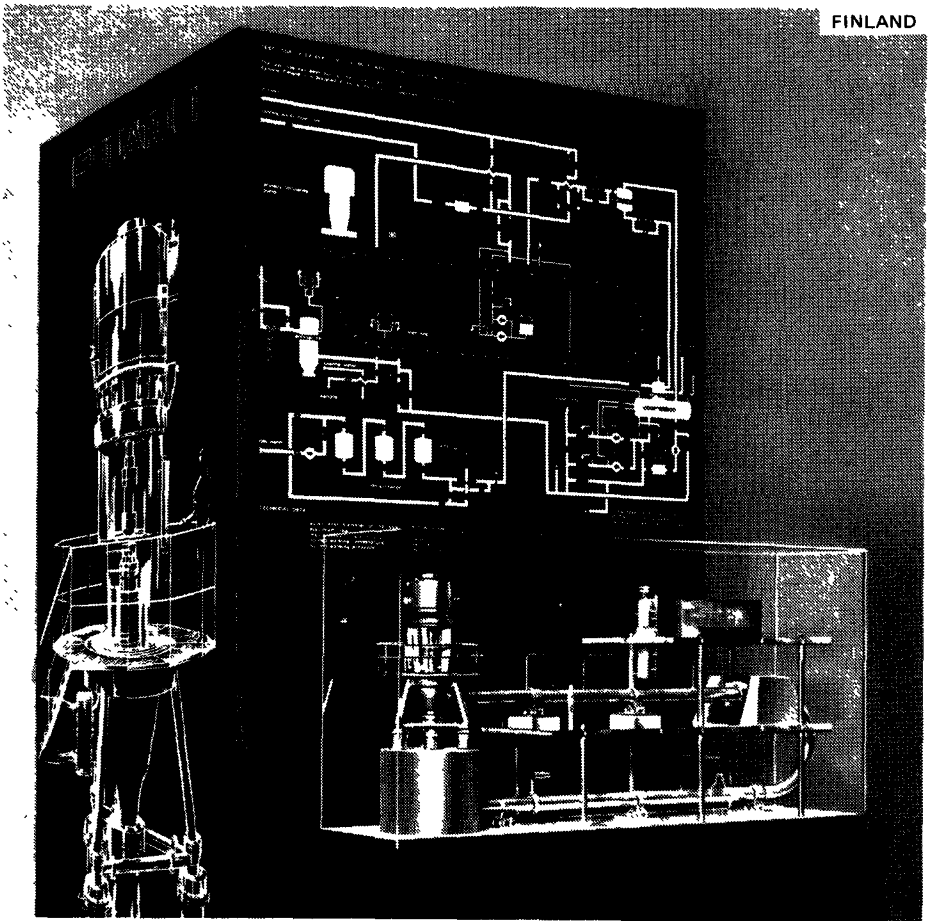
One section of the Danish stand was devoted to a display of scientific equipment. An interesting item comprised two combined density/moisture probes which may be used for subsurface and surface measurements. The necessary power supply for these probes and for data logging is provided by means of a portable scaler which permits printing out of the results. These moisture/density gauges are manufactured in Denmark.

A useful contribution to the determination of the ages of archaeological artefacts was displayed. The property of thermoluminescence – the emission of light obtained on heating certain materials – is known to be excited in certain substances if they are initially exposed to ionizing radiation. The exhibit demonstrated this phenomenon and described its application to the dating of ceramic specimens of archaeological interest.

Work on the prospecting for uranium was also described. For some years, an extensive body of uraniferous rock from the alkaline massif of Illimaussaq in the Southwest of Greenland has been the subject of intensive investigation. The recovery of uranium from this rock is rather difficult and highlights of the program were displayed.

FINLAND

The Finnish section of "Nuclear Scandinavia" was organized on behalf of the Finnish Government by Finnatom, a company founded and owned by



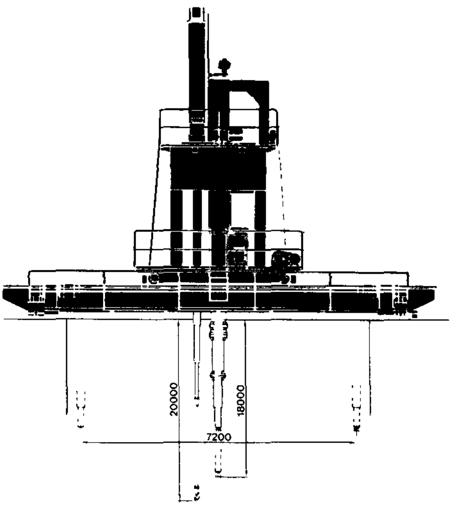
A model of the full-size test loop being developed by Finnatom, with governmental support, it is intended for testing primary pumps and other primary-circuit components; the "negative" photomontage on the left is a pump for the Loviisa PWR.

eight leading Finnish engineering industries. Finnatom co-ordinates the research and development work and quality assurance programs of its associated parent companies. It is also responsible for the marketing and sales of nuclear station components and sub-systems.

The first exhibit in the Finnish stand dealt with a multi-channel analyser. This analyser has up to 800 channels and is a computer-type instrument designed for three principal modes of operation, viz. pulse height analysis, multi-scaler and time analysis. Its design makes it suitable for both field and laboratory use. The number of channels employed may be 100, 200, 400 or 800 and the instrument is provided with a built-in high voltage supply and tape recorder.

An interesting model of the hot test loop facility at Karhula for the examination of primary circuit components was on display. The test loop is now under construction and is, in particular, intended for testing the pumps for the Loviisa 440 MW(e) pressurized water reactor under full reactor

FINLAND



The Valmet fuel handling machine developed for the Loviisa 440 MW(e) PWR. In addition to fuel charging and re-charging, a number of other functions can be performed.

operating conditions. A background photograph gave a view of one of the pumps for this power station.

A machine currently under construction for handling the fuel for the Loviisa power station was described by means of a drawing. Although designed primarily for fuel charging and discharging, the machine can perform various other tasks. It is positioned, with an accuracy of 2 to 3 mm, by means of closed-circuit TV.

The Governmental Research Institutes in Finland combined to produce several interesting exhibits. A neutron double monochromator was shown which produces a monoenergetic beam of neutrons in a constant direction but with a variable energy (wavelength). The precision instrument is provided with ball nuts so as to obtain play-free, accurate linear movement. The instrument is designed in such a way as to utilize the full area of the crystal monochromators at all wavelengths. This requires the provision of simultaneous axial and angular motion and accounts for the complexity of the monochromator. The actual instrument uses pyrolytic graphite monochromators which, for the purposes of the exhibition, were replaced by mirrors.

A related exhibit featured a neutron guide tube. These are internally polished tubes of iron, nickel or copper along which neutrons are guided by means of total reflection from the walls. The tube on display was initially polished electrolytically and then further mechanically polished using special techniques developed in Finland. The neutron guide tubes produced in this way still have macroscopic waves, but for the reflection of low energy neutrons a good microscopic smoothness is more important. Surface profiles at various stages in the manufacturing procedure were given for the tube exhibited (final Ra $\simeq$ 0.07 μm).

Wood/plastic composites have also been developed in Finland. High quality products have been obtained with vinyl monomers which are easily polymerized by means of gamma radiation. The composites developed are based on the indigenous wood species, i.e. birch, alder and aspen, and polyester-based resins. A method of lining the bottom of skis with wood/plastic composites has been developed and a gamma polymerized wood/plastic ski was exhibited.

The properties of wood/plastic composites are such as to attract decorators and sculptors. The Finnish sculptor Kauko Räsänen is noted for his sculptures in wood/plastic composites, which still keep the natural beauty of wood. One of his works entitled "Suikala" was displayed.

In a related exhibit, work on the electron-beam curing of polymer coatings on fibre boards and plywoods was described. Paints, based on polyesters and polyacrylates, have been developed for this purpose. A thin layer of wet paint, free of volatile solvents, is continuously hardened in a few seconds by irradiation with 0.4 MeV electrons. No heat is required and it is claimed that the electron curing process produces less residual stress in the coatings and no peroxide residues, thus resulting in better weather resistance as there is less after-curing than occurs with conventional curing with chemical catalysts.

The final exhibit in the Finnish stand was concerned with the construction of the Loviisa power station referred to previously. The station will consist of two Novovoronesh-type 440 MW(e) pressurized water reactors to be provided by V/C Technopromexport (TPE). TPE will deliver mainly mechanical components for the plant, the remainder being designed and delivered by suppliers in Finland and elsewhere. A pictorial display described the reactors and the work of the Finnish utility which acts as its own architect engineer and employs outside consultants to assist with specialized tasks.

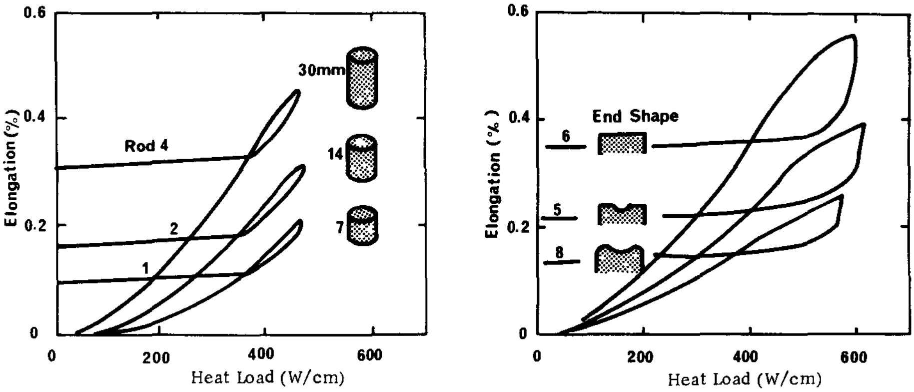
NORWAY

The Norwegian exhibit concentrated on showing national achievements in the fields of fuel technology, instrumentation and computer control. These are the fields in which the Institutt for Atomenergie, the Norwegian Centre for applied nuclear research has undertaken extensive research and development activities in close collaboration with Norwegian industry. This selectivity was admirably suited to the purposes of the scientific exhibition and made the provision of "hardware" for the stand relatively easy.

The main feature of the exhibition was a control desk operated by a Norwegian made minicomputer which utilized standard colour TV sets for the graphic and alpha-numeric display of parameters, flow-sheets, etc. Another process computer was shown being used for data collection and the processing of data derived from various instruments distributed around the exhibition. The interface for the unit is also of Norwegian origin.

Also exhibited was a compact computer for on-line applications such as multimachine configuration, data net, process control and data terminal. This computer uses stored programs and is one of several designed to be fast, reliable and economic computers with emphasis on real-time, on-line applications. A density meter, which can be used for fluids as well as for solids, and a gamma level-control gauge were also displayed in this section.

Instruments for measurements of force, strain and deformation in prestressed reactor concrete vessels were displayed. The instruments exhibited were connected to the process computer and the measurements were displayed on the TV units referred to previously.



Studies on the effect of fuel pellet shape on fuel-rod elongation behaviour during start-up made on the irradiation rig IFA-118 at the Halden reactor. The left-hand diagram shows the effect of pellet length and the right-hand diagram the effect of pellet end-shape on fuel rod elongation.

NORWAY

Assembling an instrumented fuel element. In-core instruments for use in power reactors are designed, developed and tested at the Halden Project.

On the fuel technology side, a full-scale model of an instrumented fuel assembly with the instruments developed for the OECD Halden project was shown. The assembly is equipped with instruments for measurement of channel power, moderator and fuel temperature, voidage, fission gas pressure, inlet and outlet flow in fuel channels, fuel elongation, etc.

In the Halden reactor in Norway, a rig, which allows of measuring the actual diameter of a fuel pin undergoing reactor irradiation, has been in successful operation for about one year. A full-scale working model of the equipment and facility was demonstrated. The measurements are displayed on an X-Y recorder as well as on TV sets via the process computer referred to earlier.

The Zircaloy cladding tubes manufactured in Norway were also shown. Manufacture of Zircaloy tube is based on more than 10 years experience in fuel fabrication and testing, and includes post irradiation examination at the Institutt for Atomenergie. In the Halden reactor, a series of irradiation experiments have been carried out with instrumented fuel assemblies for a study of the interaction between the Zircaloy cladding and UO_2 pellets in a highly-rated fuel. This study is aimed at defining the criteria to be used for selecting cladding dimensions and properties.

The exhibition showed a collection of anodized Zircaloy cladding tubes and demonstrated the tube specifications relating to texture, hydride orientation and physical properties.

SWEDEN

The Swedish display reflects the country's nuclear program, which was begun in 1947 with the aim of creating the capacity within the country to manufacture power reactor systems, major reactor components and reactor fuels, without recourse to foreign licences. An extensive research and development program, focussed on AB Atomenergi's nuclear research establishment at Studsvik forms the basis of Swedish work in the field of nuclear energy.

The first Swedish commercial nuclear power plant, Oskarshamn (440 MW(e)), was connected to the grid in August 1971. The Swedish nuclear power program provides for the installation of a further six reactors, which are planned to come into operation before 1980. By this date, Sweden will have 7000 MW(e) of nuclear generating capacity on line, producing more than 30% of the nation's electrical power.

As the main partner in the government-financed nuclear energy work, Studsvik has enabled Swedish industry to reach a commercial position in the field of power reactors, nuclear fuel and reactor components.

The research and development program at Studsvik also includes isotopes and equipment (chiefly for use in nuclear medicine), irradiation services and post-irradiation investigations.

In addition to AB Atomenergi, the main Swedish industries active in the nuclear field were described by means of an extensive photographic display. The exhibit was divided into several sections which included: irradiation testing; high temperature pressurized critical facility; nuclear instrumentation; heat engineering investigations; nuclear medicine; and power reactors, components and services.

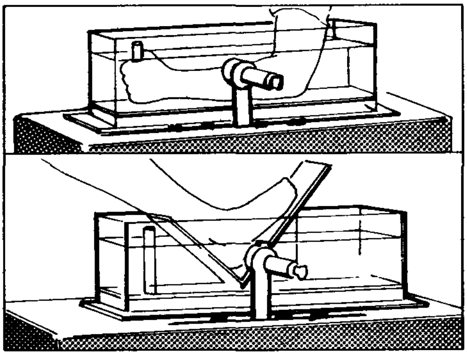
The section on irradiation testing described the irradiation facilities available at AB Atomenergi, Studsvik. Studsvik's main facility is the 50 MW research reactor R2. The reactor is of the pool type, cooled and moderated with light water and uses 90-93% enriched fuel. The relatively large core size (10×10 lattice) allows test equipment to be placed in positions between the fuel elements thus making optimum use of the high neutron flux available in the reactor. The associated hot cell laboratories are capable of performing all types of post irradiation examinations. The

The R2 research and materials testing reactor at the Swedish nuclear centre of Studsvik with a power of 50 MW(th) is one of the largest of its kind in Europe.

laboratories are provided with a full range of physical, chemical and metallurgical testing equipment.

A second photo-montage featured the KRITZ reactor at Studsvik, which is a flexible facility built for reactor physics experiments with water-moderated reactor cores. It can operate up to a maximum temperature of 245°C at a maximum reactor power of 100 W. The free height (4 m) inside the tank is large enough to permit installation of full size power-reactor fuel assemblies.

In the field of nuclear instrumentation, Studsvik's manufacturing program includes equipment for nuclear reactor control, radiation protection, on-line data processing and for physics research. Studsvik's specialists are prepared to undertake measuring-problem analysis, experimental



SWEDEN

Bone Scanner 7102 was developed at Studsvik to fill the need for an automatic bone-mineral test system for clinical and research use. The multiple scanning principle employed ensures accuracy and reproducibility. There is a choice between manual or automatic scanning with one or two isotopes, ^{125}I and ^{244}Am. The radiation dosage is very low. It is intended to measure the lower arm (ulna and radius) or heal (calcaneus). The measuring set-up and source holder are shown here. The limbs are measured in water in a plastic tank; if immersion is not acceptable, water-filled pads can be used.

studies of measuring methods, instrumentation system design or reliability assessments. A detailed description of this capability was presented.

The section of the exhibit on heat engineering investigations explained performance tests on fuel rods during boiling. These tests are performed by placing an electrically heated 9-rod bundle (with assymmetric power distribution) in a Plexiglass loop. Visual studies can be made during boiling of the water. Vibrations which are induced in the bundle as a result of hydrodynamic forces, arising from the two-phase flow, are detected by strategically-placed differential transformer sensors.

Studsvik's capability in the field of nuclear medicine was also described. An integrated service (including instrumentation) is available for handling special problems and developing singular systems adapted for individual users. The program includes the more commonly used radionuclides as well as specially labelled compounds. Radioactive sources of different activities and isotopes are made as standard types, but can also be tailor-made for special applications. Studsvik has developed different types of applicators for medical use, such as strontium-90 surface applicators and applicators for pituitary irradiation. A bone-mineral analyser, based on the principle that absorption of gamma rays is dependent on the mineral content of the bone, was described. Several versions of an extra-corporeal blood irradiator for therapy or suppression of immunological reactions in connection with transplantations have been designed.

The objective of manufacturing power reactors without recourse to foreign licences was mentioned earlier. This was amplified in a special section of the exhibit which was devoted to describing the capability of Swedish industry in power reactor engineering and allied components and services. One company specializes in the development, manufacture and marketing of nuclear reactors, fuel and reactor components, and is organized to carry out major nuclear power projects and provide efficient solutions to nuclear engineering problems. This company's boiling water reactors (BWR's) have conventional design principles but are supplemented (as appropriate) with special improvements in areas such as fuel and reactor containment design, main circulation and power control systems, etc. The Oskarshamn I plant, which is a turnkey project, came into operation in autumn of 1971 and was depicted. Three additional BWR's are on order.

Another Swedish organization offers services such as project-administration, architect-engineering, procurement of components and erection, supervision of installation, and testing and commissioning of nuclear, as well as fossil-fuelled,power plant projects. This particular organization has overseas affiliates and has experience of pressurized water reactors (PWRs) and provides specialized know-how in the field of radioactive waste treatment. It is comprised of a group of progressive Swedish industries and has available much technical knowledge and production capacity for investment in nuclear and other advanced markets.

A section of the exhibit dealt with the ability to provide such items as pressure vessels, Zircaloy tubes, special alloys etc. A fully integrated speciality-line exists for making cladding material and tubes for nuclear engineering. Zirconium alloys in the form of seamless canning tubes for fuel elements in nuclear reactors and pressure tubes are also made in Sweden, as are stainless steels and nickel-base alloys (suitable for fuel element canning), steam-generator tubing, composite tubing for control rod inlets in pressure vessels, and strip and wire for cladding. Several examples of tubing were on display.

The facilities for manufacturing BWR and PWR pressure vessels of up to 1500 MW(e) output were described. In 1969 a joint venture between Swedish industry, an overseas company and the Swedish Government was established in order to further develop the vessel fabricating facilities previously available in Sweden. The fabrication program also comprises reactor vessel internals, steam generators, pressurizers, heavy pressure vessels, primary piping components and steel containments.

A new high-capacity plate heat exchanger was described. This heat exchanger has an effective heating-exchange surface of 640 m^2. The standard plate material is titanium, and a new manufacturing technique has made it possible to press large plates in this difficult-to-work metal of a thickness of only 0.6 mm. It is capable of withstanding test pressures of up to 10 atm.

The work of an international company, specializing in nuclear safety, was depicted. This company is a non-profit-making organization and is involved in work for ensuring the safe operation of nuclear power plants. The company plays a dominating role in the testing and inspection work for nuclear reactor plants in Sweden, and has experience of such work in many other countries.

A novel feature of the exhibit concerned new ideas for the use of surplus heat from thermal power plants. Approximately two-thirds of the energy liberated in a nuclear power plant is wasted; for fossil-fuel plants the figure is a little lower. At present this surplus heat can only be used for heating purposes. In order to stimulate new and unconventional ideas of how the surplus heat might be utilized, the Swedish Association of Engineers and Architects, supported by the Swedish power producers, held a worldwide brain-storming-contest. The three first-prize-winning ideas were presented at the exhibition.

CONTRIBUTORS TO THE NORDIC COUNTRIES' STAND

DENMARK

Danish Atomic Energy Commission, Copenhagen;

Danish Isotope Centre, Copenhagen;

Danish Academy of Technical Sciences, Copenhagen;

University Hospital, Copenhagen;

NEA, Nordisk Elektrisk Apparatfabrik, Ballerup;

Nunc A/S, Kamstrup, Roskilde;

Radest A/S, Formervangen, Glostrup.

NORWAY

Institutt for Atomenergie, Kjeller and Halden;

A/S Norsk Data-Elektronikk, Oslo;

A/S Kongsberg Vapenfabrikk, Kongsberg;

Noratom-Norcontrol A/S, Oslo;

Tandberg Radiofabrikk A/S, Oslo;

Geonor A/S, Oslo.

FINLAND

Finnish Atomic Energy Commission, Helsinki;

OY Finnatom AB, Helsinki;

State Institute for Technical Research,
Otaniemi Reactor Laboratory, Otaniemi;

Department of Radiochemistry, University of Helsinki;

Imatran Voima Osakeyhtio, Helsinki;

OY Nokia AB Electronics, Helsinki;

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Valmef Rautpohja, Jyvaskylä;

A. Ahlström Osakeyhtio, Karhula Laboratories, Karhula.

SWEDEN

AB Atomenergi, Studsvik;

Alfa-Laval AB, Lund;

AB Asea-Atom, Vasteras;

AB Monitor, Goteborg;

Sandvikens Jernverks AB, Sandviken;

Tetniska Rontgencentralen AB, Stockholm;

Uddcomb Sweden AB, Degerfors;

Vattenbyggnadsbyrån AB, Stockholm.

ROMANIA

Stand 4

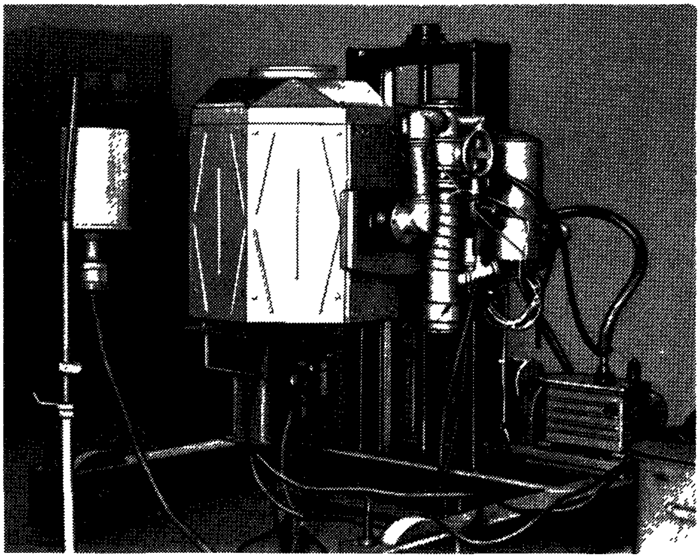
The exhibit of the Socialist Republic of Romania was devoted to a display of nuclear instrumentation and research in agriculture, industry and medicine. Also featured in the exhibit were components for reactors and other nuclear installations.

Several items were on display, one of the main items being a model of a fuel element based on a silicon-ceramic material (UO_2 - SiO_2). Centrifugal filters for the collection of radioactive aerosols were displayed together with the associated control apparatus.

Radiation equipment exhibited included a portable gamma radiography source using ^{192}Ir, density and level gauges and gamma switches. Of particular interest was a small, easily transportable 15 MeV betatron suitable for the non-destructive testing of thick wall vessels. This device is produced in Romania on a reasonably large scale.

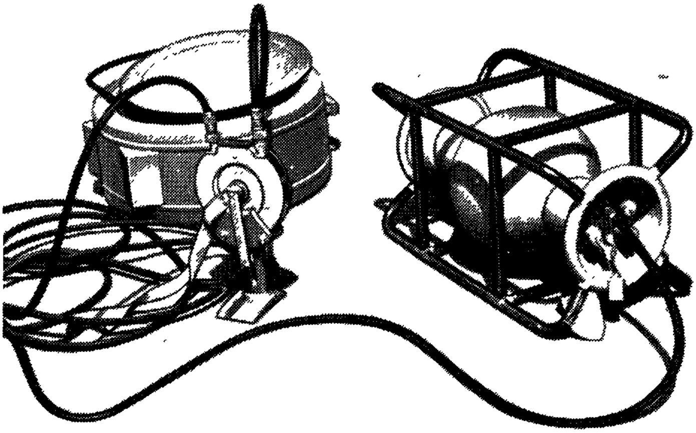
Several interesting examples of nuclear electronics and radiation detectors were on display. These included a portable ratemeter suitable for use with scintillation probes and which may be used either in the field or in the laboratory, a vibrating reed electrometer suitable for use with ionization chambers, and radiation detectors based on gas counters which

ROMANIA/ROUMANIE



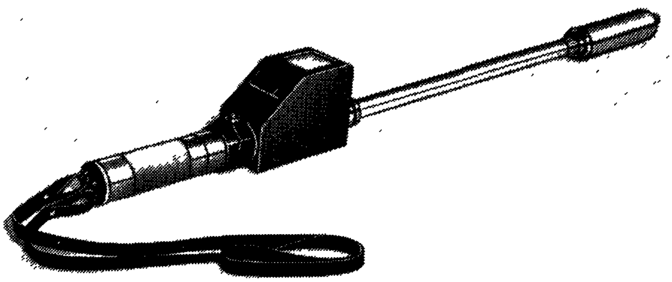
A small, easily transportable 15 MeV betatron suitable for non-destructive testing of thick-walled vessels.

Petit bêtatron facilement transportable de 15 MeV pour le contrôle non-destructif des pièces à parois épaisses.



Portable γ-radiography source using ^{192}Ir.

Appareil portatif pour la gammagraphie au moyen d'une source à ^{192}Ir.



Milliroentgenmeter equipped with gas counters for making radiation field measurements.

Milliroentgenmètre à compteurs à gaz pour le contrôle des champs de radiations sur le terrain, surtout pour les applications des radio-éléments.

are suitable for both field and laboratory use. Also on display were a paramagnetic resonance spectrometer used in laboratory studies. Examples were given of its application in chemistry, biology and medicine. This section also included a thermal neutron polarization analysis system.

Each of the items displayed was accompanied by a graphic presentation, comprised of photographs, transparencies, diagrams, etc., and illustrated well the possible applications in science and nuclear technology. The exhibit conveyed a clear picture of the progress and capability of Romanian industry in developing nuclear instrumentation.

The Romanian exhibit was organized by the State Committee for Atomic Energy.

ROUMANIE

(An English translation precedes this text)

Le stand de la République Socialiste de Roumanie était consacré au développement des composants pour réacteurs et autres installations nucléaires, des appareils pour les applications des rayonnements et des radioéléments dans l'industrie et l'agriculture, des appareils électroniques de mesures nucléaires et des appareils de recherche dans le domaine de la physique atomique et nucléaire.

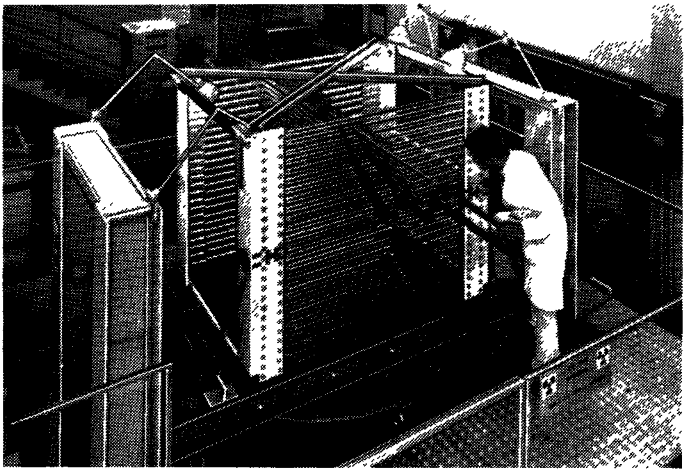
Parmi les principaux objets présentés figuraient un échantillon de barre de combustible nucléaire à base de matériaux vitrocéramiques UO_2 - SiO_2 et des filtres spiralisés pour la rétention des aérosols radioactifs avec l'appareillage pour le contrôle des propriétés de ces filtres.

Le matériel exposé comprenait un appareil portatif pour gammagraphie utilisant une source à ^{192}Ir, un appareil à rayons gamma pour la mesure des densités des liquides, une jauge de niveau et des relais à rayons gamma pour le contrôle des processus industriels. Autre dispositif particulièrement intéressant: un bêtatron transportable de 15 MeV pour le contrôle non destructif des pièces à parois épaisses. La Roumanie le fabrique à une assez grande échelle.

Plusieurs exemples intéressants d'appareils électroniques de mesures nucléaires et de détecteurs de rayonnements étaient exposés. Il y avait notamment un compteur d'impulsions portatif à sonde à scintillation pour les applications des radioéléments au laboratoire et sur le terrain, un électromètre à condensateur vibrant pour utilisation avec des chambres d'ionisation et un milliroentgenmètre à compteurs à gaz pour le contrôle des champs de rayonnements sur le terrain. Un spectrographe de résonance paramagnétique électronique pour des études en laboratoire était également exposé; des exemples de ses applications en chimie, biologie et médecine étaient donnés. Cette section comprenait aussi un système d'analyse de la polarisation des neutrons thermiques.

Une présentation graphique était associée aux appareils exposés, comprenant des photos, diapositives, etc., avec des aspects des réalisations roumaines dans les domaines de la recherche et des applications des sciences et techniques nucléaires.

Le stand roumain avait été organisé par le Comité d'Etat pour l'énergie nucléaire.



Nuclear engineering laboratory of the Swiss Federal Institute of Technology, Lausanne; the CACTUS sub-critical assembly.

SWITZERLAND

Stand 3

The theme of the exhibit was "Switzerland", a small, highly industrialized country, its traditions, its high-class products and its world-wide contacts. The stand was divided into three sections.

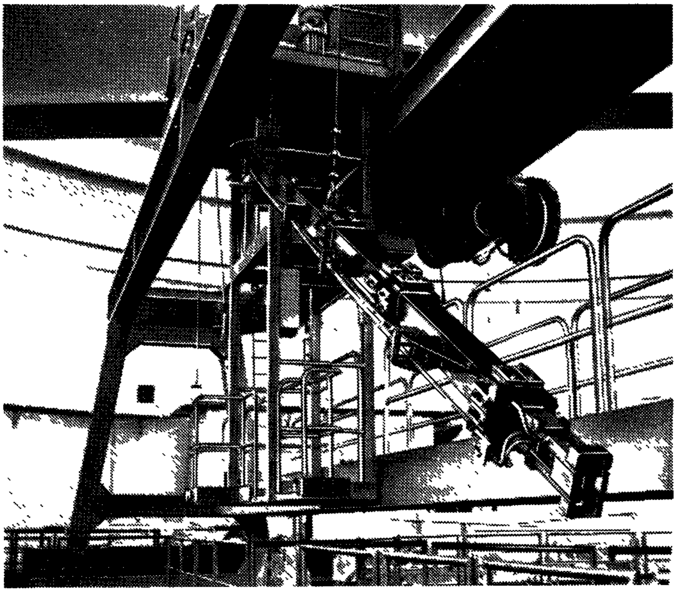
The first section dealt with the utilization of nuclear energy. By means of panels a detailed picture was given of the nuclear plants in service or being commissioned. This section also gave statistics of power demand, both past and projected, as well as the means of satisfying the demand. A map of Switzerland showed proposed locations for projected nuclear plants.

The second section had as its theme participation in research and development, and gave details of the Swiss institutes, universities and technical schools where training in nuclear science and technology is available. In the field of nuclear engineering the following were described: Project studies on reactor types including fast breeder reactors and high-temperature reactors; research in the physics of fast and thermal reactors using the zero-energy reactor PROTEUS; experiments on research reactors; out-of core thermodynamic studies; and research on nuclear fuels.

Applications of isotopes and radiation were described including the production of radioisotopes, radiobiology, nuclear medicine, radioisotope batteries, industrial developments, irradiation installations and food preservation by irradiation. One particularly interesting panel showed an industrial electron accelerator incorporated into a paint curing facility.

Descriptions were also given of advanced applications including research in magnetohydrodynamics and plasma physics.

The third section of the Swiss exhibit gave an account of Swiss industrial activities and world-wide relations. Included were panels describing the fabrication of reactor components of all sizes ranging from containment vessels over turbo-sets to circulators. A feature of this section was the varied range of consulting activities covering planning, technical studies and studies with regard to the realization of projects for nuclear power



The refuelling machine for the 306 MW(e) BWR of Mühleberg Power Station of the Bernische Kraftwerke AG.

plants. These were described through typical examples. Noteworthy was the portion dealing with studies on the thermal effects of heated cooling water on the river water and a model for cooling water studies.

The Swiss exhibit was concluded with a map of Switzerland indicating the principal centres of activity in the field of nuclear energy together with a map of the whole world showing where industrial firms or consulting engineering organizations have their main branches.

CONTRIBUTORS TO THE SWISS STAND

RESEARCH INSTITUTES

Arboricultural, Viticultural and Horticultural Research Station, Wädenswill;

Atomic Engineering Laboratory, Institute of Technology, Lausanne;

Battelle Institute, Geneva;

Centre for Plasma Physics Research, Lausanne;

Federal Institute for Reactor Research, Wurenlingen;

Institute of Radiobiology, Zurich University;

Radium Institute, Berne;

School of Physics, Basle University;

School of Physics, Geneva University;

University Medical Clinic, Lausanne;

POWER COMPANIES, INDUSTRY, CONSULTING ENGINEERS

Aare-Tessin AG für Elektrizität, Olten;

Ateliers de Charmilles, Geneva;

Baumgartner Frères, Grenchen;

Bernische Kraftwerke AG, Berne;

Bonnard & Gardel, Consulting Engineers, Lausanne;

Brown, Boveri & Co., Baden;

Consulting Engineers Suiselectra, Emch & Berger, Basle;

Electro-Watt Engineering Services, Zürich;

Energie de l' Ouest-Suisse, Lausanne;

Haefely & Cie., Basle;

Motor-Columbus, Consulting Engineers, Baden;

Nordostschweizerische Kraftwerke AG, Baden;

Société Générale pour l' Industrie, Geneva;

Sulzer Bros., Winterthur.

UNION OF SOVIET SOCIALIST REPUBLICS

Stand 11

The Soviet section of the Governmental Scientific Exhibition complemented in visual form the papers presented at the Fourth International Conference on the Peaceful Uses of Atomic Energy and reflected the achievements of Soviet scientists and engineers in nuclear science and technology. Fourteen new scientific and technical films were shown in a cinema with a seating capacity of 70; in addition, a number of automatic film projection units were in constant operation. The Soviet section also included a display of books on topics relating to atomic energy published during recent years in the Soviet Union.

The exhibits and their arrangement were fully in keeping with the motto of the Conference - "Atoms for Development".

Considerable space was devoted to illustrating the development of nuclear power generation in the Soviet Union. The Soviet Union is a country blessed with ample natural energy resources. Because of their uneven geographical distribution, however, industry in the European part of the USSR and in the Ural region - while possessing the necessary infrastructure, labour and raw materials - is faced with a growing shortage of energy available on economically reasonable terms. Accordingly, in the next five years it is planned to provide a significant expansion of nuclear power generation through the construction of large electric power stations based on reactors with unit capacities of 1000 MW(e) or more. By 1975, nuclear power stations with a total generating capacity of 6000 to 8000 MW(e) will be in operation, and by 1980 the total generating capacity of nuclear power stations in the Soviet Union will be 30 000 MW(e).

Models of reactors and nuclear power stations under construction and in operation in the Soviet Union were shown at the Exhibition. Among the most thoroughly proven reactor types are the pressure-vessel reactors already in operation at the Novo-Voronezh Nuclear Power Station (the first and second units) and at Melekess; further reactors of this type are under construction at Novo-Voronezh (the third and fourth units), at the Kola Nuclear Power Station and elsewhere. They were represented at the Exhibition by a reactor model and a diorama of the 440 MW Kola Nuclear Power Station.

The first nuclear power station, which was commissioned in the Soviet Union in 1954, was a channel-type reactor with graphite moderator. It was followed in 1958 by the Siberian Nuclear Power Station at Troitsk with a capacity of 100 MW(e) (its total capacity was increased in later years to 600 MW(e) by adding additional units), and in 1964 and 1967 by the first and second units of Kurchatov Nuclear Power Station at Beloyarsk, with a total capacity of 300 MW(e); all these reactors are of the channel type. The reactors at the Beloyarsk Nuclear Power Station have an excellent radiation safety and reliability record and have demonstrated the feasibility of nuclear steam superheating on an industrial scale. At the Exhibition, a model of the second unit of the Beloyarsk Nuclear Power Station and a diorama illustrated the design of such reactors.

The channel principle of reactor design proved to be so attractive that it was decided to develop reactors of the channel type with capacities up to 2000 MW(e). A nuclear power station with two channel-type reactors having a total capacity of 2000 MW(e) is under construction near Leningrad. Its design permits of fuel-cycle optimization and the use of high-quality core components mass-produced at low cost. A model of one of the reactors being built near Leningrad and a diorama of the station were displayed.

Fast reactors are a means of making the most effective use of nuclear source materials, permitting the introduction of uranium-238 and thorium into the fuel cycle. Intensive work is being done in the USSR on fast reactors. Following a series of experimental fast reactors of low thermal capacity (BR-1, BR-2, BR-3, BR-5, BFS), the 60 MW(th) research reactor BOR-60 was commissioned in 1970. Nearing completion at Shevchenko is a nuclear power station with a fast reactor (BN-350) that will have an equivalent output of 350 MW(e) and which is coupled to a desalting plant. In addition, construction work has begun on the third unit of the Beloyarsk Nuclear Power Station, which will be powered by a 600 MW(e) fast reactor (BN-600). The operation of these three fast reactors, models of which were shown at the Exhibition, will provide the experience necessary for a major program of fast-reactor power station construction, this being the general trend in the development of nuclear power.

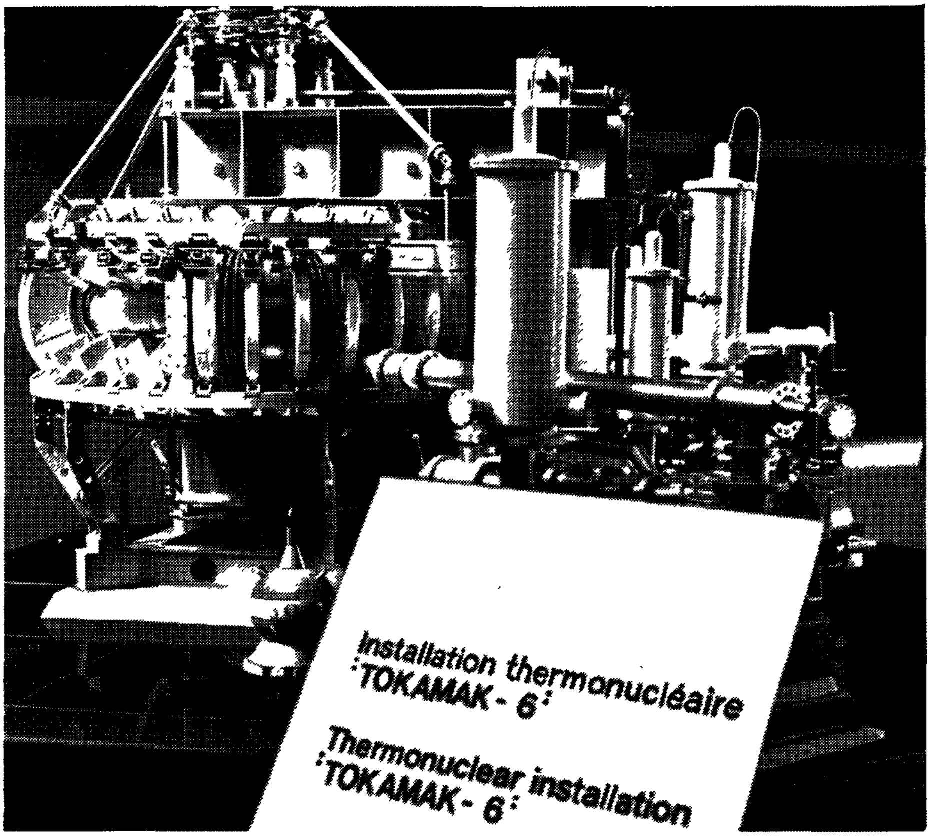
Also shown at the Exhibition were actual fuel assemblies of a number of research and power reactors, including assemblies from the second unit of the Beloyarsk Nuclear Power Station used for steam generation and superheating to over 500°C, assemblies from the Leningrad Nuclear Power Station, the fabrication of which is based on recent advances in the production of heat-resistant zirconium alloys for the pressure tubes and cladding of the uranium oxide fuel rods, an assembly from the second unit of the Novo-Voronezh Nuclear Power Station, and several fast-reactor fuel assemblies.

The economics of nuclear power depend to a great extent on the technology of nuclear fuel reprocessing. With any reprocessing system, the chemical apparatus used must be extremely reliable and must lend itself to remote handling. These requirements are met by the extractors, filter-thickeners, pumps, chemical reaction vessels and other pulsation equipment produced in the Soviet Union, which are highly efficient and have no moving parts. These various forms of pulsation equipment subject reagents to low-frequency reciprocating motion, which in turn is converted into motion of the required kind (translational, rotary, spiral, etc.) by means of stationary deflectors of different designs.

Another Soviet exhibit was an industrial pneumatic pulsator capable of long-term maintenance-free operation and designed for flexible control of the pulsation intensity. A multi-chamber extractor of the mixer-settler type on display at the Exhibition is particularly suited for work in hot cells. It has 17 stages, each of which is equipped with a pulsation mixer and a pump. All operate from one pulsator, which is connected with the extractor by a tubular collector.

A pulsation pump, made of clear plastic, was shown operating with a closed fluid circuit. A filter-thickener with pulsed current regeneration was shown together with a pulsator. The principle of operation was demonstrated by the separation, in a closed-circuit system, of a suspension into a filtrate and a thickened pulp.

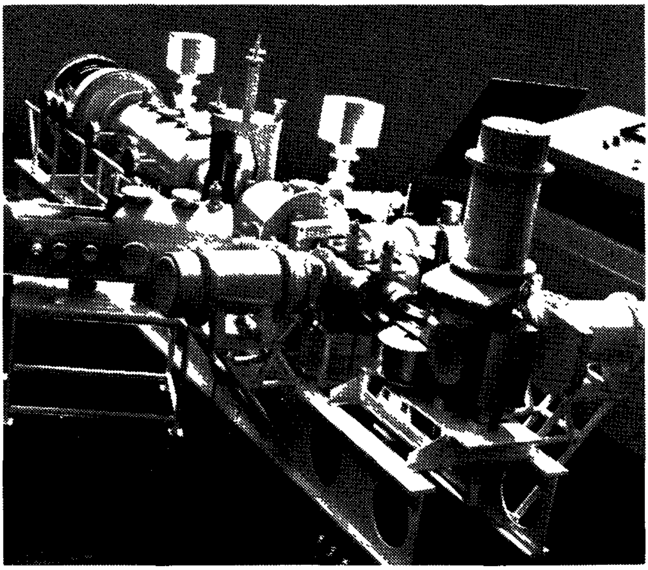
High-efficiency packing material, developed for 76, 200, 600 and 900 mm pulsation columns and possessing a permeability 2.5 times that



A model of Tokamak-6, the latest of this series of thermonuclear devices.

Макет новейшей модели Токамак-6 из серии термоядерных установок.

USSR/CCCP



Model of OGRA-3 device.

Модель установки ОГРА-3.

of the materials normally used, was also shown. The efficiency of all the columns, from 76 mm to 900 mm, was the same, this being the main advantage of the packing material in question.

A method of power generation which holds great promise for the future is nuclear fusion – the utilization of the energy released in the fusion of light elements. Fusion, a thermonuclear reaction, can occur only when the nuclear fuel (light elements) is heated to very high temperatures – some hundreds of millions of degrees. Almost all methods for producing and confining hot plasmas are based on the principle of providing thermal insulation by means of a magnetic field.

Soviet scientists are engaged in an extensive program of thermonuclear fusion investigations, and the exhibits reflected the three main lines of research:

1. Closed magnetic traps;
2. Open magnetic traps;
3. Devices of the "plasma focus" type.

The first type was represented by a model of the latest Tokamak device – Tokamak-6. This device is distinguished from its predecessors by the absence of a diaphragm limiting the diameter of the plasma column and by the arrangement of the copper stabilizing sheath. Tokamak-6 is being used for the verification of theoretical deductions.

A model of LIN-5 demonstrated the operating principle of the devices used in the second line of research. LIN-5 is a device of the Ogra or PR-6 type, differing from them in that it has superconducting windings. In LIN-5, the magnetic trap is filled by injecting a beam of neutral atoms with an equivalent current of 0.5 A.

The third line of research was represented at the Exhibition by the working experimental device termed "Belka" (Squirrel). In this device, the plasma is produced by a capacitor bank discharge between two specially shaped electrodes in a deuterium gas atmosphere. The discharge proceeds in such a way that the plasma accumulates in a small volume of 0.1 cm^3 (plasma focus). The density and temperature of the plasma at the focus are very high, which gives rise to thermonuclear reactions and neutron emission. The plasma in the "Belka" device can be observed through special windows.

The large thermonuclear research program has stimulated intensive work in several allied fields of science and technology. Considerable success has been achieved, especially in high-current pulse technology and in the physics and engineering of powerful pulsed magnetic fields. The prerequisites now exist for using the technological knowledge gained in thermonuclear experiments to solve practical problems in other fields.

A further Soviet exhibit was a magnetic-pulse device (MIS-5) designed for hermetically sealing reactor fuel element cans. The end of the tubular can material is introduced into a single-turn coil in which a strong pulsed magnetic field is induced. The magnetic pressure causes radial compression of the tube end, forming a "solid" rod. This process occurs without melting the metal, gives rise to virtually no welding seam and ensures 100% hermetic sealing of fuel elements.

MIS-5 consists of a magnetic section (a pulsed, multiplex-operation solenoid) fed by a pulsed-current generator of the capacitance type. The main characteristics of MIS-5 are: magnetic field strength 600 kOe; operating frequency 150 kHz; capacitor energy 40 kJ; and power consumption of 5 kW. The MIS-5 device, which is provided with a system for introducing the end of the tubular material into the coil for sealing, can operate automatically, performing up to 100 operations in an hour.

Working installations, models, photographs and charts gave a graphic picture of Soviet achievements in the field of controlled fusion and illustrated some of the applications of thermonuclear technology.

Five main branches of radiation technology were represented at the Exhibition:

1. Radioisotopic power generation;
2. Large irradiation devices;
3. Apparatus for the elemental analysis of materials;
4. Flaw detection;
5. Therapeutic equipment.

From the wide range of radioisotopic thermoelectric generators developed in the USSR, the Exhibition featured generators of the "Beta-S" and "Penguin" types, with strontium-90 sources, and a thermal energy generator which has a polonium-210 source; the latter is of the same type as that of the automatic lunar laboratory Lunokhod-1. The performance of these generators is impressive: The operating life of a "Beta-S" generator, which is widely used for powering automatic radiometeorological stations and other terrestrial installations, is 10 years; "Penguin" generators supply energy to stations measuring variations in the Earth's magnetic field; the polonium-210 generator supplying thermal energy to the thermostat system of Lunokhod-1 has been functioning for about a year.

In the field of radiation chemistry, several commercial processes have been developed in the Soviet Union either for making the existing technology more efficient or for obtaining substances with valuable new properties.

Among the processes belonging to the former category is the radiation-induced sulphochlorination of paraffin hydrocarbons, which was achieved in the Soviet Union on an industrial scale in 1966. The monosulphochloride resulting from the reaction is an intermediate in the production of highly efficient biodegradable emulsifiers and detergents. The radiation sulphochlorinator, a model of which was shown at the Exhibition, does not have the disadvantages inherent in existing photochemical sulphochlorinators and its productivity is approximately 20 times as high. Its compactness, its simplicity and virtually absolute safety of operation, its efficient (~ 70%) utilization of radiation and its high economic efficiency indicate that the process has a great future in large-scale sulphochlorination.

Also shown at the Exhibition was a flow diagram display illustrating equipment for the radiation-induced telomerization of ethylene. The equipment consists of two main parts – a telomerization section and a rectification section. The telomerization section has two radiation chemistry reaction vessels with a radiation utilization factor of 38%. Another type of equipment was represented by a functional diagram demonstrating the irradiation of polyethylene insulation of electric cables. An electron accelerator of the transformer type, ELT-1.5, is used as ionizing radiation source. By means of a conveyor system, designed so as actually to delimit the irradiation zone, the cables are passed repeatedly through the electron beam zone (beam scanning area 200 cm^2). To allow for the screening effect of the cable core, the cable is turned through 180° (irradiation from two sides) or 90° (irradiation from four sides) after each traversal.

By passing through the irradiation zone several times, the cables accumulate the required dose during "active" cycles which alternate with "idle" cycles. This system of "fractional" irradiation solves the problem of heat removal. The coefficient of radiation utilization in the polymer material is 70-85% when two conveyor systems are operated together. Models were also shown of various pilot-scale irradiation facilities: the "Issledovatel" ("Investigator"), UGU-200 and others.

Various nuclear physics methods are being used successfully by Soviet scientists for analysing the composition of matter; of these, activation analysis and X-ray radiometry are the most widely used. The development of activation techniques has been helped by the wide use of different types of radiation sources, including new types developed in recent years especially for fundamental analysis. They include: nuclear reactors of the RG-1M and IIN types; fast neutron generators of the NGI-1, NGI-4, NGI-5, NG-160A and NG-150I types, with accelerator tubes evacuated and then sealed by welding; betatrons; microtrons; and neutron sources based on transuranium isotopes.

Reactors of the RG-1M and IIN types serve as a basis for the design and construction of standard activation analysis laboratories.

A model of an activation analysis laboratory based on an IIN solution-type reactor illustrated the techniques used for activation and measuring the activity of samples.

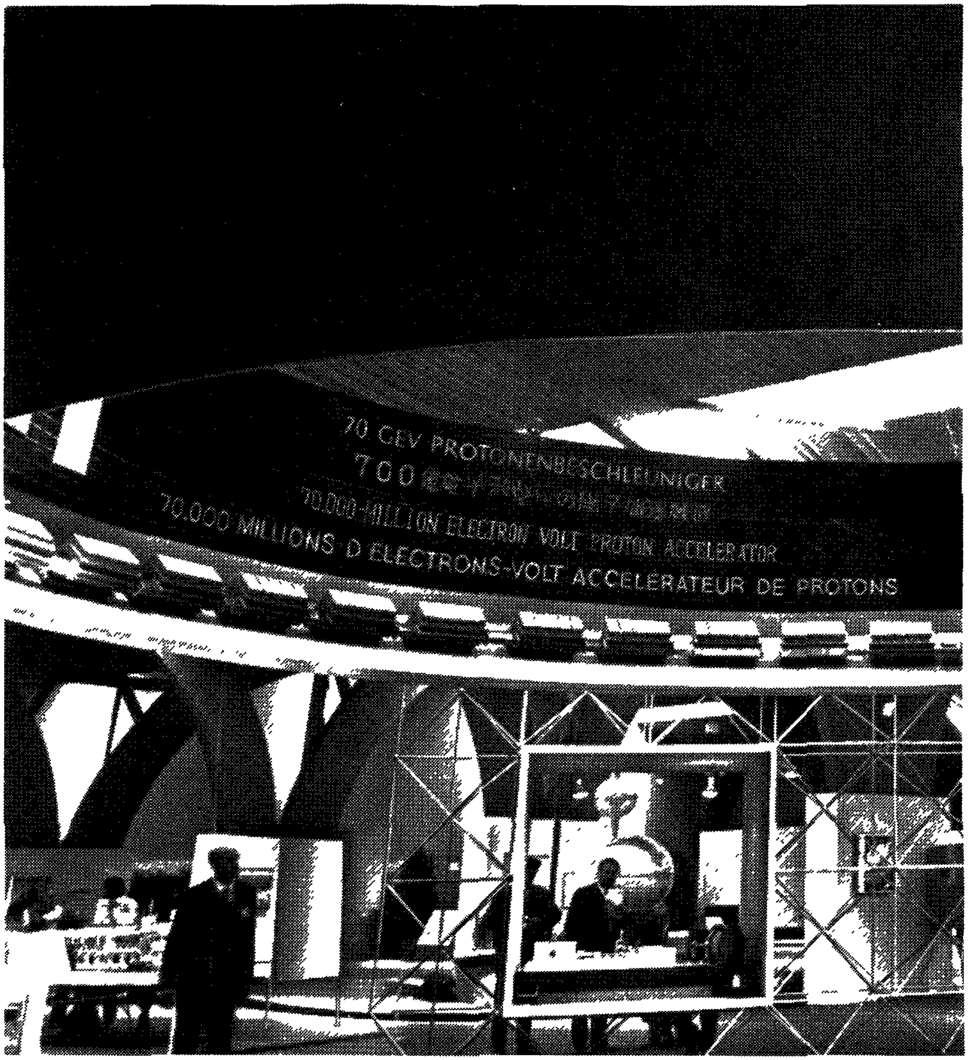
Sub-critical assemblies (neutron multipliers) are also used for activation analysis, and a moving display illustrated the cycle of measurements performed with a neutron multiplier – a facility which enables one to obtain a flux of 1.3×10^7 n/$cm^2 \cdot$ sec. The neutron multiplier illustrated at the Exhibition has one horizontal and three vertical channels equipped with pneumatic rabbit systems and a system for measuring induced activity.

From the wide range of generators developed in the Soviet Union, the Exhibition featured a neutron generator of the NG-150I type, which yields 2×10^{11} n/sec and is remarkably compact and reliable.

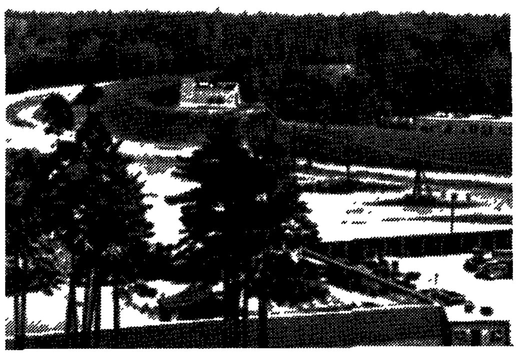
Illustrating the industrial, automated activation analysis facilities which have been developed in the Soviet Union, a model was shown of the "Kislorod" ("Oxygen") system. Electronic systems for automating the analytical processes provide for programmed control of the facility and computation of the percentage concentration of the element of interest from induced-activity data.

X-ray radiometric apparatus was represented by two instruments: "KTN-1", for determining tantalum and niobium in solutions, and "AZhR-1", for determining iron in powder samples. The sensitivity threshold is in the range 10^{-3} to 10^{-1}%, while a determination takes up to 10 min.

Radiographic methods are widely used in the Soviet Union for quality control. The flaw detectors which have been developed enable radiographic examinations to be made under almost any conditions. They are remarkably compact and reliable, and can be reloaded without interruption of the production process. The "Gazprom" flaw detector is designed mainly for



ABOVE: The impressive display modelling the 70 GeV proton accelerator at Serpukhov that formed a central feature of the USSR stand.
RIGHT: The actual Serpukhov installation giving a clear picture of the diameter of the toroidal path.



НАВЕРХУ: Модель Серпуховского протонного ускорителя на энергию 70 ГэВ в центральной части советского раздела выставки.
СПРАВА: Общий вид Серпуховского протонного ускорителя с изображением диаметра тороидального пути.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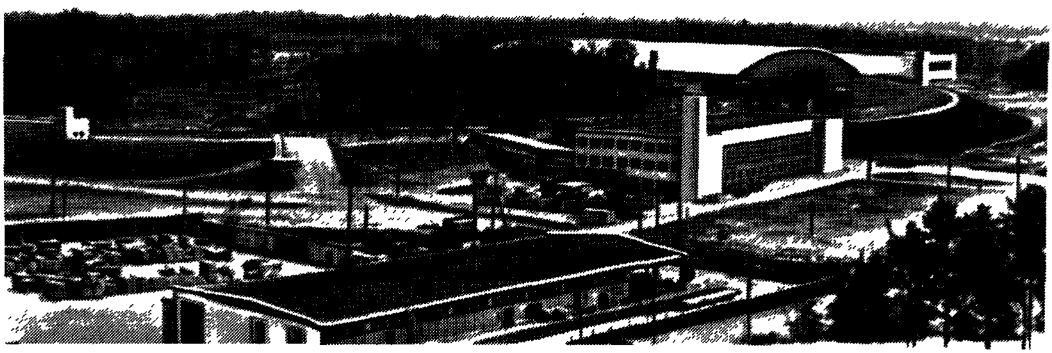


the examination of gas pipes; the "RID-11" is for use under factory conditions; the "Stapel" flaw detector is designed for use in shipyards.

Optimization methods and techniques for automating irradiation procedures are widely used in radiotherapy. One of the Soviet exhibits was "Agat-V", a facility for irradiating malignant tumours in natural cavities of the human body.

Recent advances in electronics are applied extensively in the Soviet Union in the manufacture of nuclear instruments. The use of semiconductor elements, and especially integral circuit elements, has lead to the development and routine production of instruments based on third-generation circuitry of increased stability, reliability and compactness.

A large selection of nuclear instruments for dosimetry, concentration determination and spectrometry was shown in the Soviet section of the Exhibition. It included a full range of spectrometry instruments for detecting (by scintillation and solid-state techniques), amplifying, converting and recording signals associated with nuclear particles.

One standardized set of detection units covers the entire energy range, with a caesium-137 gamma line resolution of 8.5 to 12.5 keV. It includes scintillators ranging in size from 25 mm diam. × 25 mm to 150 mm diam. × 100 mm, appropriate photomultipliers and a standardized electronic unit. A set of silicon and germanium solid-state detectors giving an improved resolution of 3 to 5 keV, with a minimum threshold of 0.5 keV, has been developed to the stage of routine production.

The "Langur" gamma spectrometer, developed for use with semiconductor detectors, measures the spectra of X-ray and gamma photons with energies ranging from a few keV to 1 MeV.

Recording instruments were represented by the AIMA-10^6-M and AI-256-6 analysers.

The million-channel analyser AIMA-10^6-M enables one to measure an energy distribution represented in the form of pulse amplitudes, time intervals or sensor co-ordinates. With it one can, in addition, carry out preliminary processing of the input data which can also be displayed visually and transferred to external units.

An important feature of the AIMA-10^6-M analyser is the combination of a periodic memory in the form of a rapidly moving magnetic drum – used as the main memory unit – with an auxiliary memory for the intermediate storage of information.

The multichannel analyser AI-256-6 is designed for use with scintillation and semiconductor detectors under laboratory and field conditions; it can accordingly be powered either from the mains or by accumulators.

A highly original solution to the problem of building the memory unit of the AI-256-6 analyser made it possible to reduce substantially the cost of components while maintaining the storage capacity. The analyser has 256 channels, each with a capacity of 2^{16}-1 (65535).

The system for pulse amplitude conversion to digital form gives a differential non-linearity of ± 2% over 98% of the scale.

The cassiterite analyser MAK-1, based on the Mössbauer effect, may be regarded as an example of instruments for determining the composition of different substances. The analyser is designed for the rapid determination of the concentration by weight of tin oxide in powder samples, a technique employed in geology for evaluating deposits. In analyses of powder deposits, the range of tin concentrations which can be covered by the cassiterite analyser is 0.05% to 4%. The minimum sample amount is 1 to 3 g, while the mean time for a measurement is 10 to 15 min.

Various types of accelerator, for both research and industrial use, were represented at the Exhibition. Among them was the 70 GeV proton synchrotron of the Institute of High-Energy Physics at Serpukhov. The maximum proton energy obtained with it so far is 76 GeV, while the maximum intensity achieved is 1.5×10^{12} protons in a pulse; the latter is to be increased by the addition of a special booster.

Scientists from all over the world - from the socialist countries, France, the United States of America, and from international organizations such as the Joint Institute for Nuclear Research at Dubna and CERN at Geneva – are taking part in various research programs. New transuranium elements with the atomic numbers 104 and 105 in Mendeleev's Periodic Table have been obtained by a group under Academician G. N. Flerov working with a multicharge ion accelerator (a 310 centimetre cyclotron) at JINR. The search for new transuranium elements using this machine is continuing.

At the Exhibition, a model representing the "collective acceleration of charged particles" demonstrated the possibility of devising new particle acceleration methods based on the use of collective interactions. With collective methods, the accelerating field is produced by a group (bunch) of charges. The field strength is proportional to the number of charges in the bunch. The ions trapped by the electron bunch will be accelerated by the bunch's own field; the electron bunch itself may in turn be accelerated by external fields of moderate strength. The model showed the injector (a linear induction accelerator with E = 3 MeV and I_n = 2000 A per pulse), the ion trapping device (адгезатор) and the acceleration system with superconducting resonators.

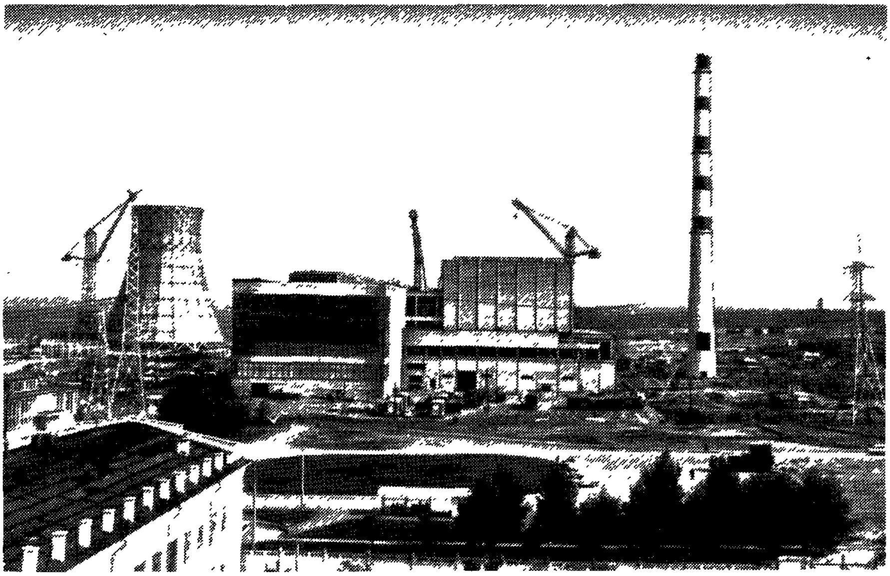
The linear electron accelerator LUE-15-10 is designed for use in radiation chemistry. Accelerator parameters were chosen such that it is possible to establish different irradiation regimes depending on the materials in question; the energy can be varied between 5 MeV and 15 MeV, while the electron beam power can be as high as 10 kW. The accelerator has a system for bending the beam through an angle of 90° and one for scanning an area of 500 cm × 25 cm. A further linear electron accelerator, LUE-8-5, is designed for industrial use – mainly for sterilizing medical instruments and blood transfusion systems as they pass on a conveyor.

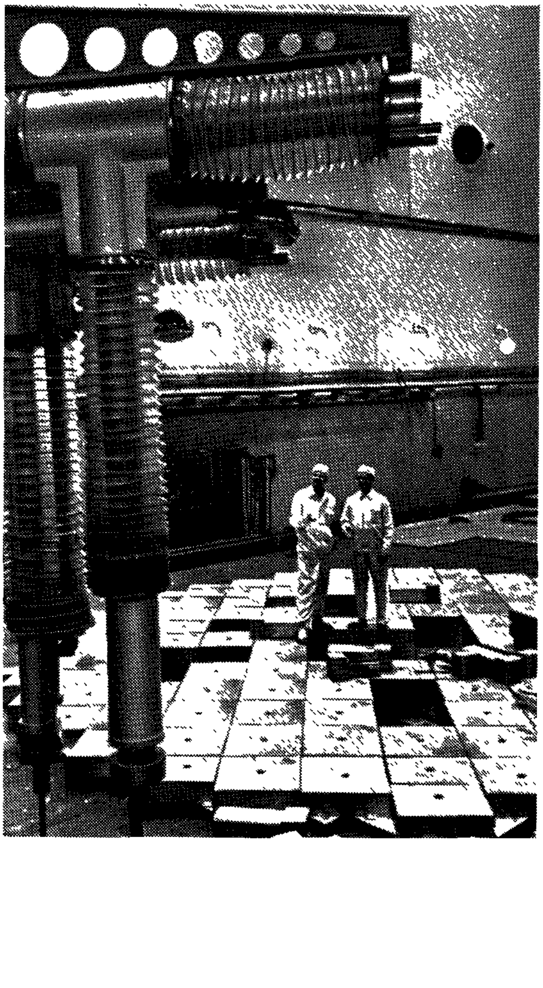
The energy of the accelerated electrons is 8 MeV, while the electron beam power is 5 kW. The accelerator also has a system for scanning an area of 500 cm × 25 cm.

Soviet scientists and engineers at the Institute of Theoretical and Experimental Physics are working on equipment for the irradiation of small intracranial targets with a proton beam. A 7 GeV synchrotron is being used for this purpose. The accelerator is adapted so as to permit work with a 200 MeV proton beam, which is used for medical treatment during intervals between the main acceleration cycles. This work was described in the exhibit.

A model representing stereotactic equipment for the irradiation of intracranial targets was shown at the Exhibition.

The Soviet exhibits attracted the attention both of specialists attending the Conference and of the general public. Together with the Soviet papers presented at the Conference, they reflected the achievements of Soviet scientists in controlling the forces and discovering the secrets of Nature.





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ABOVE: Third and fourth PWR units under construction at the Novo-Voronezh Nuclear Power Station (August 1970).
LEFT: Remote-control manipulator in the reactor hall of the Kurchatov Nuclear Power Station at Beloyarsk.

НАВЕРХУ: Строительство третьего и четвертого блоков Ново-Воронежской атомной электростанции (август 1970г.).
СЛЕВА: Манипулятор с дистанционным управлением в реакторном зале Белоярской атомной электростанции им. И.В.Курчатова.

СОЮЗ СОВЕТСКИХ СОЦИАЛИСТИЧЕСКИХ РЕСПУБЛИК

(An English translation precedes this text)

Представленные в советском разделе научно-технической выставки экспонаты являлись наглядной иллюстрацией к материалам IV Женевской конференции по мирному использованию атомной энергии и отражали достижения советских ученых и инженеров в развитии атомной науки и техники. В кинозале на 70 мест демонстрировались 14 новых научно-технических фильмов. Непрерывно работало несколько автоматических киноустановок. На выставке был организован показ книг по атомной тематике, изданных за последние годы в Советском Союзе.

Демонстрация экспонатов и оформление выставки в максимальной мере отвечали девизу конференции — "атом на службе прогресса".

Большой раздел выставки был посвящен развитию атомной энергетики в Советском Союзе. Советский Союз относится к числу стран, хорошо обеспеченных природными энергетическими ресурсами. Однако, из-за их неравномерного распределения по территории страны, промышленность Европейской части СССР и Урала, обеспеченная материально-технической базой и сырьем, испытывает возрастающий дефицит экономичных топливо-энергетических ресурсов. Поэтому в ближайшее пятилетие предусмотрено значительное развитие атомной энергетики путем строительства крупных электростанций с установкой реакторов единичной мощностью 1 млн. кВт и выше. К 1975 г. должны быть введены в действие атомные электростанции (АЭС) мощностью 6-8 млн.кВт, а к 1980 г. общая мощность АЭС составит 30 млн. кВт.

На выставке были представлены макеты реакторов и атомных электростанций, сооружаемых и эксплуатируемых в Советском Союзе. К числу наиболее освоенных типов реакторов относятся реакторы корпусного типа, действующие на первом и втором блоках Ново-Воронежской АЭС и в Мелекессе, а также устанавливаемые на третьем и четвертом блоках Ново-Воронежской АЭС, на Кольской АЭС и др. Этот тип реакторов представлен на выставке макетом реактора и диарамой Кольской АЭС электрической мощностью 440 МВт.

Первая атомная электростанция, пущенная в Советском Союзе в 1954 г., имеет реактор канального типа с графитовым замедлителем. Затем были построены и введены в эксплуатацию: в 1958 г. — Сибирская АЭС в Троицке — 100 МВт(эл), мощность которой впоследствии была доведена до 600 МВт(эл) путем строительства дополнительных блоков; в 1964 г. — первый и в 1967 г. — второй блоки Белоярской АЭС им.И.В.Курчатова общей мощностью 300 МВт(эл) с реакторами такого же типа. Эксплуатация реакторов Белоярской АЭС продемонстрировала их высокую радиационную безопасность и надежность и доказала возможность осуществления ядерного перегрева пара в промышленных масштабах. Установленный на выставке макет второго блока Белоярской АЭС с диарамой станции дает представление о конструкции таких реакторов.

Канальный принцип конструкции оказался настолько перспективным, что было принято решение о разработке реакторов такого типа мощностью до 2000 МВт(эл). Атомная электростанция такого типа с двумя реакторами общей мощностью 2000 МВт(эл), сооружаемая сейчас под Ленинградом, обеспечивает возможность оптимизации топливного цикла и комплектации активной зоны изделиями, производящимися крупносерийно, что обеспечивает их высокое качество при низкой стоимости. Макет реактора и диарама Ленинградской АЭС демонстрировались на выставке.

Быстрые реакторы позволяют наиболее эффективно использовать исходное ядерное горючее, применяя в топливном цикле также уран-238 и торий. В СССР ведутся интенсивные работы по быстрым реакторам. Вслед за серией экспериментальных быстрых реакторов небольшой тепловой мощности (БР-1, БР-2, БР-3, БР-5, БФС) в 1970 г. был введен в строй опытный реактор БОР-60 тепловой мощностью 60 МВт. Заканчивается строительство АЭС с реактором БН-350 с эквивалентной мощностью 350 МВт(эл) в г.Шевченко, совмещенной с опреснительной установкой. Начато строительство третьего блока Белоярской АЭС мощностью 600 МВт(эл) с реактором БН-600. Эксплуатация этих трех реакторов на быстрых нейтронах, макеты которых были представлены на выставке, дает возможность получить необходимый опыт для широкого строительства мощных АЭС с реакторами такого типа, что является генеральной линией развития атомной энергетики.

На выставке были также представлены натурные тепловыделяющие сборки ряда исследовательских и энергетических реакторов. В частности, демонстрировались испарительная и пароперегревательная топливные сборки второго блока Белоярской АЭС, с помощью которых осуществляется ядерный перегрев пара (выше 500°C), тепловыделяющие сборки Ленинградской атомной электростанции, при изготовлении которых используются современные достижения ядерной технологии жаропрочных циркониевых сплавов для труб давления и оболочек стержневых тепловыделяющих элементов с сердечниками из окиси урана, кассета второго блока Ново-Воронежской АЭС, а также несколько кассет для реакторов на быстрых нейтронах.

Экономика атомной энергетики в значительной мере зависит от технологии переработки ядерного горючего. При любом способе переработки к химической аппаратуре предъявляются повышенные требования в отношении надежности; обязательной является возможность дистанционного обслуживания. Таким требованиям отвечает разрабатываемое в СССР пульсационное оборудование. Разработаны экстракторы, фильтры-сгустители, насосы, химические реакторы различного назначения и т.п. Пульсационное оборудование характеризуется высокой эффективностью и полным отсутствием движущихся частей. В этих аппаратах рабочие реагенты подвергаются низкочастотным возвратно-поступательным колебаниям, которые, в свою очередь, преобразуются в движение необходимой формы (поступательное, вращательное, спиральное и т.д.) с помощью неподвижных направляющих аппаратов различной конструкции.

На выставке был представлен промышленный пневматический пульсатор. Его конструкция предусматривает длительную эксплуатацию без ремонта и гибкое регулирование интенсивности пульсации. Особенно удобен для работы в горячих камерах лабораторный многокамерный экстрактор типа смеситель-отстойник, представленный на выставке. Аппарат имеет 17 ступеней, каждая из которых снабжена пульсационной мешалкой и насосом. Все эти устройства работают от одного пульсатора, соединенного с экстрактором трубчатым коллектором.

На выставке демонстрировался действующий пульсационный насос, снабженный замкнутым жидкостным контуром. Насос выполнен из органического стекла. Фильтр-сгуститель с пульсационной токовой регенерацией был установлен на стенде вместе с пульсатором. На суспензии в замкнутых контурах по фильтру и сгущенной пульпе демонстрировался принцип действия установки.

Был представлен также набор пакетной экстракционной насадки для пульсационных колонн диаметром 76, 200, 600 и 900 мм. Эта насадка обладает по сравнению с известными насадками в 2,5 раза большей пропускной способностью и высокой эффективностью. Эффективность всех колонн от 76 до 900 мм одинакова, и это является основным преимуществом подобной насадки.

Для энергетики будущего весьма перспективным представляется использование реакций синтеза легких элементов. Термоядерная реакция может протекать лишь в случае, когда ядерное горючее нагрето до очень высокой температуры – сотен миллионов градусов. В основу многих методов удержания горячей плазмы положен принцип ее термоизоляции с помощью магнитного поля.

В Советском Союзе проводятся обширные исследования по программе термоядерного синтеза. Представленные на выставке экспонаты отражают достижения Советского Союза по трем основным направлениям термоядерной программы:

1. Замкнутые магнитные ловушки.
2. Открытые магнитные ловушки.
3. Устройства типа "Плазменный фокус".

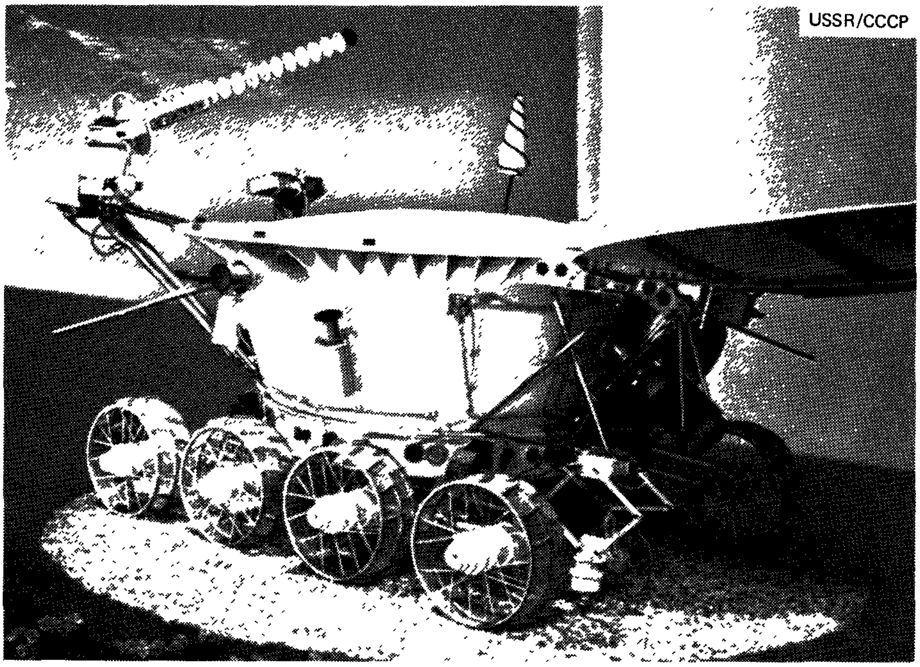
Первое из перечисленных направлений представлено макетом новейшей модели Токамаков – Токамака-6. Эта установка отличается от предыдущих отсутствием диафрагмы, ограничивающей диаметр плазменного шнура, и близким расположением медного стабилизирующего кожуха. На установке Токамак-6 проводятся исследования по проверке выводов теории.

Макет установки ЛИН-5 демонстрирует устройство и принцип действия установок второго направления. ЛИН-5 – установка типа Огры или ПР-6, отличающаяся однако от них наличием сверхпроводящих обмоток. Заполнение магнитной ловушки плазмой осуществляется в ЛИН-5 инжекцией пучка нейтральных атомов с эквивалентным током 0,5 А.

Третье направление представлено на выставке действующей экспериментальной установкой "Белка". Плазма в этой установке создается при разряде конденсаторной батареи между двумя электродами специальной формы в дейтериевом газе. Процесс разряда протекает так, что плазма стягивается в малый объем $\sim 0{,}1$ см^3 (плазменный фокус). Концентрация и температура плазмы в фокусе достигают высоких значений, что приводит к термоядерным реакциям и появлению нейтронов. Плазму в установке "Белка" можно было наблюдать через специальные окна.

Осуществление широкой программы работ по проблеме термоядерного синтеза стимулировало интенсивное развитие ряда смежных областей науки и техники. Большие успехи, в частности, были достигнуты в области сильноточной импульсной техники, а также в области физики и техники сильных импульсных магнитных полей. Были созданы предпосылки для использования достижений техники термоядерного эксперимента для решений прикладных задач.

На выставке была представлена действующая магнитно-импульсная установка МИС-5, предназначенная для герметизации защитных оболочек тепловыделяющих элементов (твэл) атомных реакторов. Для осуществления процесса герметизации конец защитной оболочки вводится внутрь



An exact replica of the Lunokhod-1, the Soviet remote-controlled exploratory vehicle on the moon, was a particular feature of the exhibit. The moon vehicle uses a polonium-210 powered thermal energy generator to operate the vehicle's thermostat system.

Модель советской автоматической станции "Луноход-1" для исследования лунной поверхности была наиболее примечательным экспонатом выставки. Генератор тепловой энергии на полонии-210 обеспечивает термостатирующую систему этой станции.

The "Rokus" 4000 Ci ^{60}Co α-therapy device (2 cm diam. beam).

Гамма-терапевтическая установка "Рокус" с источником ^{60}CO мощностью 4 000 Ки (диаметр пучка луча-2 см).

одновиткового соленоида, в котором возбуждается сильное импульсное магнитное поле. Под действием магнитного давления происходит радиальное сжатие конца трубки, завершающееся образованием монолитного стержня. Процесс происходит без расплавления металла, а сварной шов практически отсутствует. Это обеспечивает 100%-ю гарантию герметичности твэлов.

Установка МИС-5 состоит из магнитного инструмента – импульсного соленоида многократного действия и питающего его генератора импульсного тока емкостного типа. Основные характеристики установки МИС-5:

Амплитуды магнитного поля	– до 600 кэ
Рабочая частота	– до 150 гкц
Запас энергии в батарее	– до 40 кдж
Потребляемая мощность	– 5 кВт.

Установка МИС-5, укомплектованная устройством для подачи герметизируемых изделий в индуктор, может работать в автоматическом режиме с производительностью до 100 операций в час.

Действующие установки, макеты, фотографии и таблицы, представленные на выставке, дают наглядное представление о достижениях СССР в области управляемого синтеза и некоторых технологических применений техники термоядерного эксперимента.

Радиационная техника была представлена на выставке пятью основными направлениями:

1) радиоизотопная энергетика,
2) мощные радиационные установки,
3) аппаратура элементного анализа состава вещества,
4) дефектоскопия,
5) терапевтическая аппаратура.

Из широкого класса радиоизотопных термоэлектрических генераторов, разработанных в СССР, на выставке были представлены генераторы на стронции-90 типа "Бета-С" и "Пингвин", а также генератор тепловой энергии на полонии-210, установленный на автоматической лунной лаборатории "Луноход-1". Генераторы обладают высокими эксплуатационными характеристиками; так, срок службы генератора "Бета-С" составляет 10 лет, он широко используется для питания автоматических радиометеорологических станций и других устройств наземного назначения. Генератор "Пингвин" используется для питания магнитных вариационных станций. Генератор на полонии-210 около года обеспечивает тепловой энергией термостатирующую систему "Лунохода-1".

В Советском Союзе осуществлены в промышленном масштабе несколько радиационно-химических процессов с целью эффективного усовершенствования существующей технологии, а также получения веществ с новыми ценными свойствами.

К числу радиационно-химических процессов, приводящих к усовершенствованию существующей технологии, относится радиационное сульфохлорирование парафиновых углеводородов, осуществленное в СССР в промышленном масштабе в 1966 г. Получающийся в результате реакции моносульфохлорид является полупродуктом в производстве высокоэффективных биоразлагаемых эмульгаторов и детергентов. Представленный в виде макета радиационный сульфохлоратор типа ЭРС-10 лишен недостатков, присущих существующим фотохимическим сульфохлораторам. Производительность радиационного сульфохлоратора ЭРС-10 примерно в 20 раз выше производительности фотохимического.

Компактность установки, простота ее практического использования, высокая степень эффективности использования излучения (~ 70%), практически абсолютная безопасность обслуживания, а также высокие экономические показатели делают установку весьма перспективной для использования в крупномасштабном производстве. На выставке была представлена также технологическая схема радиационной теломеризации этилена. Технологическая схема состоит из двух основных частей: отделения теломеризации и отделения ректификации. Отделение теломеризации имеет два радиационно-химических реактора с коэффициентом использования излучения 38%. Второй тип установок представлен кинематической схемой облучения полиэтиленовой электрической изоляции кабельных изделий. В качестве источника ионизирующего излучения используется ускоритель электронов трансформаторного типа ЭЛТ-1,5. Конвейерное устройство, формирующее собственно зону облучения, позволяет пропускать кабельные изделия в зоне электронного пучка (площадь развертки пучка 200 $см^2$) многократно с поворотом на 180° после каждого прохода для устранения экранирующего эффекта жилы (двустороннее облучение) или с поворотом на 90° (четырехстороннее облучение).

Многократное пропускание кабельного изделия через зону облучения позволяет набрать требуемую дозу отдельными циклами, чередующимися с нерабочими циклами. Такая система "дробного" облучения решает проблему теплоотвода. Коэффициент использования излучения в полимерном материале при совмещенных двух конвейерных системах составляет 70 ÷ 85%. Были представлены также макеты различных облучательных установок исследовательского и полупромышленного типа: "Исследователь", УГУ-200 и др.

В СССР успешно используются различные ядерно-физические методы анализа состава вещества, из которых наибольшее практическое применение находит активационный и рентгенорадиометрический. Успешному развитию активационных методов способствовало широкое использование разнообразных источников излучений, в том числе новых, созданных в течение последних лет специально для целей элементного анализа. К ним, в частности, относятся атомные реакторы типа РГ-1 М и ИИН, генераторы быстрых нейтронов с откачными и запаянными ускорительными трубками типа НГИ-1, НГИ-4, НГИ-5, НГ-160 А, НГ-150 И, бетатроны, микротроны, а также трансурановые изотопные источники нейтронов.

На базе реакторов РГ-1 М и ИИН созданы типовые проекты лабораторий активационного анализа.

Макет лаборатории активационного анализа на базе реактора растворного типа ИИН показывает технологию проведения активации и измерения активности образцов.

Для целей активационного анализа используются также подкритические сборки (нейтронные размножители); на кинематической схеме был показан цикл измерений, проводимых с использованием нейтронного размножителя. Нейтронный размножитель позволяет получить поток $1{,}3 \cdot 10^7$ нейтр/$см^2$·сек. В установке имеется три вертикальных и один горизонтальный канал, снабженные пневмопочтой и системой измерения наведенной активности.

Из широкого класса разработанных генераторов на выставке был представлен нейтронный генератор типа НГ-150 И, дающий выход $2 \cdot 10^{11}$ нейтр/сек и отличающийся высокой компактностью и надежностью.

Из разработанных промышленных автоматизированных установок на выставке был представлен макет системы "Кислород". Электронные устройства автоматизации процесса анализа обеспечивают программное управление установкой и вычисление процентного содержания определяемого элемента по данным о наведенной активности.

Рентгенорадиометрическая аппаратура представлена в виде двух приборов: "КТН-1", предназначенного для определения тантала и ниобия в растворах, и "АЖР-1", служащего для определения железа в порошковых пробах. Порог чувствительности лежит в пределах $10^{-3} \div 10^{-1}$ %, длительность определения – до 10 минут.

В СССР широко используются радиографические методы определения качества продукции. Разработанные дефектоскопы позволяют проводить радиографию практически в любых условиях. Аппараты отличаются компактностью, надежностью и позволяют производить перезарядку дефектоскопов в производственных условиях. Дефектоскоп типа "Газпром" предназначен в основном для дефектоскопии труб на газопроводах, "РИД-11" – для применения в заводских условиях и "Стапель" – для кораблестроительных заводов.

В практике лучевой терапии широко используются методы оптимизации процессов облучения и их автоматизация. На выставке был представлен, в частности, аппарат "Агат-В", предназначенный для облучения злокачественных новообразований, локализованных в полостях тела человека.

В советском ядерном приборостроении широко используются достижения современной электроники. Применение полупроводниковых и, в первую очередь, интегральных элементов позволило разработать и освоить серийный выпуск приборов с использованием схем третьего поколения, обладающих повышенными характеристиками по стабильности, надежности и компактности.

В разделе ядерного приборостроения был представлен широкий круг приборов для дозиметрии, определения содержания веществ и спектрометрии. Так, в разделе спектрометрии представлена вся гамма приборов, обеспечивающих детектирование (сцинтилляционное и полупроводниковое), усиление, преобразование и регистрацию ядерных частиц.

Унифицированный ряд блоков детектирования охватывает весь энергетический диапазон с разрешением по гамма-линии цезия-137 от 8,5 кэВ до 12,5 кэВ. В набор входят сцинтилляторы размером от $\phi 25 \times 25$ мм до $\phi 150 \times 100$ мм, а также соответствующие фотоумножители и унифицированный электронный блок. С целью увеличения разрешения разработан и серийно освоен набор полупроводниковых кремниевых и германиевых детекторов, которые обеспечивают разрешение от 3 до 5 кэВ при минимальном пороге 0,5 кэВ.

Для работы с полупроводниковыми детекторами представлен гамма-спектрометр "Лангур", который позволяет измерять спектры рентгеновского и гамма-излучений в диапазоне энергий регистрируемых квантов от нескольких килоэлектронвольт до мегаэлектронвольт.

В качестве регистрирующих приборов были представлены анализаторы АИМА-10^6-М и АИ-256-6.

Миллионканальный анализатор АИМА-10^6-М позволяет измерять распределение энергий, представленное в виде амплитуд импульсов, интервалов времени, координат датчиков.

Кроме того, анализатор позволяет проводить предварительную обработку набранной информации, а также ее визуальное наблюдение и вывод на внешние устройства.

Существенной особенностью анализатора АИМА-10^6-М является сочетание периодического запоминающего устройства (З.У.) на быстродействующем магнитном барабане, используемом в качестве основного запоминающего устройства, и ассоциативного З.У. для промежуточного хранения информации.

Многоканальный анализатор АИ-256-6 предназначен для работы со сцинтилляционными и полупроводниковыми детекторами в лабораторных и полевых условиях, для чего он обеспечен возможностью питания как от промышленной сети, так и от аккумуляторных батарей.

В анализаторе оригинально решена проблема построения запоминающего устройства, что дало возможность резко сократить затраты элементов при сохранении метрических характеристик. Анализатор имеет 256 каналов при емкости каждого канала 2^{16} -1 (65535).

Преобразователь амплитуд импульсов в цифровой код обеспечивает дифференциальную нелинейность ± 2% на 98% шкалы.

В качестве примера приборов для определения состава вещества может быть рассмотрен мессбауэровский анализатор кассерита МАК-1. Анализатор предназначен для экстренного определения весового содержания окисла олова в порошковых пробах, что находит применение в геологии при подсчете запасов месторождений. Диапазон измеряемых концентраций олова, входящего в кассерит при анализе порошковых проб, 0,05% ÷ 4%. Необходимая навеска 1 ÷ 3 грамма. Среднее время одного измерения 10-15 мин.

На выставке были представлены различные типы ускорителей, предназначенные как для проведения научных исследований, так и для применения в народном хозяйстве страны. Среди них – протонный синхротрон на энергию 70 ГэВ Института физики высоких энергий в Серпухове. Максимальная энергия протонов, полученная на этом ускорителе в настоящее время, составляет 76 ГэВ, а максимальная интенсивность – $1{,}5 \cdot 10^{12}$ протонов в импульсе. Ведутся работы по увеличению интенсивности ускорителя путем установки специального бустера.

В выполнении научно-исследовательской программы на ускорителе принимают участие ученые Франции и США, а также международных организаций – ОИЯИ и ЦЕРНа.

В Объединенном институте ядерных исследований (г.Дубна) на ускорителе многозарядных ионов (МЗИ) – 310-сантиметровом циклотроне – группой под руководством академика Г.Н.Флерова получены новые трансурановые элементы, которые в таблице Менделеева занимают номера 104 и 105. Работы на данной установке по поиску новых трансурановых элементов продолжаются.

Представленный на выставке макет "коллективного ускорителя заряженных частиц" иллюстрирует возможности осуществления новых механизмов ускорения с использованием коллективных взаимодействий. В коллективных методах ускоряющее поле создается некоторой группой (сгустком) зарядов. Напряженность поля пропорциональна числу зарядов в сгустке. Ионы, захваченные электронным сгустком, ускоряются при некоторых условиях его собственным полем; в свою очередь, сам электронный сгусток может быть ускорен внешними полями умеренной напряженности. На макете установки представлены: инжектор-линейный индукционный ускоритель (E = 3 МэВ, $I_п$ = 2000 А в импульсе), адгезатор и ускоряющая система со сверхпроводящими резонаторами.

Линейный ускоритель электронов ЛУЭ-15-10 предназначен для осуществления радиационно-химических процессов с использованием пучка ускоренных электронов. Параметры его выбраны таким образом, чтобы иметь возможность устанавливать различные режимы облучения в зависимости от применяемых для облучения материалов: пределы изменения энергии от 5 до 15 МэВ, мощность в пучке электронов до 10 кВт. Ускоритель снабжен системой поворота пучка на 90° и системой развертки пучка в полосу (500×25) $см^2$.

Другой линейный ускоритель электронов ЛУЭ-8-5 также предназначен для использования в народном хозяйстве. Основное его назначение – стерилизация медицинских инструментов и систем для переливания крови на конвейере промышленного предприятия.

Энергия ускоренных электронов – 8 МэВ, мощность в пучке электронов – 5 кВт. Ускоритель также снабжен системой развертки пучка в полосу (500×25) $см^2$.

В Советском Союзе в Институте теоретической и экспериментальной физики проводятся исследовательские работы и идет подготовка оборудования, предназначенного для облучения малых внутричерепных мишеней протонным пучком. Для этой цели используется синхротрон с энергией 7 ГэВ. Ускоритель переоборудован таким образом, чтобы создалась возможность проводить работы с протонным пучком энергией 200 МэВ, который используется для медицинских целей в промежутке между основными циклами ускорения.

На выставке был представлен макет комплекса стереотаксического оборудования, предназначенного для облучения внутричерепных мишеней.

Вместе с докладами советских ученых на конференции выставка отражает достижения советских специалистов в обуздании сил природы и в познании ее тайн. Выставка явилась демонстрацией достижений советского народа, поставившего "атом на службу прогресса".

UNITED KINGDOM

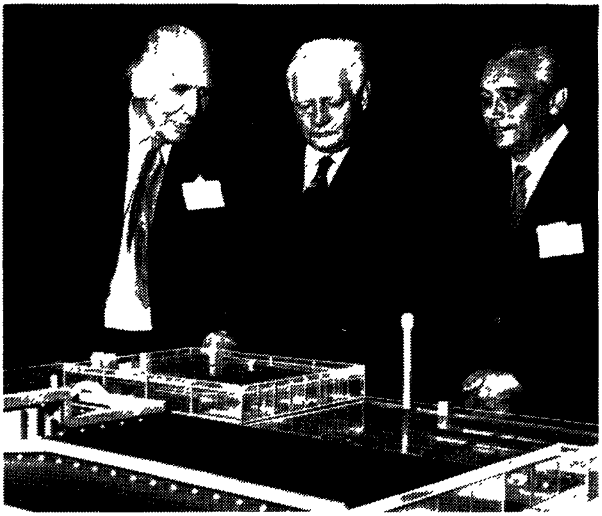
Stand 10

Over 50 British Government organizations and private companies contributed the equipment, material and information incorporated in the United Kingdom exhibit. The stand was designed to provide a representative cross-section of the practical applications of atomic energy, with examples drawn from a wide range of British sources. Organizations participating in the composition of the exhibit included the electricity generating boards, a number of Government research laboratories, the United Kingdom Atomic Energy Authority and more than 40 industrial and commercial firms.

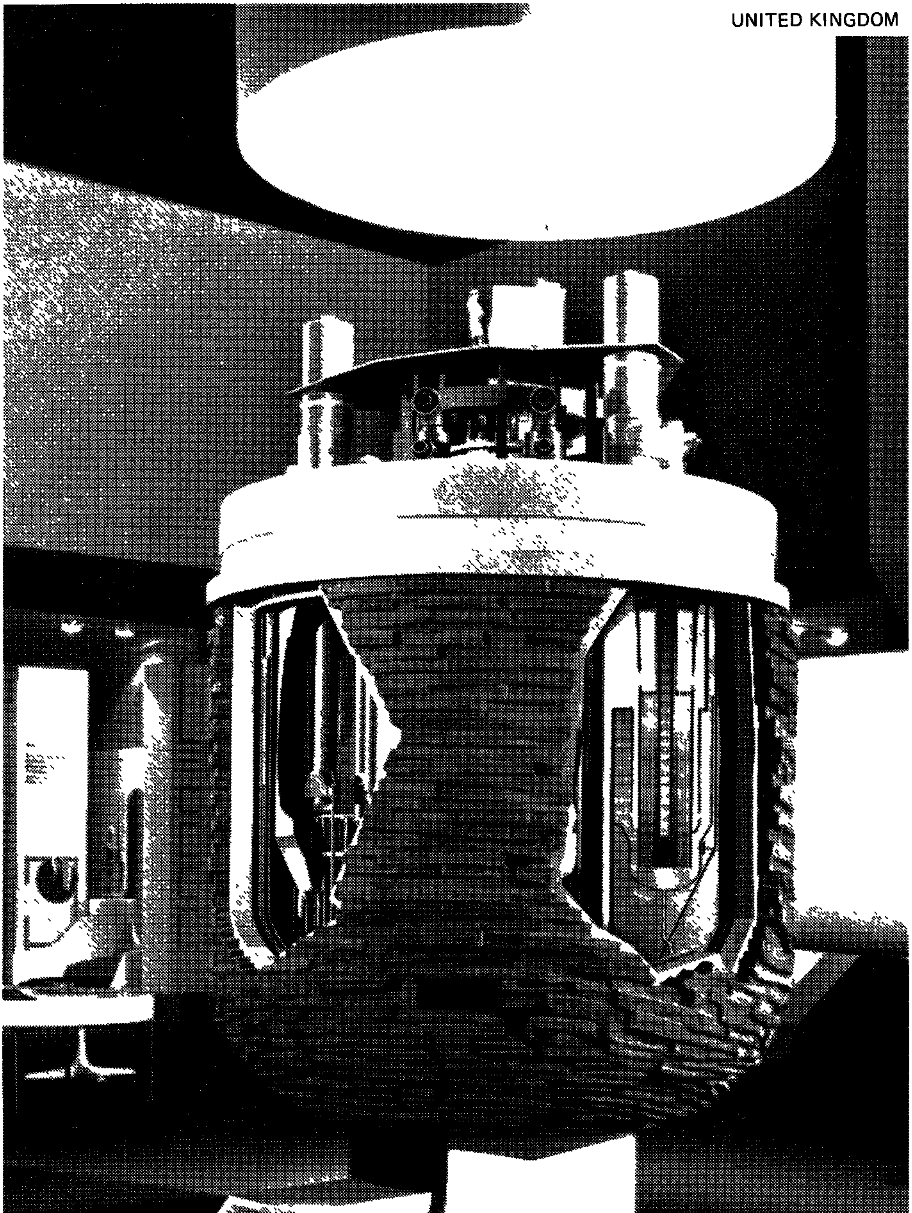
The exhibit was divided into five main sections: Power Reactors; Components and Instrumentation; Nuclear Fuels; Radioisotope Applications; Research and Development.

Mr. Glenn T. Seaborg, President of the Conference (left centre) and Mr. Vittorio Winspeare Guicciardi, Director-General of the UN Office in Geneva (right), visiting the UK stand. Mr. G.M. Insch is discussing the model of his company's 907 MW high-temperature gas-cooled reactor.

The United Kingdom exhibit at Geneva.



Mr. D.E.H. Peirson, General Manager of CENTEC, discusses with H. E. Mr. E. A. Midgley, British Ambassador to Switzerland (centre), and Sir John Hill, Chairman of the UKAEA (right), the collaboration of the Federal Republic of Germany, The Netherlands and the UK in the development and exploitation of the gas centrifuge process for producing enriched uranium; two tri-partite companies are involved, CENTEC and URENCO. The model is that of the Ultra-Centrifuge Netherlands Ltd. enrichment plant.



Centrepiece of the UK exhibit was the model of the 250 MW(e) Prototype Fast Reactor (PFR) at Dounreay. It had three cutaway sections and was animated to show the mode of operation.

POWER REACTORS

The Power Reactors section signalized the fact that by the year 2000 Britain will generate more than 75% of her electricity from nuclear power and that half of her nuclear generating capacity at that date will consist of fast breeder reactors.

Britain's nuclear power strategy was first formulated at Harwell twenty-one years ago, when it was already envisaged that there should be a program of uranium-fuelled thermal reactors which would produce not only electricity but also plutonium that could be utilized in a series of fast breeder reactors.

This section of the exhibit drew attention to the fact that by the mid-1970s, Britain would have 13 000 MW(e) of thermal nuclear stations operating and would be placing her first orders for commercial fast breeders.

This aspect of British nuclear power development was emphasized by the prominence on the stand of a large working model – more than 2 m high and $1\frac{1}{2}$ m in diameter – of the Prototype Fast Reactor, under construction at Dounreay in Scotland and due for completion in 1972. The model had three cutaway sections and was animated to illustrate the reactor's system of operation. Also shown was a model of a commercial fast reactor design.

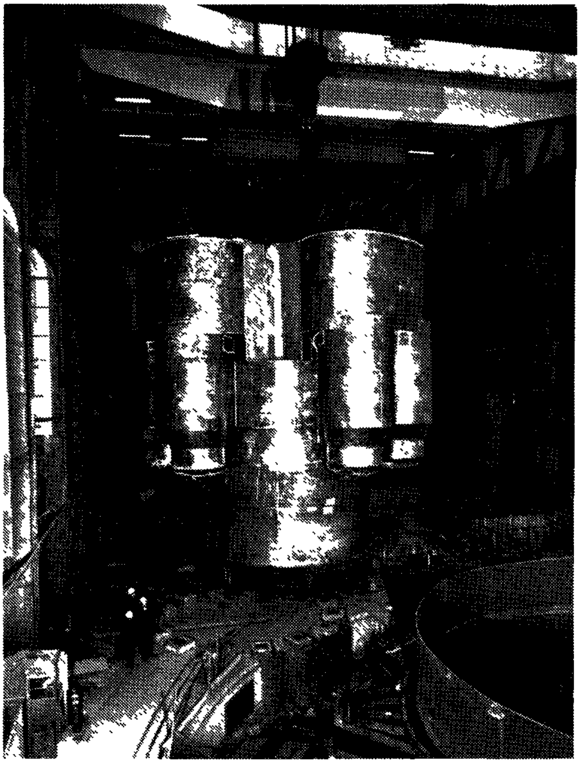
A large part of the power reactor section was devoted to the development of gas-cooled reactors. Britain's first nuclear power program was based on the natural uranium graphite-moderated design (Magnox) of the Calder Hall reactors which went on power as long ago as 1956. The second phase of the program uses the more sophisticated Advanced Gas-Cooled Reactor, which has slightly enriched uranium oxide fuel. A natural development in the Magnox - AGR series is the High Temperature Gas-Cooled Reactor, which uses helium instead of carbon dioxide as a coolant and, because it works at a higher temperature, can achieve higher thermal efficiencies. Two British companies had, prior to the exhibition, each submitted a detailed and priced design of a commercial HTR station to the Central Electricity Generating Board and the exhibit included models of these.

Also in the display were models, illustrations and data on a 500 MW Steam Generating Heavy Water Reactor, which the same two companies had also designed. A panel was included illustrating the easy refuelling of the SGHWR.

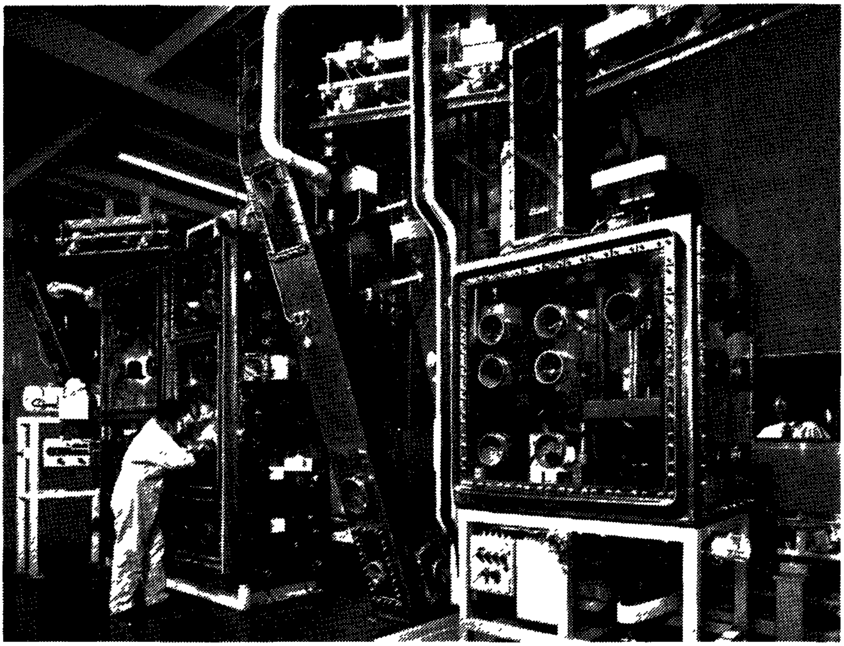
COMPONENTS AND INSTRUMENTATION

The Components and Instrumentation section was designed to demonstrate the way in which a nuclear power program stimulates the growth of industrial skills and capacity to meet the exacting requirements of a new technology, drawing illustrative examples from the United Kingdom, where a large-scale reactor development program embracing gas-cooled, water-cooled and sodium-cooled (fast) reactors had necessarily given rise to a considerable versatility in the provision of components and instrumentation for a wide variety of reactor systems. Noteworthy among the exhibits here

UNITED KINGDOM



LEFT: The 250 MW(e) PFR under construction at Dounreay. In the photograph, the reactor jacket is situated beside the reactor void. BELOW: The first large-scale pilot plant for the manufacture of plutonium-enriched fuels has been built at Windscale. It will produce fuel for the PFR and other reactors. The plant is extensively automated and remotely controlled, particularly in the ceramic stages. Plant operation is based on fully continuous processing equipment. The photograph shows the fully continuous, remotely operated press feed manufacture and pressing of mixed-oxide reactor fuel. The control-panel operator can be seen outside the fully sealed operating face.



were instruments associated with sodium technology, an area in which Britain had made significant advances in the context of fast reactor development.

NUCLEAR FUELS

The Nuclear Fuels section provided an historical survey of the growth of this new British industry from its early beginnings in 1948 up to 1971, when it achieved an annual output of a quarter of a million fuel elements. Dominating this section was a display of twenty different types of fuel element now in production and details were given of nuclear fuel manufacture, hexafluoride production, reprocessing, and the transportation of irradiated fuel. A sub-section of particular interest was that concerned with plutonium fuels, where details were given of a new plant at Windscale where 30 000 fuel pins containing $4\frac{1}{2}$ million PuO_2/UO_2 pellets were being made for the Prototype Fast Reactor.

The same section of the exhibit described aerial survey techniques used by prospectors for uranium and other minerals.

RADIOISOTOPE APPLICATIONS

For many countries the first practical applications of nuclear energy to be brought into wide and general use are those connected with radioisotopes and a special section of the exhibit was therefore devoted to a representative selection of such applications, including environmental applications, medical applications, radioisotope power supplies, applications in mining and agriculture.

Environmental Applications

In the display on the sea-bed tracing of china clay wastes, a series of charts showed how the movement of micaceous residues deposited experimentally on the sea-bed was followed by tracer techniques, and a plan for large-scale sea-bed deposition of residues at that point shown to be unsuitable.

A new model for rainwater percolation in chalk had been determined using radioisotope tracing methods. The method had shown that water moves downward through chalk principally by slow percolation and not, as was previously thought, by rapid fissure flow. (This is important in the exploitation of water resources in areas overlaying chalk and similar aquifers.)

Tritiated water has been used to investigate the water movements from a disused mine-working to test the possibility of using the mine as an additional water-supply for a steel works. The display showed how water samples taken in the neighbourhood of the mine established that it contributed water to a river at certain points, but not to certain drinking-water supplies.

Medical Applications

Portable equipment was illustrated for extracorporeal blood irradiation. It had a strontium-90 irradiation source for use in portable and transportable irradiators for the treatment of leukaemia.

To provide scanning agents for use in medical diagnosis, a most rapidly developing section of nuclear medicine, sterile generators have been introduced as a convenient source of short-lived radioisotopes.

Power

A battery using a plutonium-238 heat source and a thermopile has been developed at Harwell. Power outputs of from 400 μW(e) to 10 mW(e) can be obtained by varying the fuel content. This exhibit included miniature batteries and a model of the implantable heart pacemaker that uses the Harwell battery.

Mining

A portable mineral analyser was shown that was based on non-dispersive X-ray fluorescence spectrometry, using a radioisotope source. A borehole logger which uses a radioisotope X-ray fluorescence probe was also shown. It will operate in dry boreholes up to 33 m deep and will measure tin concentrations of 0.1% or more in situ, with a measuring time of about 20 seconds. There was a mineral slurry analyser designed for the continuous automatic analysis of 0.01% or more of copper in the tailings of a mineral processing plant.

Of particular interest was a radon survey meter designed to measure the radon content of sub-soil air. It is used to locate and assess uranium deposits too deeply buried for direct measurement of their gamma radiation.

Agriculture

One display in this section described how radioisotopes are being used by the Agricultural Research Council to investigate the effects of reduced cultivation on the performance of cereal crops and to examine the root systems of semi-dwarf wheat varieties.

Soil density measurement by gamma-ray transmission was possible with equipment developed by the Scottish Station of the National Institute for Agricultural Engineering. This technique has the advantages that it is sensitive to narrow layers of differing density, is rapid, and causes little disturbance.

Miscellaneous

A soil moisture probe system was shown that uses neutrons to measure the moisture content of soil and that could also be used to measure water contents of constructional materials, slag, etc.

Techniques using radioisotopes for the accurate measurement of fluid flow in pipes, ducts and hydraulic machinery were presented: these have been used in power-station cooling water systems, hydro-electric power plants, dockyard installations and gas supply systems in a number of countries.

RESEARCH AND DEVELOPMENT

The introduction to the Research and Development section pointed out that, although the nuclear industry envisaged at the first "Atoms for Peace" Conference in Geneva in 1955 was now a reality, the technology on which it was based was still developing; existing techniques were being improved and, even more important, new ideas that offered the prospect of major advances in the future were being studied.

A representative sample was shown of the wide-ranging research and development which is carried on in the United Kingdom Atomic Energy Authority, the Central Electricity Generating Board, in private industry and in universities.

The UKAEA, at its Culham Laboratory, is already investigating ways and means for using what is likely to be the major energy source of the 21st Century – power from fusion.

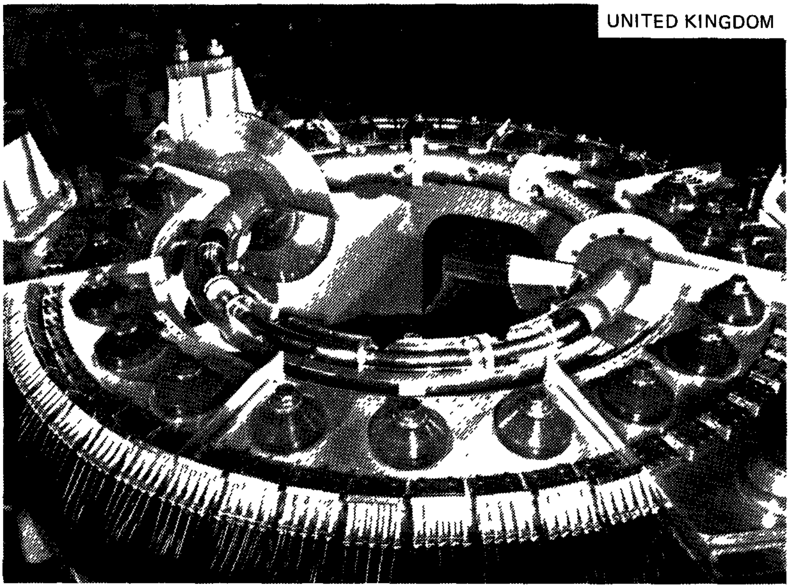
Examples of the other UKAEA research and development in support of fast reactors included: the study of irradiation damage in experimental fuels – using the Dounreay Fast Reactor as an irradiation facility, together with post-irradiation examination techniques; a description of fast reactor fuel development and experimental work on advanced fuel; manufacturing, quality control, inspection and evaluation techniques associated with the production of core and breeder fuel-elements of the Prototype Fast Reactor. Also described was a major program concerned with examining the behaviour of reactor fuel, cladding and structural materials and reactor components operating in liquid sodium, and with acquiring information on the behaviour of liquid metal coolant.

Sodium technology for fast reactors was illustrated by the following exhibits: study of reactor materials in liquid sodium in small test loops; testing and endorsement of major reactor components in large rigs which use liquid sodium as a working fluid; primary circuit hydraulics; heat transfer; detection of small leaks in secondary heat exchangers; fluid dynamics; sodium circuit instrumentation.

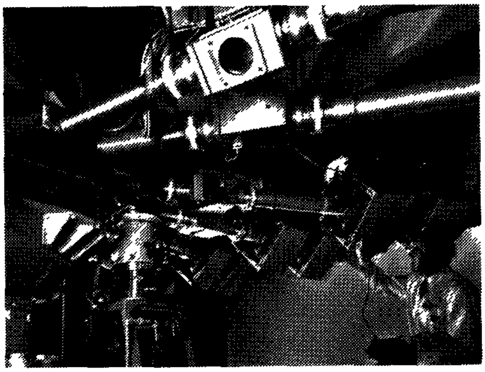
The main research at the Culham Laboratory of the UKAEA is directed towards the development of a power-producing fusion reactor and the exhibit included a three-dimensional model giving a simple indication of the progress towards a fusion reactor achieved in laboratory experiments on high-temperature plasmas. Also illustrated were some aspects of the technology developed at Culham in support of its fusion experiments, e.g. high-voltage pulse techniques, superconductors, and laser applications.

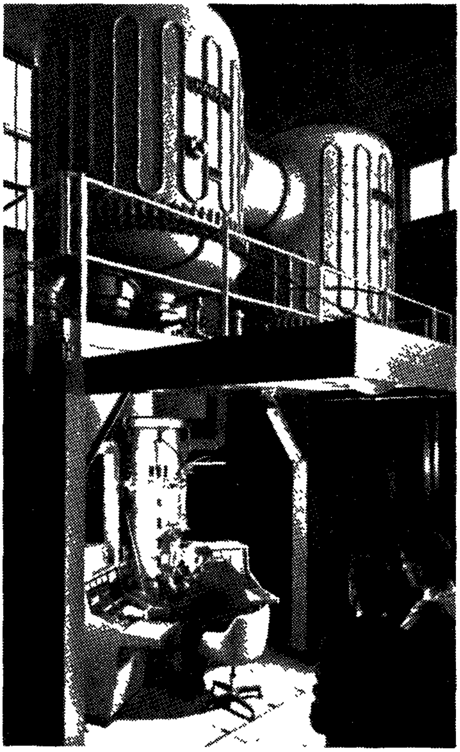
Work at Harwell associated with reactor physics was illustrated. It included: the determination of several key nuclear cross-sections to a high degree of precision, making use of the 45 MeV linear electron accelerator; the creation and study of void formation using the 1 MeV electron microscope; an autoradiographic technique for the analysis of boron in solids; an eddy current technique for testing sodium-bonded fuel; the study of the behaviour of ceramic fuels subjected to irradiation in a materials testing reactor; fissile material analytical techniques; and a display of post-irradiation examination facilities.

One of the main features of this section – a recent Harwell development – was a working demonstration of a stereoscan for examining irradiated fuel elements.



High-β Toroidal Experiment at Culham nearing completion. Part of the UK effort in fusion research, the copper ring which simulates the plasma during initial electrical testing can be seen.





ABOVE: AERE Harwell variable energy cyclotron. Designed, constructed and commissioned for the UKAEA by the Rutherford High Energy Laboratory, the cyclotron will be one of the most versatile in the world. Quadrupole magnets and scintillator boxes on the beam tubes are shown in the photograph.

RIGHT: The first commercial million-volt electron microscope to be built in Europe installed at Harwell. The instrument is intended for studies on neutron irradiation damage in reactor materials and for the non-nuclear program. The high voltage makes it possible to obtain sharp images with thick specimens.

The CEGB (which today operates eight nuclear power stations providing a designed output capacity of 4486 MW(e)) has the largest nuclear research facility of any utility in the world. The work is associated with the United Kingdom's extensive commercial nuclear power station program. Carried out at the Berkeley Nuclear Laboratories, their program is one of objective basic research, directed to solving at laboratory level the technological problems occurring in the design of reactor systems. The CEGB's contributions to the exhibit included: fuel management – the minimization of fuel costs in a commercial Advanced Gas-Cooled Reactor; fast reactor safety – assessment of possible accident sequences involving coolant boiling and fuel-coolant interactions; studies, using a 1 MeV electron microscope, of irradiation damage; radiological calibration (assessment of the accuracy of instruments); an inertial dust collector (device which removes dust from high-velocity gas streams); and tribology in nuclear reactors (surface engineering).

A display presented by the Rutherford High Energy Laboratory of the Science Research Council showed work in connection with a proposal to transfer energy of about 10^8 Joules reliably and economically to the magnet systems of a proton synchrotron, using a system of three concentric superconducting coils.

FILMS

Film-loops were screened, showing a number of short research films covering a wide range of interests. Among those shown were: Transient tube burst tests; void formation in copper; fast reactor safety studies; hot-stage microscopy; non-destructive testing; thermoluminescent dosimetry; high-resolution radiography, mass transfer tests as an aid to heat transfer studies; silicon carbide manufacture; portable neutron radiography; computer-controlled welding processes; on-line computers for reactor physics research; Gleeble thermo/tensile test; modelling of heat transfer processes; flash evaporation; fluidized-bed coated particles; experimental techniques for reactor physics research; etc.

Included in the stand was a cinema. A number of the films were provided with "simultaneous interpretation" so that the viewer might, at choice, hear the commentary in English, French, German or Spanish. The program included:

FAST REACTORS, UK: A complete survey of fast reactor development in the United Kingdom up to the summer of 1971.

NUCLEAR KNOW-HOW: An up-to-date report on UKAEA experimental facilities and services for reactor and fuel development.

(Both of the above films were given their first public showing at the 1971 Geneva Conference.)

GOOD NEIGHBOURS: A description of the various stages of planning, consultation, geological surveying and negotiation of way-leaves which take place prior to Government consent to the construction of a power station in the UK.

NEW NEIGHBOURS: The impact of a nuclear power station project on the neighbourhood of its site and its acceptance as an integral part of the community.

RADIOISOTOPES IN MEDICAL DIAGNOSIS AND INVESTIGATION: Made for the medical profession, this film shows the uses of radioisotopes in such techniques as dilution analysis, tracing studies, scanning and renography.

CRITICALITY: An up-dated version of the popular 1957 film explaining the basic principles of criticality and describing the precautions which have to be taken when dealing with fissile materials.

ON THE SAFE SIDE: Describing the precautions necessary for workers in a high-voltage research establishment.

THIS IS BNFL: A comprehensive description of the manufacture and reprocessing of nuclear fuels.

WATER FOR LIFE: Desalination: including discussion of dual-purpose plants to generate electricity from a nuclear reactor and at the same time to produce desalted water.

WHAT PRICE WATER?: A sequel to the preceding film, discussing the economics of desalination and describing research and development designed to improve them.

LORD RUTHERFORD: A few days before the 1971 conference began - on 30th August, to be exact - there fell the centenary of the birth of Lord Rutherford, the pioneer of nuclear physics.

A novel feature of the United Kingdom stand was a TV monitor for the showing of video-tapes made especially for conference delegates. One of these – entitled "Yesterday, Today and Tomorrow" – surveyed nuclear power in the United Kingdom from its earliest beginnings up to 9171, and it included a rare sound-film (made in 1935) of Lord Rutherford discussing his discoveries and what their future significance might be. The tape also included an interview with the late Sir John Cockcroft; recollections by Mr. R.V. Moore (now a Member of the UKAEA) of the famous Harwell meeting of 1950 at which Calder Hall and the whole of Britain's nuclear power program was first foreshadowed; and a live interview with Lord Hinton, giving his impressions of the First Geneva Conference in 1955.

Another tape – "Environment and the Atom" – comprised an interview with Mr. H.J. Dunster, of the National Radiological Protection Board.

An information desk for the assistance of visitors to the stand was staffed by representatives of the United Kingdom Atomic Energy Authority and the British Nuclear Forum, with the assistance of other participating organizations.

CONTRIBUTORS TO THE UNITED KINGDOM STAND

A.E.I. Scientific Apparatus Ltd., Urmston, Manchester;

Anglo Great Lakes Corporation Ltd., Newburn Haugh, Newcastle-upon-Tyne;

Applied Research Laboratories, Luton, Bedfordshire;

Babcock & Wilcox (Operations) Ltd., London;

British Insulated Callenders Cables Ltd., Warrington, Lancs.;

British Nuclear Design & Construction Ltd., Leicester;

British Nuclear Fuels Ltd., Warrington, Lancs.;

Cambridge Scientific Instruments Ltd., Cambridge;

C.F. Casella & Co. Ltd., London;

Central Electricity Generating Board, Berkeley, Glos.;

China Clay Association, St. Austell, Cornwall;

Clarke-Chapman-John Thompson Ltd., Gateshead, Durham;

E.K. Cole & Ekco Instruments Ltd., Southend-on-Sea, Essex;

Devices Implants Ltd., Welwyn Garden City, Herts.;

Dunlop Ltd., Manchester;

Elcomatic Ltd. (English China Clays Ltd.), Neilston, Glasgow;

Fairey Nuclear Ltd., Hounslow, Middx;

Fairey Surveys Ltd., Maidenhead, Berks.;

C.W. Fletcher & Sons Ltd., Sheffield;

Flextube Ltd., Hemel Hempstead, Herts.;

Flight Refuelling Ltd., Wimborne, Dorset;

G.E.C. – English-Electric Reactor Equipment Ltd., Leicester;

G.E.C. – Elliott Process Instruments Ltd., London;

Graviner Manufacturing Co. Ltd., Gosport, Hants.;

Hayward Tyler & Co. Ltd., Luton, Beds.;

Head Wrightson & Co. Ltd., Stockton-on-Tees, Co. Durham;

H.M. Hobson Ltd., Fordhouses, Wolverhampton;

Honeywell Information Systems Ltd., Brentford, Middx;

Hunting Aero Surveys and Hunting Geology & Geophysics Ltd., Borehamwood, Herts.;

Imperial Metal Industries Ltd., Witton, Birmingham;

Institute of Electrical Engineers, London;

Institute of Geological Sciences (NERC), London;

Institute of Hydrology (NERC), Wallingford, Berks.;

Letcomb Laboratory (ARC), Wantage, Berks.;

Lintott Engineering Ltd., Horsham, Sussex;

Lucas Gas Turbines Ltd., Birmingham;

Sir Robert McAlpine & Sons Ltd., London;

Mining & Chemical Products Ltd., London;

National Institute of Agricultural Engineering, (Scottish Station) (ARC), Penicuik, Midlothian;

National Physics Laboratory, Teddington, Middx;

Nuclear Engineering International, London;

Nuclear Enterprises Ltd., Edinburgh, Scotland;

Oxford Instrument Co. Ltd., Oxford;

D.A. Pitman Ltd., Weybridge, Surrey;

The Plessey Co. Ltd., Poole, Dorset;

Rank Precision Industries Ltd., London;

Reyrolle Parsons Ltd., Heyburn, Co. Durham;

Science Research Council (Daresbury & Rutherford Laboratories), Nr. Warrington, Lancs;

South of Scotland Electricity Board, Glasgow;

R.A. Stephen & Co. Ltd., Mitcham, Surrey;

Strachan & Henshaw Ltd., Ashton, Bristol;

Taylor Woodrow & Co. Ltd., Southall, Middx;

Telsec, Littlemore, Oxford;

The British Nuclear Forum, London;

The Nuclear Power Group Ltd., Knutsford, Cheshire;

The Radiochemical Centre Ltd., Amersham, Bucks.;

Tube Investments Ltd., Birmingham;

Twentieth Century Electronics Ltd., Croydon, Surrey;

United Kingdom Atomic Energy Authority, London;

University of Birmingham, Dept. of Electron Physics and Space Research, Birmingham;

Vickers Ltd., Swindon, Wilts.;

Warren Spring Laboratory, Stevenage, Herts.;

Whessoe Ltd., London;

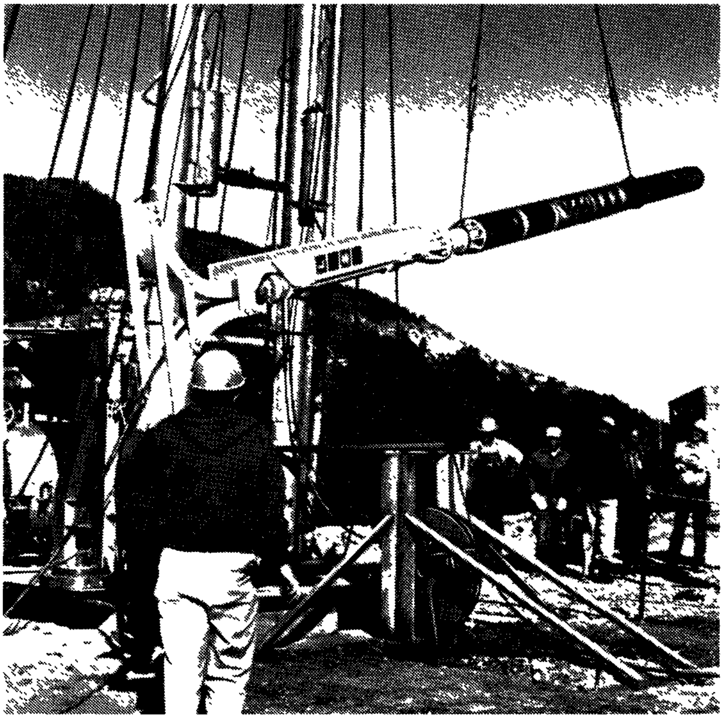
George Wimpey, London.

UNITED STATES OF AMERICA

Stand 12

The United States exhibit – Nuclear USA – depicted nuclear techniques developed in response to such world needs as pollution control, electrical power production, release of trapped geological resources and heart-assist devices.

A multiple-image photographic interpretation of the nation was presented continuously in the Reception Area of the exhibit. The purpose was to convey a sense of the sort of nation – geography and natural resources, peoples and life-styles, schools and teachers, technological outlook and



ABOVE: Recon computer terminal that could be used by visitors to the exhibition to obtain lists of documents in response to a technical query from a USAEC science data bank at Oak Ridge, Tennessee, or from the ESRO data bank at Darmstadt.

LEFT: Project Rulison. The 40 kt nuclear-explosive canister being hoisted before lowering for emplacement at a depth 2570 metres underground. The detonation served to raise the permeability in the natural gas reservoir and, hence, increase the gas output.

UNITED STATES
OF AMERICA

industrial know-how, sports and hobbies, scientists and technicians, philosophies and aspirations – that could attain excellence in the peaceful uses of atomic energy.

The primary purpose of "Nuclear USA" was to present recent accomplishments of both Governmental and industrial groups in the USA in applying nuclear science and technology to many of the problems that face society. Covering a dozen different topics, the display was designed by the United States Atomic Energy Commission and incorporated equipment on loan from United States industry.

Displayed in the "Plowshare" section of the exhibit was a full-size replica of the canister that had contained the 40-kiloton nuclear explosive set off underground near Grand Valley, Colorado, in 1969 to release natural gas entrapped in rock formations. Other potential applications of peaceful nuclear explosions were also shown.

Implantable radioisotope-powered heart-pacer and heart-pump devices were displayed together with a simple artificial-kidney cartridge which is also under development.

The National Aeronautics and Space Administration provided a demonstration of how nuclear techniques may be employed to provide ultra-rapid analysis of various kinds of samples, such as environmental materials and drugs, by remote access to a computer. NASA is one of a dozen federal agencies which contributed to the USAEC Exhibit.

An elaborate display of power reactors manufactured in the USA included representative models of reactors currently in production. Looking to the near future there was also an area devoted to advanced breeder reactors. The various approaches and recent successes in the United States research program on nuclear fusion were depicted.

"Nuclear USA" received live signals from nuclear-powered instruments on the moon, relayed to Geneva from NASA's Goddard Space Flight Center from a world-wide network of tracking stations. It also showed a lunar rock sample, a SNAP-27 generator* of the type which is powering the instruments on the moon, and a SNAP-19, the type providing supplementary power for the NIMBUS-III weather spacecraft experiment launched in 1969 and still sending data.

An overseas computer link-up joining the exhibit with a science data bank at a USAEC facility at Oak Ridge, Tennessee, gave exhibit visitors an almost instant list of pertinent documents in response to technical questions. A similar service was provided at various times in co-operation with the European Space Research Organization (ESRO) using the ESRO data bank in Darmstadt where International Aerospace Abstracts, Scientific and Technical Aerospace Reports, and the ESRO electronic components data bank can be searched remotely. A comprehensive technical information section containing printed materials for display and distribution was also part of the exhibit.

Thirteen USAEC motion pictures on recent United States nuclear science and technology developments were shown for the first time in Geneva, both at the exhibit's 30-seat theatre and at other Conference theatres.

The central lounge around which the "Nuclear USA" exhibits were grouped provided a place to meet and discuss a particular subject with a

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* SNAP· Systems for Nuclear Auxiliary Power.

knowledgeable United States technical representative. At one end of this lounge was a special viewing area from which the Conference proceedings could be watched together with special programs televised in colour from the Palais des Nations.

The exhibit was divided into several parts as described below.

POWER NEEDS AND THE ENVIRONMENT

This part gave a photographic representation of increasing power demands and methods of supply for these demands. Photographs illustrated the reason for the public's ever increasing concern with environmental problems.

The environment area was divided into four sections: meteorological, radiological, ecological and thermal.

The first section was concerned with meteorology, where a complete automatic meteorological monitoring system was operating. A film describing meteorological research programs being conducted at the Calvert Cliffs Nuclear Power site in Maryland was also shown.

In the radiological section several pieces of equipment were on display. These included remote radiation monitors, a tritium monitor and a display of aircraft-mounted monitoring equipment. A film described the radiological monitoring program now being conducted at the site of the Brown's Ferry Nuclear Power Station in Alabama.

The ecological section was high-lighted by displays and photos of studies regarding the effects on food chains of effluent releases from nuclear stations. Another film in this section described the shad tagging program on the Connecticut River. There are several nuclear power stations now operating on this river.

In the thermal section, two pieces of equipment were displayed. These were a buoy which is used for monitoring temperature gradients in the Crystal River in Florida and a camera which takes infra-red pictures of the thermal plumes coming from the discharged cooling water of nuclear power stations. A film described the modelling of complete watershed systems to study, properly scaled, thermal effects from nuclear power stations.

BIOMEDICAL

The biomedical applications of radiation and radioisotopes were displayed. A feature in this part was a camera for organ imaging. The use of short-lived isotopes in conjunction with this improved instrument has greatly increased the value and versatility of this diagnostic technique for detecting and locating tumors and other organ abnormalities.

On the wall to the left of the entryway was a large 9 ft × 9 ft transparency of a medical cyclotron. This "CS-30" cyclotron is to be installed at the Mount Sinai Hospital, in Miami Beach, Florida. The cyclotron can be used to produce a variety of short-lived isotopes for medical use by bombarding suitable targets with 26 MeV protons, 15 MeV deuterons and 38 MeV helium ions. Eight medical cyclotrons are now operational in the United States of America. Also displayed was a small model of a complete medical cyclotron facility. Another display showed an alternative method for the production of short-lived isotopes. In this case, a parent nuclide decays into a daughter nuclide (the short-lived isotope) and it is possible to separate and remove the daughter nuclide by elution. At the right of this 'isotope cow' was a mirror wall in which were reflected 16 mm motion pictures featuring the use of the medical cyclotron and a scanning camera at a hospital in New York, plus a brief presentation on the "Autofluoroscope" installed at Hahnemann Hospital in Philadelphia. A further picture wall contained transparencies of the "Autofluoroscope" and "Pho-Gamma" radioisotope cameras plus a scanning instrument for measuring bone size, density and mineral content. Colour photos displayed on the picture wall illustrated the use of radioisotopic cameras for organ imaging and other diagnostic procedures.

Near the rear section of the Biomedical area was a display featuring a head phantom useful in tumor diagnostic studies and several specialized miniature and microminiature probes which are used for specific diagnostic and therapeutic procedures. The probes utilize semiconductor detectors and microminiature electronic circuitry.

Proceeding through a passageway one saw a reflected image of the Los Alamos Meson Physics Facility (LAMPF) model. Around the corner to the left was the model itself, together with a large accompanying graph showing the predicted effectiveness of pi-mesons as compared with other types of radiation used for cancer therapy. The pi-meson's greater effectiveness is due to its penetrating power, its localization, and its characteristic combination with atoms of the tissue being bombarded with resultant "star burst" of nuclear fragments which in turn destroy the tumor tissue. While the LAMPF will be used for many types of physical experiments its emphasis here is for tumor therapy. Starting with the Cockcroft-Walton accelerator in the injector building, the "red" beam line could be followed along the length of the linear accelerator to the target and switching area where pi-mesons are produced. The pi-meson beam will then be diverted to the Radiobiology and Therapy Research building for experimental work in tumor therapy.

The following section comprised a display of californium-252 medical sources which are currently being evaluated for use as brachytherapy devices for destruction of tumor tissue. The display also contained artwork illustrating insertion of the sources into tumor areas.

The last area of the Biomedical exhibit comprised several displays featuring biomedical "spin-off" of nuclear research. The right wall showed a series of illustrative displays covering a micro-fluorimeter which uses fluorescent dyes and laser instrumentation to provide a quantitative determination of the DNA content of cells. Also in the top bank of the wall were photos dealing with Albert Crewe's transmission-scanning electron microscope with the first pictures of individual atoms. The second tier consisted of displays of nuclear-powered pacemakers for the heart. First shown was a device which represented a conventional type nuclear pacemaker, and then the "Intra-cardiac" pacemaker — an entirely new concept in pacemaker design.

Also shown was a display illustrating the new type of haemodialyser unit developed by Argonne National Laboratory. When the unit is produced commercially, it is expected to be of great benefit and convenience to patients who must regularly undergo renal dialysis. Nearby was a display

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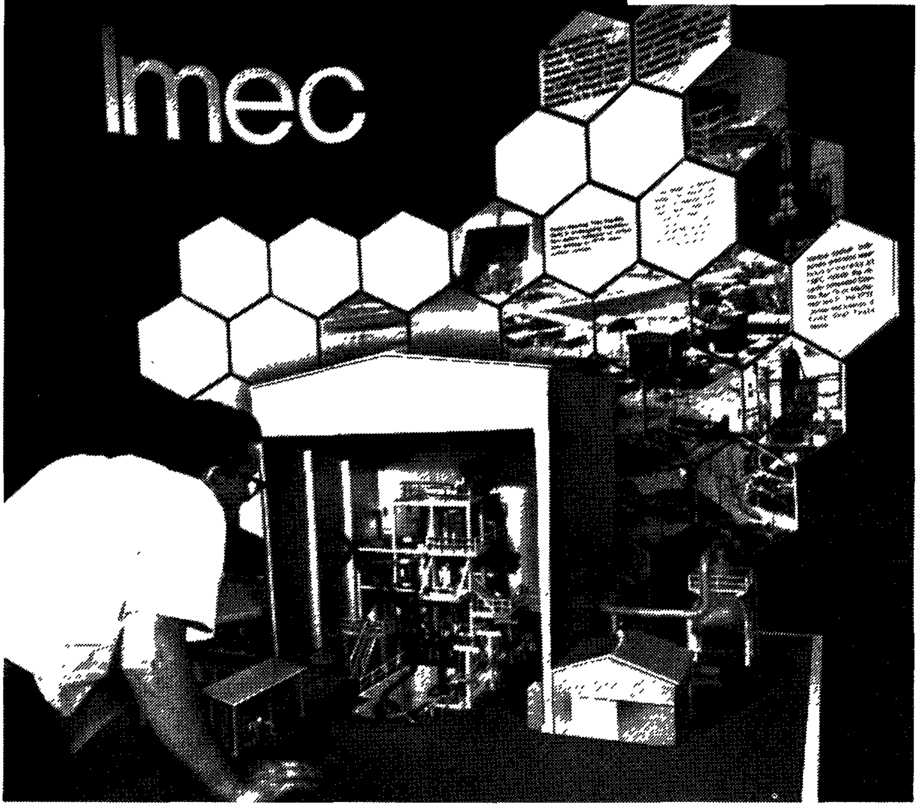
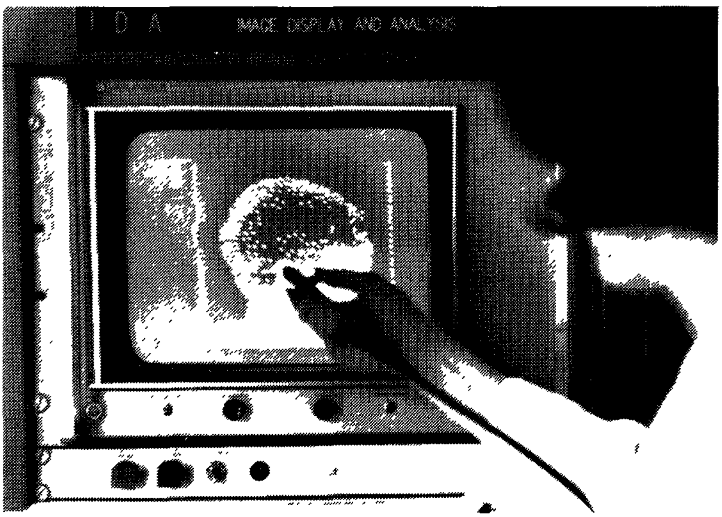


Description of the USAEC's Liquid Metal Engineering Center (lmec) and the model of the sodium component test installation.



Studies of cerebral blood flow made using a radioisotope tracer (Tc-99m). The computer-generated image is displayed on a CRT screen, and the light pen can be used to 'flag' regions of interest. Simultaneous viewing of computer-generated quantitative data and original images taken at various time intervals enhance diagnosis (see Vol. 13 of these Proceedings, page 19 et seq.).

pertaining to the zonal ultracentrifuge which is proving to be of great use in medicine and in biological research since it makes possible the preparation of purified vaccines and viruses in large quantities. At the far right was another instrument developed at the Oak Ridge National Laboratories and now in commercial production. This is the GEMSAC automated testing machine which greatly increases a medical laboratory's capacity for performing analyses of blood samples and permits analyses to be made at a fraction of the cost of the usual manual analytical techniques.

On the end wall of this area was a display of photos and a short film clip which dramatically demonstrated the effectiveness of L-dopamine therapy for patients with Parkinson's syndrome. This treatment was developed at the Brookhaven National Laboratories.

INDUSTRIAL AND ENGINEERING APPLICATIONS OF RADIATION AND RADIOISOTOPES

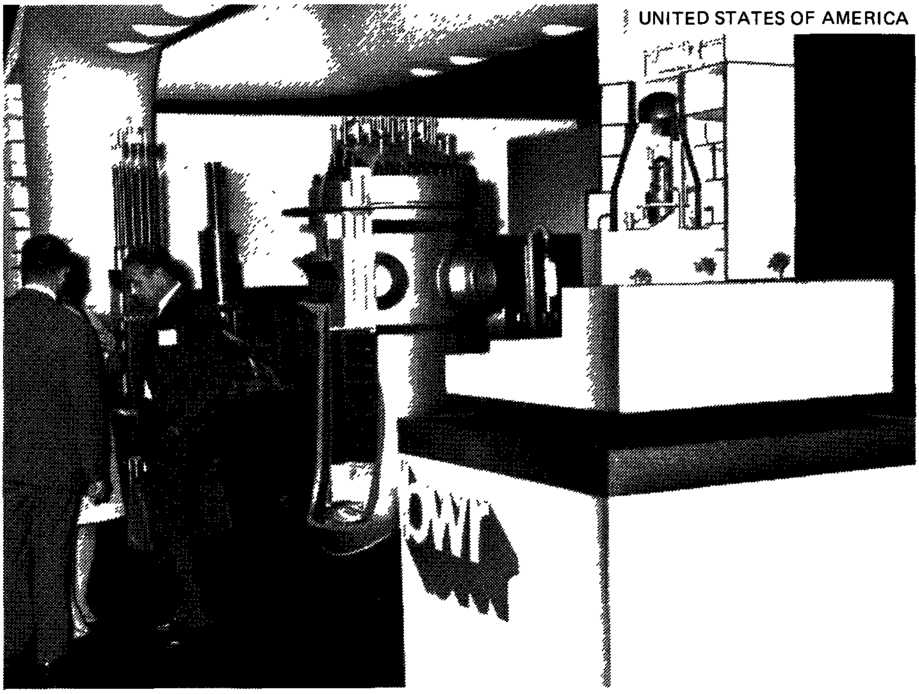
In this part of the exhibit was a display of radiation processed material including: (1) radiation treated sewage — brown before irradiation and clear after irradiation; (2) radiation sterilized prepackaged medical supplies; (3) radiation-cured coatings for automobile parts; (4) plastic shrink-fit packaging materials; (5) plastic shrink-fit electrical insulation; (6) wood/plastic and concrete/plastic materials made possible by in situ radiation polymerization of plastic monomers; (7) a 1024 bit memory unit produced by ion implantation techniques using accelerators; (8) graft polymerization of plastic to fabric to increase crease and soil resistance; (9) radiation treatment of potatoes to retard sprouting; and (10) self-luminous signs using radioisotopes and phosphorus.

Opposite the display of radiation processed materials was a display featuring the two types of irradiation facilities, a ^{60}Co gamma irradiator and an electron beam irradiator.

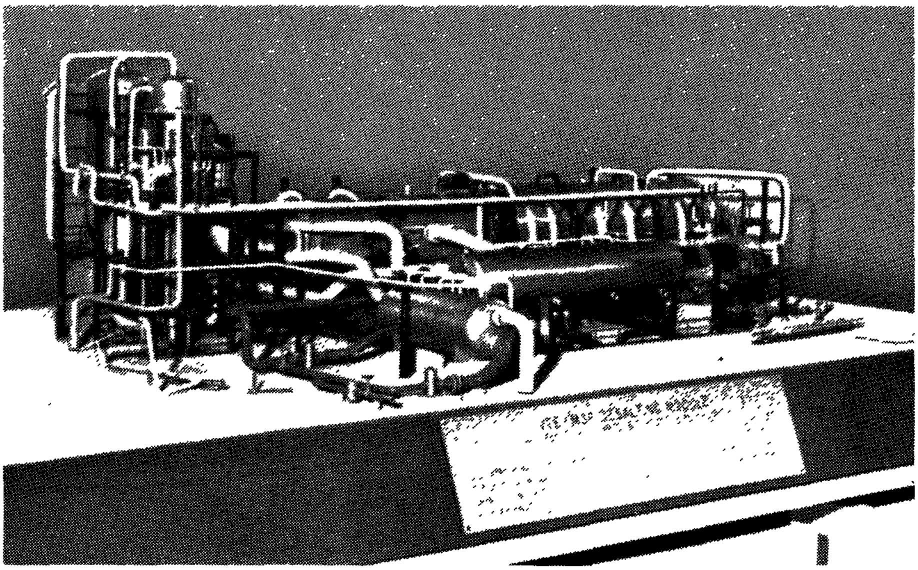
The nuclear instrumentation display section included a section of irradiated pinewood-plastic flooring that had already been walked on by 8 million people during the New York World's Fair.

The instrumentation section had a display of four representative examples of instrumentation using radioisotopes: a moisture-density gauge, an X-ray fluorescence spectrometer, a fill-level control system, and solid-state detection equipment. Featured in the instrumentation area were two demonstrations of neutron activation analysis. The first was a simple demonstration in which samples of single elements were activated by neutrons with the necessary electronics and display equipment to show characteristic single-element gamma spectra. The second demonstration illustrated remote semi-automatic computer analysis of complex materials using prompt or radiative capture gamma analysis spectra resulting from neutron bombardment of the material. In both demonstrations the isotope californium-252 was used as a neutron source.

The instrumentation area led into the radioisotope production area which displayed the Triga reactors, the HFIR reactor and a fuel element of the Savannah River production reactor. Also included in this area was a display on cobalt-60 production. A graphic display featured the use of the Triga reactor for radioisotope production, neutron activation analysis and neutron radiography. Photographic transparencies on the walls related to Governmental and industrial production of radioisotopes.



Display of power reactor models from major United States reactor manufacturers.



VTE/MSF (vertical tube evaporator/multi-stage flash) desalting module having four effects of an ultimately 16 effect plant giving 12.5 million gallons per day of desalted water.

REACTORS NOW

The "Reactors Now" part of the exhibit was devoted primarily to the five reactor manufacturers in the United States of America. Each of these manufacturers had prepared an exhibit showing their competence in the supply of central station nuclear power plants. The items shown were:

1. A model of a four-loop pressurized water nuclear power station. Used in this exhibit were transparencies showing the numerous capabilities which exist to design and construct central nuclear power stations.
2. A model of the latest boiling water reactor design was displayed which emphasized concrete containment and reactor vessel construction.
3. The next exhibit centred on the new facility at Lynchburg, Virginia, which has been installed to completely train central nuclear station operating personnel. The viewer could see films of the training capabilities and also slides and other graphic displays showing the training complex. In addition, a pressurized water reactor plant model was shown together with models of important reactor components.
4. This exhibit comprised three items: a model of a 3-loop 1500 MW(e) plant, a large model of the reactor internals starting at the pressure vessel, and a model of advanced water reactor fuel bundles.
5. American high-temperature gas-cooled reactor capability was shown. This included two models of HTGRs, a model of a fuel bundle, and two examples of reactor instrumentation which has been developed.

Additional displays in this part included: two large transparencies showing operating experience from Dresden I and II and from Yankee Rowe; a digital counter adding nuclear megawatts (electrical) now being generated in the United States of America; a computer read-out of actual fuel cycle costs for thermal power reactors; and enlarged photographs showing various stages of reactor component construction, reactor installation, reactor start-up, etc.

FUEL CYCLE

In this display were shown the major steps of the fuel cycle, highlighted by photographs. Mining, milling, UF_6 conversion, enrichment, conversion to UO_2, fuel fabrication, nuclear power generation, reprocessing and nuclear waste management were referred to.

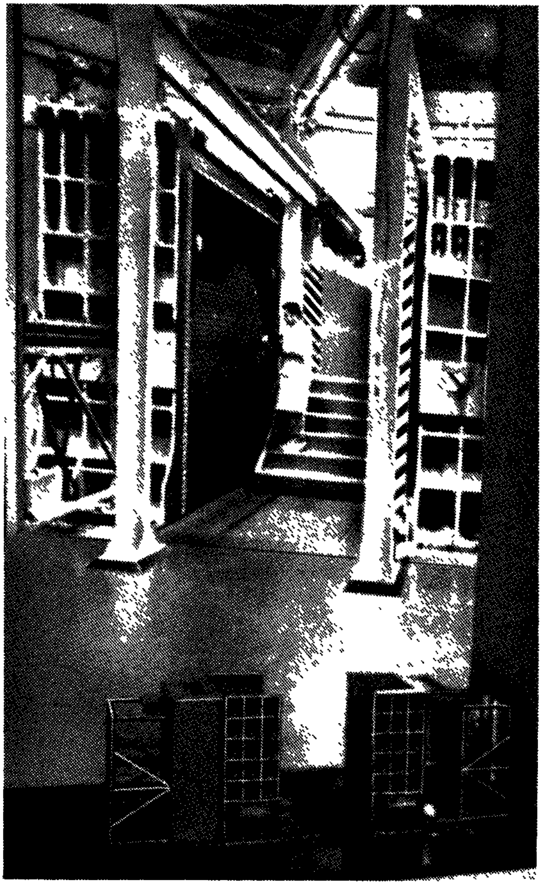
The exhibit showed a computer print-out illustrating the use of computers for analysis of ore deposits initiated by the USAEC in the early 1960s.

A chart provided an extensive picture of existing and planned fuel cycle services of United States companies.

In the exhibit was a fuel module for a boiling water reactor, as well as a model of one of the four assemblies comprising the module. This assembly was fabricated of stainless steel, Zircaloy and Inconel. Photos showed several of the more important steps in the fabrication of fuel for reactors. A short film summarized all significant steps. Fuel reprocessing has been available in the USA since 1966.

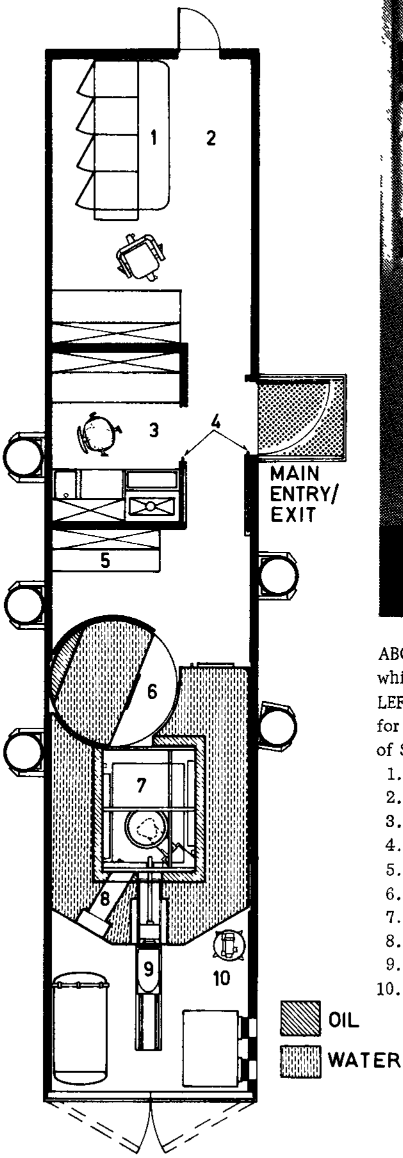
A film gave a quick idea of the significance of research and development efforts in the transportation of nuclear materials.

Photographs of the interior of a gaseous diffusion plant at Oak Ridge, Tennessee, were shown.



ABOVE: Model of the Zero-Power Plutonium Reactor, behind which is a photograph of the reactor face.
LEFT: Floor plan of the large MONAL trailer which can be used for passive and active physical assays needed in implementation of Safeguards programs.

1. Electronics
2. Control console and data aquisition
3. Sample preparation
4. Sliding doors
5. Electronic workbench
6. Rotating door
7. Experimental cavity with crane
8. Gamma port
9. Neutron generator
10. Equipment room



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The treatment and disposal of waste materials in solid form can be accomplished using four processes: (1) the phosphate glass solidification process; (2) the spray solidification process; (3) the pot solidification process; and (4) the spray-in-pot melting process. Wastes can be stored in mined-out areas such as the one located in Lyons, Kansas.

A head frame of a uranium mine was shown. Approximately 243 such mines are operating in the USA.

SAFEGUARDS

This part of the exhibit was concerned with the management and accountability of special nuclear materials. Special programs and instrumentation are being designed in the USA to ensure that nuclear materials designated for peaceful applications are not diverted to military or other unauthorized use.

A variety of displays dealt with Safeguards instrumentation, including a tread-actuated, gamma-ray-and-neutron-sensitive, doorway-type, personnel Safeguards monitor which uses passive detectors and associated electronic circuitry to detect the unauthorized removal of nuclear materials. The doorway was designed for and is used at the USAEC Rocky Flats facility.

The main portion of the Safeguards exhibit contained displays of physical, non-destructive assay devices as follows:

1. Sealed-tube neutron interrogation equipment which uses a small accelerator to produce 14 MeV neutrons which are, in turn, used to interrogate the materials being assayed. Suitable detectors and electronic circuitry are used to provide assay data.

2. A mobile neutron-coincidence detector which permits passive assay measurements to be made by detection of coincidence neutrons that result from spontaneous fission.

3. A fuel-rod assay instrument based on prompt neutron detection. This instrument uses neutrons spontaneously emitted from a californium-252 source to initiate fission events in the materials being analysed.

4. A low-level liquid-stream monitor to detect small amounts of nuclear materials in effluents and other liquid streams.

5. A small portable nuclear-materials assay system developed at Brookhaven National Laboratory for physical non-destructive assay based on the neutron coincidence characteristic of spontaneous fission.

6. An isotopic source assay system for bulk sample assay of materials containing uranium or plutonium. Using californium-252 as a spontaneous source of neutrons for interrogation, quantitative determinations of nuclear material contained in heterogeneous samples may be performed non-destructively with an accuracy as high as 99%.

7. An overhead display of photographs indicated the various stages in the fuel cycle at which Safeguards checks and assays are applied.

8. A display of tamper-proof seals used in the protection of nuclear materials was mounted on the sloping roof of the structure that led into the Safeguards exhibit. These seals are used as a means of ensuring that any unauthorized removal of nuclear materials may be easily detected.

The Safeguards graphic wall contained photographs illustrating two types of mobile non-destructive assay systems developed for use in the Safeguards program. These were the large MONAL* trailer, used for both passive and active physical assays, and the small van, used for passive assay only. Also included were photographs depicting some of the work involved in collecting, processing and reporting nuclear materials information.

The Safeguards slide-show featured a brief introduction to the International Safeguards Personnel Training program conducted by the USAEC at Argonne National Laboratory, and a brief survey of the chemical assay laboratory work conducted at the USAEC's New Brunswick Laboratory.

BREEDER REACTORS

The Breeder Reactor part of the exhibit showed, primarily, the effort in the USA to develop a Liquid Metal Fast Breeder Reactor (LMFBR). The first portion introduced the American program in breeder development and showed why breeders are necessary in the United States of America. Technology programs were discussed, including the high-temperature gas-cooled breeder, the molten salt breeder and the light water breeder program.

This section was laid out to simulate a PERT chart (Programme Evaluation and Review Technique), the small area within the Breeder Exhibit representing significant milestones in ultimately building a 1000 MW(e) LMFBR.

The first section was devoted to the Experimental Breeder Reactor Facility. The exhibits included:

1. An animated model of the xenon tagging technique developed to locate failed fuel-elements in the reactor.
2. Reactor fuel rods and assemblies containing many specimens which are now being tested in the Experimental Breeder Reactor.
3. In-core test assemblies which show instruments for testing materials and reactor instruments being tested.
4. A model of the Fuel Evaluation Facility which is a part of the Experimental Breeder Reactor complex.
5. A film of actual hot-cell operations which take place in the Fuel Evaluation Facility.

The next section was the Zero Power Reactor area, and the primary exhibit here involved the large Zero Power Plutonium Reactor. One panel in this area simulated a portion of a face of the Zero Power Plutonium Reactor. There was also a model of this reactor and transparencies showing the overall facility.

The next section was the Liquid Metal Engineering Centre where components for LMFBR's are tested. A model of the Sodium Component Test Installation was shown and photographs mounted on panels described other test facilities.

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* MObile Non-destructive Assay Laboratory.

The next section was devoted to the Fast Flux Test Facility. The three primary exhibits in this area included:

1. A model of the Fast Flux Test Facility.
2. Fuel assemblies which have been developed for the Fast Flux Test Reactor. These fuel assemblies were the subject of a film describing their development.
3. An actual, operating, control-rod-drive mechanism which is a prototype of the unit to be used in the Fast Flux Test Facility. There was a film describing the test program for developing this mechanism.

The final two areas comprised photographic displays of Demonstration Reactor plants and the 1000 MW(e) plants which either are to be constructed in the future or which have been studied in the USA.

NUCLEAR ENERGY IN SPACE

The USAEC and the National Aeronautics and Space Administration have worked in close partnership since the creation of NASA in 1958. The exhibit showed a photo mosaic of the lunar crater Tycho, taken from the Jet Propulsion Laboratory Surveyor spacecraft.

A photograph of Surveyor was displayed, as was a photograph of the nuclear-equipped alpha scatter instrument which was carried on three Surveyors. Its purpose was to analyse the top surface of the lunar soil, which was successfully achieved.

An engineering model of the alpha scatter instrument showed how the device was lowered onto the moon's surface.

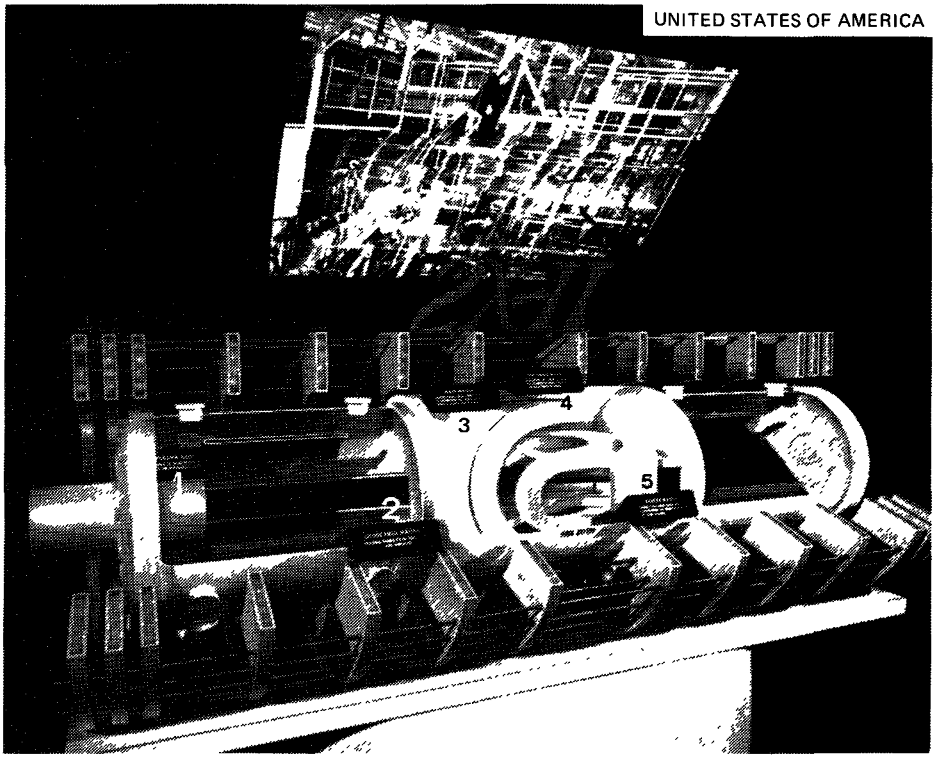
To date the most dramatic use of United States nuclear technology on the moon has been the powering of the Apollo Lunar Scientific Experiments Package (ALSEP), shown in a large transparency, together with the SNAP-27 radioisotope-fuelled thermoelectric generator displayed in a full-scale cutaway model. Three ALSEP's and three SNAP-27s are now functioning on the moon. To Geneva, through space networks and equipment supplied by NASA, were brought live signals from the Apollo 15 ALSEP, placed on the moon in July of this year, as well as from Apollos 12 and 14.

In addition to radioisotope electrical supplies, reactor-powered electric systems, such as the SNAP 10A which was successfully tested in space orbit for 1000 h in 1961, are being developed.

One of the actual moon rocks was displayed. Powerful nuclear techniques have been put to work to analyse these rocks. They include neutron activation analysis, as shown in a brief film, and gamma ray spectrometry as depicted in photographs.

A nuclear reactor will provide the propulsion heat for the NERVA nuclear rocket, displayed in an animated model. A film gave details of the NERVA testing sequence at the Nevada test site. Next to it was a full-scale replica of one of the 1900 fuel elements used in the NERVA reactor. This reactor is more powerful and three times hotter than any earthbound commercial electric reactor in the USA.

Electrical power supplies for future use in space will generate large amounts of power. The thermionic reactor system has an output of



Animated model of the 2X-II device. From left to right are the plasma gun (1), the guide field magnets (2), the gate magnet (3), the Yin Yang magnet (4) and the barrier magnet (5). Above is a photo of the full size installation.

Seining for juvenite shad at Windsor Locks, Conn., on the Connecticut River in experiments to determine the effects of thermal discharges on these fish. These studies were started in 1965, as several nuclear power stations use this river water for cooling. This fish species was chosen as it is the single most valuable fishery resource in the Connecticut River, with an annual capitalized value of $21.5 million. It is an anadromous species with a highly developed homing instinct and, after several years of extensive migration in the sea, it returns to spawn once more in its parent stream. Thus a blockage, due to thermal or other effects, could even obliterate the entire run within a decade. (See also MERRIMAN, D., in Environmental Aspects of Nuclear Power Stations (Proc. Conf. New York, 1970), IAEA, Vienna (1971) page 507 et seq.)

millions of watts. The uranium-zirconium hydride system will yield from 10 000 to 100 000 W. Either system could be used for powering the large manned space station shown in a transparency.

One very useful idea which has come into focus in the development of American space nuclear equipment is the 'tele-operator', where man and machine are joined to perform useful work under difficult or dangerous conditions.

Between 1972 and 1975 the USA will explore Mars with the unmanned Viking spacecraft and the giant planet Jupiter with the unmanned Pioneer. These space-craft will receive all of their electricity from the 35 W SNAP-19 isotopic power supply, shown in the exhibit, which is capable of years of continuous operation.

Plans are now under way for the Grand Tour exploration of the outer planets, as delineated in a large transparency. This venture may mark the beginning of a new era of nuclear rocketry, using a gaseous-core reactor system now in the early stages of development and depicted in photographs. It promises to be about 10 times more efficient than the NERVA rocket which uses a solid core.

DESALINATION

Additional fresh water and new energy resources are rapidly needed to meet growing demands throughout the world. By developing the technology of desalting sea-water, it will be possible to use the oceans to meet the demand for fresh water. The combination of desalination technology and nuclear power from large dual-purpose plants should lead to the cleaner production of electrical energy and abundant energy for desalting sea-water.

The heat transfer tubes displayed in the exhibit were developed in the USA. The shorter lengths have the same heat transfer capacity as the long tubes thus making major savings possible. The tubes shown are being used in a distillation process called VTE/MSF (Vertical Tube Evaporator/Multi-Stage Flash). This plant will produce 3 000 000 gallons (11 355 000 litres) of water per day.

The exhibit showed the scaling up process from a 3 MGD (million gallons/day) to a 200 MGD plant, which would utilize a dual purpose nuclear reactor.

Agricultural-industrial centres may become possible by using the very low cost heat from large dual-purpose plants. Two studies have been made for such centres, one for Puerto Rico and the other for the Gulf of California. Examples were given of commercial desalting facilities, the largest being the one at Rosarito, Mexico. A chart showed sea-water desalting costs for different plant sizes. Photos of research and development installations at San Diego, California and a chart gave an idea of the growth of desalting plant capacity in the world. A film gave two examples of research being done at the USAEC's Oak Ridge National Laboratory.

FUSION

This part of the exhibit displayed, in a specially designed enclosure, the most recent advances in the United States attempts to achieve controlled thermonuclear reactions. The exhibit enclosure had been designed to simulate the high-vacuum requirements of controlled thermonuclear research and the importance of reflecting plasma particles with magnetic fields. The exhibits in this area were:

1. An introduction describing the three parameters involved in classical confinement of the thermonuclear plasma. These parameters are temperature, density and confinement time, and they were represented in an animated film which was inside an unusual geometric shape which resembled that of a minimum B-field for confining plasmas.

2. Two transparencies showed recent advances in the Stellarator program and the spherator program. Also demonstrated was ring-levitation.

3. A transparency of the Ormak device and a cut-away model of a hot ion injector used with Ormak.

4. A transparency of a multiple machine and an actual multiple machine (Doublet I — which had been cut away to reveal its interior), were on display.

5. The Lawrence Radiation Laboratory showed an animated film showing the characteristics of the Astron machine.

6. The Los Alamos Scientific Laboratory showed a model of Scyllac.

7. The Lawrence Radiation Laboratory displayed an animated model of the 2X-II device.

8. Another model demonstrated direct energy conversion with the particles coming from a mirror-type fusion reactor.

9. The end of the exhibit comprised a 3-dimensional schematic model of a fusion reactor which uses indirect conversion techniques for producing electricity.

On the side of the exhibit enclosure were large, backlit transparencies of the four most advanced fusion devices in the United States of America.

An important characteristic of the fusion exhibit was that, for all controlled thermonuclear reaction machines that were described in the exhibit, a bar graph was displayed directly on the exhibit item showing the achievement in the three basic parameters involved in classical confinement of a thermonuclear plasma.

TECHNICAL INFORMATION CENTRE

The Technical Information Centre contained three main sections: a RECON information retrieval demonstration, an exhibition of recent technical books in the field of science and technology, and a section for the distribution of selected nuclear publications. Also available was a small collection of scientific reference works.

The RECON demonstration included a 'TV' type computer terminal with a printing device and two additional TV monitors. The terminal permitted visitors to query in a "conversational" manner a data base stored in a computer at Oak Ridge, Tennessee. Most visitors needed only a very brief orientation before using the system.

The display of technical books included some 350 titles selected by a panel of experts.

Publications available in the distribution area included "Understanding the Atom" booklets in four languages, a special issue of Nuclear News, and various other publications of interest to Conference participants.

CLOSED-CIRCUIT TV SYSTEM AND FILMS

A closed-circuit television system operated during the Fourth International Conference on the Peaceful Uses of Atomic Energy.

The Television system enhanced the possibility for delegates to participate more broadly in the Conference and provided a record of selected material for use at later scientific discussions.

The use of television at the Conference marked the first time that a technical conference of this size has had full broadcast-type coverage, and the first time that a laser system was used to transmit a television signal on a continuous, routine basis through the atmosphere without other aids or protection.

The Conference coverage included several special programs as well as presentations of general and technical sessions. These special programs included a daily "Nuclear Forum", during which journalists from several nations had an opportunity to interview distinguished scientists attending the Conference. Another feature of the coverage was a "Nuclear Round-table". This daily broadcast included a host scientist and two or three other leaders in the field of nuclear science who engaged in an informal discussion on a topic of current interest to the Conference participants.

Included in the stand was a cinema, at which the following films, specially commissioned by the USAEC for the Conference, were shown:

NUCLEAR POWER IN THE UNITED STATES: The energy philosophy of the United States nuclear power industry expressed in terms of its thermal reactors, its plutonium recycle programs, its Liquid Metal Fast Breeder Reactor program and other advanced reactor concepts.

THE BITTER AND THE SWEET: Large-scale desalting technology and large-scale nuclear power plants being combined to influence the future economics of large-scale freshwater supplies to be won from the sea.

TO IMITATE THE SUN: Two decades of controlled thermonuclear research have produced a series of both open and closed systems, as well as the experiments in internal ring machines. The philosophy behind TWO-X-TWO, Scylla-IV and Scyllac, Astron, Stellarators and Tokamaks are indicated.

SPACE AND THE ATOM· Nuclear energy in space – from pioneering radioisotopic generators on Apollo missions through to the advanced generator systems for Mars, Jupiter and 'Grand Tour' missions and the development of the 75 000 lbf (34 000 kgf) thrust Nuclear Rocket Engine.

DOORWAY TO DIAGNOSIS: Revolutionary advancements in biomedical instrumentation – semiconductor detectors, image intensifiers, improved X-ray conversion, and improved resolution and performance of the tomographic scanner and the Mark III brain scanner.

SHORT-LIVED RADIOISOTOPES IN NUCLEAR MEDICINE: The revolutionary influence of new short-lived radioisotopes and improved scanning techniques in nuclear medicine. Parent-daughter generators, medical cyclotrons, high flux reactors, and attributes of the tomographic scanner and the computerized Mark III brain scanner.

THE RADIOISOTOPE-POWERED CARDIAC PACEMAKER: The joint three-year program of the U.S. Atomic Energy Commission and the National Institutes of Health to develop a radioactive-isotope-powered cardiac pacemaker.

THE ZONAL CENTRIFUGE: One of the most powerful tools of the molecular biologist is the zonal ultracentrifuge. Improved separation capabilities permit important fractionation of cell constituents and purifications of vaccines.

RADIATION PROCESSING: A NEW INDUSTRY: Uses of radiation for industrial processing in the United States of America have increased rapidly during recent years. Examples of radiation sterilization and chemical processing are shown. Electron-beam treatment of durable-press fabrics is depicted publicly for the first time.

NUCLEAR INNOVATIONS IN PROCESS CONTROL: Nuclear methods that are available for control of industrial processes and non-destructive testing are used in determining moisture content, alloy composition, highway road-bed density, defects in turbine blades, etc.

ISOTOPES IN ENVIRONMENTAL CONTROL: Radioactive atoms are being used to help man safeguard his environment. Included in this film are techniques used to trace oil spills, to determine absorption of oxygen by flowing water, drifting of sand on the ocean floor, and to study air pollution.

TO DEVELOP PEACEFUL APPLICATIONS FOR NUCLEAR EXPLOSIVES: Emphasizes research procedures which support, and the stringent requirements which govern, all nuclear explosive engineering experiments in the United States Plowshare Program. Voices of program participants describe work related to recent experiments in nuclear stimulation of natural gas fields.

DECISION FOR TOMORROW: This around-the-world film shows nuclear power has 'come-of-age' as a means of meeting power needs of developing nations. Explains the extensive United States nuclear services available to international customers.

CONTRIBUTORS TO THE UNITED STATES OF AMERICA STAND

FEDERAL AGENCIES

U.S. Public Health Service;

U.S. Weather Bureau;

U.S. Coast and Geodetic Survey;

United States Information Agency;

U.S. Geological Survey;

USA Satellite Communications Agency;

U.S. Office of Saline Water, Department of the Interior;

National Aeronautics and Space Administration;

Tennessee Valley Authority;

U.S. Army Natick Laboratories;

U.S. Air Force.

USAEC FACILITIES

Argonne National Laboratory;

Brookhaven National Laboratory;

Lawrence Radiation Laboratory;

Los Alamos Scientific Laboratory;

New Brunswick Laboratory;

Oak Ridge Associated Universities;

Oak Ridge National Laboratory;

Sandia Laboratories;

Savannah River Plant.

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Baltimore Gas and Electric, Baltimore, Md.;

Bara Photographics, Hyattsville, Md.;

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Case Western Reserve University

CER Geonuclear Corporation, Las Vegas, Nev.;

Chicago Bridge & Iron Co., Oak Brook, Ill.;

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Commonwealth Edison, Chicago, Ill.;

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Gamma Industries, Baton Rouge, La.;

General Electric Company, New York, N.Y.;

W.R. Grace and Company, Duncan, S.C.;

Gulf Energy & Environmental Systems, San Diego, Calif.;

Hahnemann Hospital, Philadelphia, Pa.;

Industrial Nucleonics Corporation, Columbus, Ohio;

International Harvester (Solar Division), San Diego, Calif.;

Ionics Inc., Watertown, Mass.;

Jersey Nuclear Co., Bellevue, Wash.;

Jet Propulsion Laboratory, Pasadena, Calif.;

Kerr-McGee Corp., Oklahoma City, Okla.;

Lockheed-Georgia Corporation, Marietta, Ga.;

Lunar & Planetary Laboratory, University of Arizona, Tucson, Ariz.;

Mallinckrodt Nuclear, St. Louis, Mo.;

Martin Marietta, Denver, Colo.;

Monsanto Research Corporation, Miamisburg, Ohio;

National Geographic Society, Washington, D.C.;

National Nuclear Corp., Palo Alto, Calif.;

Neutron Products, Inc., Dickerson, Md.;

Norland Associates, Inc., Fort Atkinson, Wis.;

North American Rockwell, Canoga Park, Calif.;

Nuclear Chicago Corporation, Des Plaines, Ill.;

Nuclear Fuel Services, Inc., Rockville, Md.;

Nuclear Materials and Equipment Corporation, Apollo, Pa.;

Ohio Nuclear, Incorporated, Cleveland, Ohio;

Olin Industries, New Haven, Conn.;

Panametrics, Waltham, Mass.;

Phelps Dodge Copper Products Corp., Dayton, N.J.;

Picker Corporation, North Haven, Conn.;

POWER Magazine, New York, N.Y.;

Princeton University, Plasma Physics Laboratory,&c., Princeton, N.J.;

Raychem Corporation, Menlo Park, Calif.;

Reynolds Metals Co., Richmond, Va.;

Sloan-Kettering Memorial Hospital, New York, N.Y.;

Solid State Radiation, Inc., Los Angeles, Calif.;

E.R. Squibb & Sons, New Brunswick, N.J.;

Stearns-Roger Corporation, Denver, Colo.;

Teledyne Isotopes, Timonium, Md.;

The Dow Chemical Company, Golden, Colo.;

Tim Evans Design, Washington, D.C.;

Todd Shipyards, Galveston, Tex.;

Troxler Electronic Laboratories, Inc., Raleigh, N.C.;

Union Carbide Corporation, Tuxedo, N.Y.;

Union Carbide (Linde Division), Tonawanda, N.Y.;

United Nuclear Corporation, Elmsford, N.Y.;

University of California

University of Oregon, Eugene, Oreg.;

University of Texas, M.D.Anderson Hospital & Tumor Institute, Houston, Tex.;

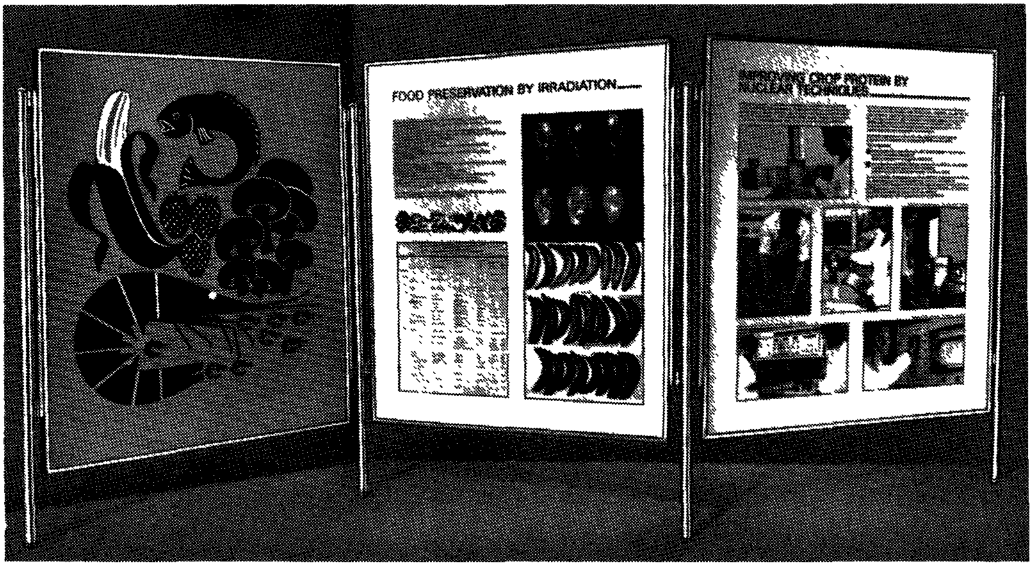
U.S. Radium Corporation, Blumsburg, Pa.;

Victoreen Instrument Company, Cleveland, Ohio;

WADCO Corporation, Richland, Wash.;

Westinghouse Electric Corporation, Pittsburgh, Pa.;

Yankee Atomic Electric Company, Westboro, Mass.



IAEA EXHIBIT

As mentioned previously, the Agency had, as part of the Governmental Scientific Exhibition, prepared an exhibit which was located in the Salle des Pas Perdus behind the Assembly Hall. Because of its favourable location, this exhibit was well attended and aroused much interest and comment.

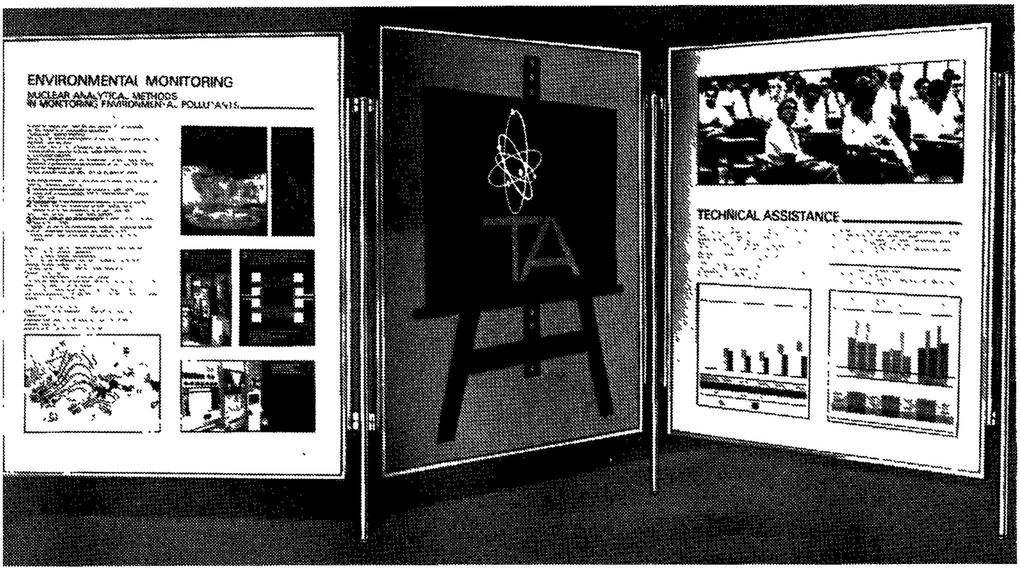
The display consisted of a number of panels depicting, by means of diagrams, statistics, photographs and text, various branches of the Agency's work. The overall purpose was to show the organizational structure of the Agency and its main activities. Also included was a display of Agency publications, which added a splash of colour to the Salle des Pas Perdus.

Illustrated panels described some work on medical applications of nuclear science, and included accounts of scintigraphic techniques, radioimmunoassay, and iron nutrition studies. The displays gave a general account of the principles involved and details were given of the projects being carried out in various parts of the world both by the Agency and the World Health Organization.

The work of the Nuclear Data Section was briefly described. With the co-operation of Member States, four nuclear data centres have been established which collect and exchange important nuclear data.

The work of the Agency's Laboratories at Seibersdorf and Monaco, and the International Centre for Theoretical Physics at Trieste (which is partly financed by the Agency) was also reviewed. Brief details were given of the programs of research being undertaken both at Seibersdorf and Monaco.

The work of the Agency on Safeguards was depicted. Under the terms of the Treaty on the Non-Proliferation of Nuclear Weapons (NPT), the Agency is required to safeguard nuclear facilities in Member States party to the



Some of the many panels depicting Agency activities.

treaty. Panels illustrated how this is accomplished by means of containment, surveillance systems and by a system of accountability.

Nuclear techniques play an important role in the production and preservation of food. Panels described how crop yields and crop protein may be improved by means of nuclear techniques. A further exhibit showed how food wastage can be reduced by using ionizing radiation to preserve foods. Also featured was a general survey which showed the irradiated food products which have been cleared for general consumption.

Technical Assistance is one of the Agency's major activities. Panels described how the Agency's Technical Assistance program is implemented through the provision of experts, supply of equipment and award of Fellowships for individual study, scientific visits, study tours and short-term training.

In the contexts of nuclear power, uranium exploration, mining and production, reactor physics and nuclear desalination, the Agency has continued to promote the peaceful uses of atomic energy and has paid special attention to the needs of developing countries. Panels illustrated the projected growth of nuclear power, the application of nuclear power to desalting water and the Agency's activities in uranium exploration, mining and production. Details were given of UNDP Special Fund Projects in mineral prospecting carried out in conjunction with the Agency's Technical Assistance program. A selection of uranium ores was displayed as part of the exhibit. Agency activities in the field of research reactor utilization include fourteen Regional Study Group Meetings on Research Reactor Utilization which have been held since 1962.

Of considerable importance to developing countries is the process of information exchange. Information exchange is facilitated by the Agency's International Nuclear Information System (INIS), which was described as part of the exhibit.