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FOREWORD

When the General Assembly approved the convening of the Third International Conference on the Peaceful Uses of Atomic Energy (resolution 1770 (XVII) of 29 November 1962), it stipulated that the Conference should be "considerably more limited in size and cost than those held in 1955 and 1958 and at a minimum expense to the United Nations". The agenda was consequently more concentrated and more specific, embracing various technical and economic aspects of atomic energy as a source of power capable of making a major contribution to world development. This circumscription of the theme of the Conference brought its own advantage; it enabled highly topical issues to be probed in depth, not only by the scientists and technologists who had hitherto had the field virtually to themselves, but also by power engineers, economists and administrators.

These volumes containing the Proceedings of the Third International Conference on the Peaceful Uses of Atomic Energy will, I believe, prove to be of great practical value to all those called upon to plan, develop and watch over the use of atomic energy as a factor of growing significance in the power balance-sheet of their respective countries. As such a working tool, these Proceedings continue to reflect the generosity and good will of Governments, their willingness to share vital information and their readiness to co-operate in its application for the common good that marked the two earlier Conferences.

I would like to record my appreciation of the generous and effective co-operation received throughout the preparations for and during the Conference from Dr. Sigvard Eklund, Director General of the International Atomic Energy Agency, who himself contributes the Preface to these Proceedings, and from the Scientific Secretariat, drawn largely from his staff. The pattern of collaboration between members of the United Nations family thus established provides an example which might with benefit be followed in the future in similar projects.

I would like also to express my thanks to the members of the United Nations Scientific Advisory Committee for their invaluable assistance and wise counsel, without which the intricate preparations for the Conference could not have been brought to a successful conclusion, and through them to their respective Governments for their contribution to the staffing of the Scientific Secretariat.

U THANT
Secretary-General of the United Nations

PREFACE

The Third International Conference on the Peaceful Uses of Atomic Energy, of which these Proceedings constitute the scientific record, was an important milestone in the development of atomic energy, since it recognized that this is no longer a scientific novelty but a world economic reality. Consequently, attention was focused not so much on whether or not atomic energy can help to meet national and world power requirements, but rather on how and when it will be able to do so within the framework of conventional power requirements. The Conference did much to remove the barrier, arbitrarily erected, between nuclear and other power, suggesting that the former will soon be regarded in the same light as power derived from conventional sources. It was apparent from the papers and discussions that nuclear energy will come into use at an increasing pace, and at costs which will compare more and more favourably with the costs of conventional power. It was equally clear that the economics of nuclear power depend both on local conditions and on the size of plant units, and that what might appear uneconomic for larger industrialized countries might well be economic, in given circumstances, in less developed countries; for it has been wisely said, with reference to developing countries, that "there is no power so expensive as no power". It became evident in this context, however, that in weighing different concepts of power reactors, each design must be viewed against the background of the local conditions under which it will operate, if its potential in any specific location is to be evaluated properly.

The papers on power reactors showed that several current types can already be regarded as standard; and operating experience has established that their safety and availability records, as well as their capital and fuel costs, are such as to make them competitive with conventional power generating stations, particularly where units are large. Major research on the development of a variety of systems offering better fuel utilization enhances the prospect of their speedy introduction, thereby helping, incidentally, to conserve the world's limited resources of fossil fuels. It is generally recognized that the development of breeder reactors should not only improve the utilization of the world's resources of nuclear materials, but should also lower the incidence of the fuel component in power generating costs, and thus make it possible to mine low-grade uranium ores economically. Special attention was devoted to the prospects for supply and demand of nuclear raw materials, and to the possibility of recovering uranium from sea water on an economic basis. Operating results obtained with experimental breeder reactors in certain countries strongly support the view that their use on an industrial scale is solely a matter of time, target dates for such a development ranging from the middle 1970s to the middle 1980s.

The Conference also brought out the excellent safety record of the nuclear power industry; this is due to the high factors of safety already used in design, in the testing of materials and in construction controls, etc. Experience acquired in reactor operation, which has enabled standard procedures to be established, has minimized the risk of accidents and their consequences. As regards plant equipment, interesting information was presented about reactor containment, in particular on the use of prestressed concrete pressure vessels and the development of materials capable of retaining adequate stability under conditions of high temperature, pressure and radiation. At the same time, it became evident that further work is needed in this field. Important information was submitted on heat transfer problems, particularly when approaching critical heat flux conditions, and on the use of superheated steam as a coolant. Significant progress, too, was reported in the improvement of fuel-element heat transfer through the development of more complex heat transfer surfaces. Better methods of disposing of radio-active waste were described, including its incorporation in glass and its disposal in suitable underground formations, salt formations in particular being regarded as eminently suitable for this purpose.

So far as controlled nuclear fusion is concerned, developments have mainly been confined to research into and knowledge of plasma physics; these developments have given an indication of the technical difficulties that have still to be overcome. The Conference learned of some interesting developments in direct methods of converting nuclear into electrical energy, the present objectives of which are to increase conversion efficiency and to produce compact, reliable and long-lasting power supplies for use in special conditions. The papers on such small-scale devices as "ROMASHKA" (USSR) and "SNAP" (USA) were among the practical examples of this which excited considerable interest.

A special application of nuclear energy which aroused considerable interest at the Conference is its use for the dual purpose of producing electricity and process heat which, where base-load demand exists for both water and power, could be used for the desalination of salt and brackish waters. While it is recognized that with the present stage of technology such dual-purpose plants would have to be of large size and capacity to be an economic proposition, the increasing world shortage of fresh water and continual improvements in technology justify the work being done to harness the great potential of nuclear power to this end. Encouraging papers were also presented describing experience gained in the use of nuclear explosives for mining and civil engineering which demonstrated the great possibilities of their use in the building of harbours, canals, water-storage ponds, etc., at costs which might become competitive with conventional explosives, depending upon the nature, location and magnitude of each project.

The Conference also brought out the substantial progress made in international and regional co-operation in the development and use of nuclear energy. Although the use of isotopes received only passing attention, the survey papers presented on this subject showed the steady progress which has been made in this field, and the virtually routine use of isotopes in important areas in medicine, agriculture and industry.

The theme of the Conference—reactors and nuclear power—was a reflection of the advance of nuclear power from the laboratory study to commercial application. Consequently, it was not surprising to find that commercial interests were well represented among those attending the Conference. But it was gratifying to note that the veil of secrecy with which these aspects of nuclear power are usually shrouded did not obscure a liberal and frank exchange of views on reactor concepts, types and systems which should have beneficial effects on the growth of atomic energy as a source of electricity.

Sigvard EKLUND
Director General, International Atomic Energy Agency

AVANT-PROPOS

Lorsque l'Assemblée générale a approuvé la convocation de la troisième Conférence internationale sur l'utilisation de l'énergie atomique à des fins pacifiques [résolution 1770 (XVII) du 29 novembre 1962], elle a précisé que cette conférence devait être « d'une importance beaucoup plus limitée que celles de 1955 et 1958 et organisée de façon à n'imposer aux Nations Unies qu'un minimum de frais ». En conséquence, un ordre du jour moins ambitieux mais plus concret prévoyait l'étude, sous divers aspects techniques et économiques, de l'énergie atomique considérée comme source d'énergie pouvant contribuer puissamment au développement mondial. Cette limitation du thème de la Conférence a eu son avantage; il a été possible ainsi de faire étudier en profondeur des problèmes de grande actualité, non seulement par les savants et les techniciens qui s'en étaient occupés pratiquement seuls jusqu'alors, mais encore par des ingénieurs spécialistes de l'énergie, des économistes et des administrateurs.

Ces volumes qui contiennent les Actes de la troisième Conférence internationale sur l'utilisation de l'énergie atomique à des fins pacifiques seront, j'en ai la conviction, d'une grande valeur pratique pour tous ceux qui sont appelés à prévoir, mettre au point et surveiller l'utilisation de l'énergie atomique en tant qu'élément d'importance croissante du bilan énergétique de leur pays. Instrument de travail pratique, les Actes de la troisième Conférence témoignent de la générosité, de la bonne volonté, de l'empressement à mettre en commun des connaissances d'importance capitale et du bon vouloir à collaborer à leur application pour le plus grand bien de tous — dont les gouvernements avaient déjà fait preuve lors des deux premières conférences.

Je tiens à exprimer officiellement ma gratitude à M. Sigvard Eklund, Directeur général de l'Agence internationale de l'énergie atomique, qui a rédigé la préface des Actes de la Conférence, et au Secrétariat scientifique, composé en majeure partie de membres de son personnel, pour le concours généreux et efficace qu'ils m'ont accordé pendant toute la durée des travaux préparatoires et pendant la Conférence elle-même. Ce type de collaboration qui s'est instauré entre les organes de la famille des Nations Unies est un exemple dont on pourrait utilement s'inspirer dans l'avenir pour des tâches similaires.

Je tiens à remercier aussi les membres du Comité consultatif scientifique des Nations Unies de leur aide précieuse et de leurs conseils judicieux, sans lesquels il eut été impossible de mener à bonne fin les travaux si complexes de préparation de la Conférence, et, par leur truchement, je remercie les gouvernements intéressés d'avoir bien voulu détacher du personnel au Secrétariat scientifique de la Conférence.

U THANT

Secrétaire général de l'Organisation des Nations Unies

PRÉFACE

La troisième Conférence internationale sur l'utilisation de l'énergie atomique à des fins pacifiques, dont les Actes ci-après constituent le bilan scientifique, a marqué une étape importante du développement de l'énergie atomique puisqu'il y a été reconnu que l'énergie nucléaire ne représente plus une nouveauté scientifique mais une réalité économique mondiale. Le centre d'intérêt s'est donc déplacé et l'on ne cherche plus tant à savoir si l'énergie atomique peut ou non aider à faire face aux besoins nationaux et mondiaux d'énergie, mais plutôt quand et comment elle pourra le faire dans le cadre des besoins d'énergie classique. La Conférence a beaucoup contribué à abolir la distinction arbitraire entre l'énergie d'origine nucléaire et les autres formes d'énergie et l'on peut penser que l'énergie d'origine nucléaire sera bientôt considérée sous le même angle que les autres sources d'énergie. Les mémoires et les débats ont fait ressortir clairement que l'utilisation de l'énergie d'origine nucléaire va se généraliser rapidement et que son prix de revient pourra se comparer de plus en plus favorablement à celui de l'énergie classique. Il est apparu tout aussi clairement que la rentabilité de l'énergie d'origine nucléaire est fonction à la fois des conditions locales et de la taille des unités de production et que telle installation qui risquerait de ne pas être considérée comme rentable dans de grands pays industriels pourrait fort bien être économiquement viable, dans des conditions données, dans les pays moins développés; car on a fort bien dit qu' « il n'existe pas d'énergie qui soit aussi coûteuse que l'absence d'énergie ». Il est devenu évident à cet égard que, lorsqu'on veut juger les différents types de réacteurs de puissance, il faut pour évaluer convenablement leurs possibilités en un lieu donné considérer chacun d'eux en tenant compte des conditions locales dans lesquelles il fonctionnerait.

Il ressort des mémoires présentés sur les réacteurs de puissance que plusieurs des modèles actuels peuvent désormais être considérés comme des réacteurs types, et l'expérience pratique a montré que du point de vue de la sécurité et de la continuité du fonctionnement, ainsi que des immobilisations et des dépenses de combustible, ces réacteurs peuvent soutenir la concurrence des centrales électriques classiques, surtout s'il s'agit de grosses unités. L'effort de recherche considérable poursuivi pour mettre au point toute une gamme de systèmes assurant une meilleure utilisation du combustible augmente encore les chances de leur mise en service prochaine, ce qui, incidemment, permettrait de ménager les ressources mondiales en combustibles fossiles, qui sont limitées. On s'accorde généralement à reconnaître que la mise au point de réacteurs surgénérateurs devrait permettre non seulement d'améliorer l'utilisation des ressources mondiales en matières nucléaires, mais encore de réduire le poste « combustible » dans le coût de production de l'électricité et de rendre ainsi rentable l'extraction de minerais à faible teneur en uranium. On s'est particulièrement préoccupé des perspectives de l'offre et de la demande de matières premières nucléaires et de la possibilité d'extraire de façon rentable l'uranium de l'eau de mer. Les résultats obtenus dans certains pays avec des réacteurs surgénérateurs expérimentaux sont tels que l'on peut considérer que leur utilisation à l'échelle industrielle n'est qu'une question de temps, les dates avancées se situant entre 1975 et 1985 environ.

La Conférence a montré aussi les excellentes conditions de sécurité dans lesquelles travaille l'industrie énergétique nucléaire en raison des normes de sécurité élevées que l'on applique dans la conception des réacteurs, les essais des matériaux, le contrôle en cours de construction, etc. Grâce à l'expérience acquise dans le fonctionnement des réacteurs, on a pu mettre au point des règles types et minimiser les risques d'accident et leurs conséquences. En matière d'équipement des réacteurs, des renseignements intéressants ont été fournis sur l'enveloppe de sécurité, en particulier sur l'utilisation de caissons étanches en béton précontraint et sur la mise au point de matériaux capables de conserver la stabilité voulue dans des conditions de température, de pression et d'irradiation élevées. Il est cependant apparu à l'évidence qu'il faut poursuivre les travaux dans ce domaine. Des renseignements importants ont été présentés sur les problèmes de transfert de chaleur, notamment au voisinage de conditions de flux thermique critiques, et sur l'emploi de vapeur surchauffée comme fluide caloporteur. On a également signalé que de grands progrès avaient été réalisés dans l'amélioration du transfert de chaleur des éléments de combustible grâce à la mise au point de surfaces de transfert de chaleur de forme plus complexe. On a traité aussi du perfectionnement des méthodes d'élimination des déchets radioactifs, notamment de celle qui consiste à les incorporer dans du verre et à les enfouir dans certaines formations souterraines, les formations salines en particulier se prêtant parfaitement, estime-t-on, à cet usage.

Quant au domaine de la fusion nucléaire contrôlée, on peut y mentionner surtout les recherches visant à élargir les connaissances en matière de physique des plasmas; ces recherches ont donné des indications sur les difficultés techniques qui restent à surmonter. La Conférence a entendu des exposés sur d'intéressants travaux concernant des méthodes de conversion directe de l'énergie nucléaire en énergie électrique; les objectifs actuels de ces travaux sont d'améliorer le rendement de la conversion et de fabriquer des générateurs d'électricité qui soient de faible encombrement, de fonctionnement sûr et de longue durée, pouvant être utilisés dans des conditions spéciales. Parmi les réalisations pratiques qui ont été citées à la Conférence, il convient de mentionner les communications sur les appareils de taille réduite « ROMASHKA » (URSS) et « SNAP » (Etats-Unis), qui ont éveillé un intérêt considérable.

L'une des applications de l'énergie nucléaire qui ont suscité le plus d'intérêt à la Conférence est celle qui permet de combiner la production d'électricité et celle de chaleur; là où il existe une demande constante d'eau aussi bien que d'électricité, une installation conçue à cette fin peut être utilisée pour le dessalement de l'eau de mer et des eaux saumâtres. Certes, dans l'état actuel de la technique, ces installations à double fin doivent pour être rentables avoir une taille et une capacité de production considérables, mais la pénurie croissante d'eau douce dans le monde et les progrès incessants de la technique justifient les efforts entrepris pour exploiter les possibilités immenses que l'énergie nucléaire offre dans ce domaine. Des communications intéressantes ont été faites aussi sur l'utilisation d'explosifs nucléaires dans l'extraction minière et le génie civil; elles témoignent des vastes possibilités qu'offrent ces procédés pour la construction de ports, le creusement de canaux, l'aménagement de bassins d'accumulation d'eau, etc., moyennant un coût qui pourrait arriver à soutenir la concurrence de celui des explosifs classiques, compte tenu de la nature, de l'emplacement et de l'ampleur des travaux à réaliser.

La Conférence a mis en relief l'étendue des progrès accomplis dans la coopération internationale et régionale pour l'étude et l'emploi de l'énergie nucléaire. Si l'utilisation des radioéléments n'a retenu que brièvement l'attention, il ressort des rapports d'ensemble présentés à ce sujet que des progrès constants sont réalisés dans ces applications et que les radioéléments sont d'un usage presque classique dans d'importants domaines de la médecine, de l'agriculture et de l'industrie.

Le thème même de la Conférence — les réacteurs et l'énergie d'origine nucléaire — illustre les progrès accomplis en matière d'électricité nucléaire, laquelle est passée du stade de l'étude en laboratoire à celui des applications commerciales. Il n'y avait donc pas lieu d'être surpris que les intérêts commerciaux fussent bien représentés à la Conférence. Mais il a été agréable de constater que le secret qui entoure habituellement ces aspects de l'énergie d'origine nucléaire n'a nullement empêché de larges et francs échanges de vues sur les projets, les types et les systèmes de réacteurs propres à accroître le rôle de l'énergie atomique en tant que source d'électricité.

Sigvard Eklund

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

ВВЕДЕНИЕ

Когда Генеральная Ассамблея одобрила созыв третьей Международной конференции по использованию атомной энергии в мирных целях (резолюция 1770 (XVII) от 29 ноября 1962 г.), она предусматривала, что эта Конференция должна быть «значительно более ограниченной по своим масштабам и расходам, чем конференции, состоявшиеся в 1955 году и 1958 году, при минимальных расходах для Организации Объединенных Наций». Повестка дня Конференции была, соответственно, более концентрированной и конкретной, охватывающей различные технические и экономические аспекты атомной энергии, как источника энергии, способного внести важный вклад в мировое развитие. Это ограничение темы Конференции имело свои преимущества; оно позволило осуществить глубокое рассмотрение в высшей степени актуальных вопросов не только учеными и техническими специалистами, которые до сего времени фактически пользовались своего рода монополией в этой области, но также инженерами-энергетиками, экономистами и представителями административных органов.

Эти тома, содержащие Труды третьей Международной конференции по использованию атомной энергии в мирных целях, будут, как я полагаю, иметь большую практическую ценность для всех тех, кто призван заниматься планированием и развитием атомной энергии, а также наблюдением за ее использованием, поскольку атомная энергия становится все более важным фактором в энергетических балансах их стран. Будучи такого рода орудием, эти Труды продолжают являться отражением бескорыстия и доброй воли правительств, их готовности делиться важной информацией, а также их готовности к сотрудничеству в деле ее использования для общего блага, что являлось характерным и для двух предыдущих конференций.

Разрешите мне выразить мою благодарность Генеральному директору Международного агентства по атомной энергии д-ру Сигварду Эклунду за широкую и эффективную поддержку, которую он оказывал в ходе подготовки и проведения этой Конференции, причем он сам подготовил предисловие к настоящим Трудам, а также Ученому секретариату, сформированному в основном из членов его персонала. Налаженное таким образом сотрудничество между членами системы Организации Объединенных Наций представляет собой пример, которому можно было бы с пользой следовать в будущем при проведении аналогичных мероприятий.

Мне хотелось бы также выразить мою признательность членам Научного консультативного комитета ООН за их неоценимую помощь и мудрые советы, без которых сложная работа по подготовке данной Конференции не могла бы увенчаться успехом; через них я хотел бы также выразить мою благодарность их правительствам за сотрудничество в деле укомплектования Ученого секретариата.

У ТАН

Генеральный Секретарь Организации Объединенных Наций

ПРЕДИСЛОВИЕ

Третья Международная конференция по использованию атомной энергии в мирных целях, научным отчетом о работе которой настоящие Труды являются, была важной вехой в развитии атомной энергии, поскольку она признала, что атомная энергия уже более не является научным новшеством, а стала реальностью мировой экономики. Соответственно внимание было сосредоточено не столько на том, может ли атомная энергия играть роль в деле удовлетворения потребностей в энергии как в национальном, так и в международном масштабе, сколько на том, как и когда это можно осуществить в рамках потребностей в энергии из обычных источников. Конференция проделала большую работу в плане устранения произвольного по своему характеру барьера между ядерной энергией и другими источниками энергии и выдвинула предположение, что в ближайшее время ядерная энергия будет рассматриваться в качестве такого же источника, как и обычные источники. На основании докладов и дискуссий стало очевидным, что ядерная энергия будет использоваться во все возрастающих масштабах, причем по своей себестоимости она будет все более и более конкурентоспособной по отношению к энергии из обычных источников. Стало также очевидным, что экономика ядерной энергии связана как с местными условиями, так и с размерами агрегатов и объекты, которые можно было бы рассматривать как нерентабельные для более крупных промышленных стран, вполне могут оказаться рентабельными при определенных условиях в менее развитых странах; как было правильно сказано в отношении развивающихся стран, «нет такой дорогостоящей энергии, как отсутствие энергии». Однако в этой связи стало очевидным, что при оценке различных типов энергетических реакторов каждую конструкцию реактора следует рассматривать с учетом преобладающих местных условий, в которых он будет работать, с тем чтобы правильно оценить его потенциал в каждом отдельном случае.

Доклады относительно энергетических реакторов показали, что несколько существующих в настоящее время типов реакторов могут уже рассматриваться как стандартные модели; опыт их эксплуатации ясно показывает, что их степень безопасности и надежности, капитальные расходы и расходы на топливо таковы, что эти реакторы становятся конкурентоспособными по отношению к обычным электростанциям, особенно когда речь идет о больших агрегатах. Крупные исследовательские работы по созданию ряда систем, обеспечивающих лучшее использование топлива, приближают перспективу их быстрого внедрения, а это в конечном счете служит делу сохранения ограниченных мировых запасов ископаемого топлива. Сейчас признано всеми, что развитие реакторов-размножителей должно не только усовершенствовать использование мировых запасов ядерного топлива, но должно также понизить удельный вес топлива в себестоимости производства энергии, а это сделает рентабельным добычу низкосортных урановых руд. Особое внимание было уделено перспективам спроса и предложения ядерных сырьевых материалов, а также возможности рентабельной добычи урана из морской воды. Результаты эксплуатации экспериментальных реакторов-размножителей в некоторых странах несомненно подтверждают, что их использование в промышленном масштабе является лишь вопросом времени, причем ориентировочные сроки колеблются от середины семидесятых годов до середины восьмидесятых годов.

Конференция выявила также высокую степень безопасности на предприятиях ядерной промышленности, что обусловлено высокими коэффициентами безопасности, применяемыми уже при проектировании, при испытании материалов и при контролировании в ходе строительства и т. д. Опыт, приобретенный в ходе эксплуатации реакторов, который дал возможность установить стандартные процессы, свел к минимуму опасность несчастных случаев и их последствия. Что касается производственного оборудования, то была получена интересная информация относительно герметизации реакторов, особенно относительно использования сосудов высокого давления из предварительно напряженного бетона и создания материалов, способных сохранять достаточную стабильность в условиях высокой температуры, высокого давления и высокой радиации. Одновременно стало очевидным, что существует необходимость проводить дальнейшие работы в этой области. Была представлена важная информация относительно проблем передачи тепла, особенно при приближении к критическому уровню теплового потока, а также относительно использования перегретого пара в качестве охладителя. Было сообщено также о значительных успехах, достигнутых в деле усовершенствования передачи тепла топливными элементами путем конструирования более сложных поверхностей для его передачи. Рассматривались усовершенствованные методы удаления радиоактивных отходов, включая помещение их в стекло и в подземные формации; в частности, считают, что соляные формации являются особенно пригодными для этой цели.

Разработка управляемого ядерного синтеза осуществлялась главным образом по линии исследований закономерностей физики плазмы, а это выявило технические трудности, которые все еще предстоит преодолеть. Участники Конференции заслушали сообщения относительно некоторых интересных сдвигов в области непосредственных методов превращения ядерной энергии в электрическую; при этом в настоящее время ставятся цели повысить эффективность такого превращения и обеспечить непрерывное, надежное и длительное энергоснабжение для использования в специальных условиях. В докладах о таких агрегатах небольших размеров, как «РОМАШКА» (СССР) и «СНАП» (США), приводились практические примеры в этом плане, что вызвало значительный интерес.

Специальным видом применения ядерной энергии, вызвавшим на Конференции значительный интерес, явилось использование ее для производства как электричества, так и технологического тепла, которое в тех случаях, когда в связи с основной нагрузкой существует потребность как в воде, так и в энергии, может быть использовано для опреснения соленых и солоноватых вод. Хотя и признается, что при нынешнем уровне технологии экономичность таких установок двойного назначения требует, чтобы они были крупными и мощными, возрастающая нехватка пресной воды во всем мире и непрерывное усовершенствование технологии оправдывают работу, которая проводится с тем, чтобы высвободить большой потенциал ядерной энергии для этой цели. Были представлены оптимистические доклады относительно опыта в области использования ядерных взрывчатых веществ в горном деле и в гражданском строительстве, что выявило огромные возможности их применения для строительства гаваней, каналов, водохранилищ и т. д. по себестоимости, допускающей конкурентоспособность в сравнении с обычными взрывчатыми веществами, конечно в зависимости от характера, месторасположения и объема каждого объекта.

Конференция выявила также значительный прогресс, достигнутый в рамках международного и регионального сотрудничества в деле развития и использования ядерной энергии. Хотя вопросу об использовании изотопов было уделено лишь незначительное внимание, представленные по данному вопросу доклады выявили неуклонный прогресс в этой области и почти повсеместное использование изотопов в важных отраслях медицины, сельского хозяйства и промышленности.

Сама тема Конференции, а именно реакторы и ядерная энергия, явилась признанием перехода ядерной энергии из стадии лабораторных исследований в стадию использования в производственных условиях. Соответственно не вызвал удивления тот факт, что на Конференции были широко представлены торгово-промышленные круги. Однако было приятно отметить, что завеса секретов производства, обычно скрывающая эти аспекты ядерной энергии, не помешала свободному и откровенному обмену мнениями в отношении принципов конструкции, типов и систем реакторов, которые должны оказать благоприятное влияние на распространение использования атомной энергии в качестве источника электроэнергии.

Сигвард ЭКЛУНД

Генеральный директор, Международного агентства по атомной энергии

INTRODUCCIÓN

Al autorizar la celebración de la tercera Conferencia Internacional sobre la Utilización de la Energía Atómica con Fines Pacíficos (resolución 1770 (XVII) del 29 de noviembre de 1962), la Asamblea General dispuso que la Conferencia fuera "de magnitud y gastos mucho más limitados que las de 1955 y 1958, de modo que entrañase un costo mínimo para las Naciones Unidas". En consecuencia, su programa fue más concentrado y concreto, abarcando diversos aspectos técnicos y económicos de la energía atómica como fuente energética capaz de aportar una contribución fundamental al desarrollo del mundo. El hecho de haberse circunscrito así el tema de la Conferencia resultó ventajoso, pues permitió que problemas de gran actualidad fueran examinados a fondo no sólo por los hombres de ciencia y los técnicos, que hasta entonces eran virtualmente los únicos que los habían estudiado, sino también por ingenieros especializados en cuestiones de energía, economistas y administradores.

Estimo que estos volúmenes en que figuran las Actas de la tercera Conferencia Internacional sobre la Utilización de la Energía Atómica con Fines Pacíficos serán de gran utilidad práctica para todos cuantos están llamados a planear, desarrollar o inspeccionar la utilización de la energía atómica como factor de una significación cada vez mayor en el balance energético de sus respectivos países. En dicha calidad de instrumento de trabajo, estas Actas continúan reflejando la generosidad y la buena voluntad de los gobiernos, su deseo de compartir información vital y de cooperar en su aplicación para el bien común, que caracterizó a las dos Conferencias anteriores.

Deseo hacer constar cuánto aprecio la generosa y eficaz cooperación prestada tanto durante la preparación de la Conferencia como en el curso de la misma, por el Dr. Sigvard Eklund, Director General del Organismo Internacional de Energía Atómica, que ha redactado también el prefacio a estas Actas, y por la Secretaría Científica, constituida en gran parte por colaboradores de aquél. El tipo de cooperación que así se ha establecido entre los organismos de las Naciones Unidas proporciona un ejemplo que puede ser beneficioso seguir en lo sucesivo en proyectos análogos.

Deseo asimismo expresar mi reconocimiento a los miembros del Comité Científico Consultivo de las Naciones Unidas por su valiosísima asistencia y acertado asesoramiento, sin los cuales los complicados preparativos de la Conferencia no podrían haberse llevado tan felizmente a término, y, por conducto de ellos, a sus respectivos gobiernos por la contribución que han aportado al proporcionar personal para la Secretaría Científica.

U THANT
Secretario General de las Naciones Unidas

PREFACIO

La tercera Conferencia Internacional sobre la Utilización de la Energía Atómica con Fines Pacíficos, cuya labor científica se recoge en estas actas, representó un hito importante en la evolución de la energía atómica ya que reconoció que ésta ya no es una novedad científica, sino una realidad en la economía mundial. Por consiguiente, la atención no se concentró tanto en la cuestión de saber si la energía atómica puede o no contribuir a la satisfacción de las necesidades nacionales y mundiales de energía, sino más bien en la de determinar cómo y cuándo puede lograr esto dentro del marco de las necesidades actuales en materia de energía de tipo corriente. La Conferencia ayudó mucho a eliminar la barrera levantada arbitrariamente entre la energía nuclear y la de otra naturaleza, poniendo de manifiesto que la primera será pronto considerada de manera idéntica que la procedente de otras fuentes. Se infirió claramente de las memorias y de las deliberaciones que la energía nuclear se utilizará en medida cada vez mayor y que su costo llegará a ser tan ventajoso como el de la energía convencional. Quedó demostrado que los aspectos económicos de la producción de energía atómica dependen tanto de las condiciones locales como de las dimensiones de las centrales atómicas y que lo que pudiera considerarse como antieconómico para los países industriales más grandes, podría, en determinadas circunstancias, ser perfectamente económico en los países menos desarrollados. Como se ha dicho con razón, refiriéndose a los países en vías de desarrollo, "No hay energía tan cara como la falta de energía". Pero se advirtió a este respecto que, al analizar los diferentes sistemas de reactores de potencia, cada modelo debe considerarse teniendo en cuenta las condiciones locales en que habrá de funcionar para poder evaluar de un modo adecuado su potencial en un emplazamiento dado.

Las memorias relativas a los reactores de potencia mostraron que varias de las actuales clases de reactores pueden ya considerarse como modelos tipo, y su funcionamiento ha permitido observar que su seguridad y disponibilidad y los costos de instalación y de combustible los hacen competitivos con las centrales eléctricas de tipo corriente, sobre todo cuando se trata de grandes unidades. Las importantes investigaciones realizadas para crear una variedad de sistemas que permitan una mejor utilización del combustible, aumentan las perspectivas de una aplicación rápida de dichos sistemas, lo que incidentalmente contribuirá a conservar los limitados recursos mundiales en combustibles fósiles. Se reconoce en general que la fabricación de reactores reproductores no sólo debe permitir una mejor utilización de los recursos mundiales en materiales nucleares, sino que también debe disminuir el peso del combustible en los costos de producción de energía haciendo así económica la extracción de los minerales de uranio de baja calidad. Se prestó una atención especial a las perspectivas de la oferta y la demanda de materias primas nucleares y a la posibilidad de extraer en forma económica el uranio procedente del agua del mar. Los resultados obtenidos en determinados países con los reactores reproductores experimentales corroboran la opinión de que su utilización en una escala industrial es sólo cuestión de tiempo, estimándose que podrán emplearse industrialmente entre mediados del decenio de 1970 y mediados del decenio de 1980.

La Conferencia destacó el excelente nivel de seguridad alcanzado en la producción de energía nuclear, debido al alto factor de seguridad introducido ya en el modelo, en el ensayo de materiales y en la fiscalización de la construcción, etc. La experiencia adquirida en el funcionamiento de reactores y el establecimiento de procedimientos uniformes, ha permitido reducir a un mínimo el riesgo de accidentes y sus consecuencias. En lo relativo al equipo de las centrales, se proporcionó información interesante acerca del confinamiento de los reactores, en particular sobre la utilización de recipientes de alta presión construidos en hormigón pretensado y la elaboración de materiales que conserven una estabilidad adecuada en condiciones de temperatura y presión elevadas y radiación intensa. Al propio tiempo, se comprobó que es preciso continuar la labor en este campo. Se presentó importante información acerca de los problemas de transmisión de calor, en particular al aproximarse a las condiciones críticas del flujo térmico y acerca de la utilización de un vapor sobrecalentado como refrigerante. También se informó de que se habían logrado progresos considerables en el mejoramiento de la extracción de calor de los elementos combustibles mediante la creación de superficies transmisoras de calor más complejas. Se describieron métodos perfeccionados de eliminación de desechos radiativos, incluida su incorporación en vidrio y su evacuación en formaciones subterráneas adecuadas, considerándose en particular las formaciones salinas como muy adecuadas a dicho efecto.

Por lo que respecta a la fusión nuclear controlada, las actividades en esta esfera se han limitado casi por entero al estudio de la física del plasma, lo que ha permitido observar las dificultades técnicas que aún quedan por vencer. La Conferencia escuchó algunas exposiciones interesantes relativas a métodos directos para convertir la energía nuclear en energía eléctrica, consistiendo los objetivos actuales en aumentar la eficiencia de la conversión y producir generadores de energía compactos, seguros y de larga duración para utilizarlos en condiciones especiales. Los trabajos acerca de pequeños convertidores tales como el "ROMASHKA" (URSS) y el "SNAP" (Estados Unidos) constituyeron ejemplos prácticos de esto y suscitaron interés considerable.

Una aplicación especial de la energía nuclear que despertó considerable interés en la Conferencia fue su utilización con la doble finalidad de producir electricidad y calor, que puede emplearse para la desalinización de agua salada y salobre en los casos en que existe demanda permanente tanto de agua como de energía. Aunque en el estado actual de la tecnología se reconoce que, para que dichas centrales con esta doble finalidad tengan una aplicación económica, han de ser de gran tamaño y capacidad, la escasez mundial cada vez mayor de agua dulce y el mejoramiento continuo de la tecnología justifican la labor que se viene realizando para poder aprovechar las grandes posibilidades de la energía nuclear para este fin. Se presentaron informes alentadores relativos a la experiencia adquirida en la utilización de explosivos nucleares para la minería y la ingeniería civil que demostraban las grandes posibilidades de aplicarlos a la construcción de puertos, canales, embalses, etc., a un costo que puede llegar a ser tan ventajoso como el de los explosivos convencionales, dependiendo de la naturaleza, el emplazamiento y la magnitud del proyecto.

La Conferencia puso de relieve también los importantes progresos efectuados en la cooperación internacional y regional para la producción y el empleo de la energía nuclear. Aunque sólo se prestó a la utilización de radioelementos una atención pasajera, los documentos acerca de los estudios realizados sobre esta materia que se presentaron indicaban los progresos constantes que se han venido efectuando en este campo, y la utilización casi corriente de los radioelementos en sectores importantes de la medicina, la agricultura y la industria.

El tema de la Conferencia (reactores y energía nuclear) reflejaba el hecho de que la energía nuclear ha salido de la fase de los estudios de laboratorio para entrar en la de la aplicación comercial. Por consiguiente, no sorprendió que los intereses comerciales estuvieran bien representados entre los participantes en la Conferencia. Pero fue alentador observar que el secreto de que suelen rodearse estos aspectos de la energía nuclear no impidió un intercambio franco y liberal de puntos de vista acerca de los conceptos, tipos y sistemas relacionados con los reactores, lo que debe favorecer la madurez de la energética atómica.

Sigvard Eklund

Sigvard EKLUND

Director General del Organismo Internacional de Energía Atómica

EXPLANATORY NOTE

The Proceedings of the Third International Conference on the Peaceful Uses of Atomic Energy comprise a single, multilingual publication of sixteen volumes. This form was prescribed by the General Assembly of the United Nations in approving the Conference budget.

Papers accepted for consideration at the Conference are accordingly printed herein only in the original language of submission, each being followed by its abstract in the other three languages of the Conference.*

The budgetary arrangements for the Conference required also that Governments provide abstracts and papers in two of the Conference languages. One of the three abstracts following each paper is, therefore, in a translation provided by the Government concerned. The abstracts were translated into the other two languages either by the Division of Language Services, International Atomic Energy Agency (IAEA) in Vienna, or, with its assistance, through the intermediary of the national atomic energy authorities in London, Paris, Moscow and Madrid.

The Foreword by the Secretary-General of the United Nations, the Preface by the Director General of IAEA, and this Explanatory Note, together with the records of discussion at each of the six scientific general sessions and thirty-six technical sessions of the Conference, are published in all four languages. All other material, which is largely of a formal nature and is confined to Volumes 1 and 16, is published in the language of submission or delivery, followed in the case of French, Russian and Spanish originals by the English translation.

Governments whose national tongue is not one of the four Conference languages were consulted as to their preference for the language in which their papers should appear in these Proceedings.

The Table of Contents in each volume gives the titles of papers in the original language, or language of choice, followed in the case of French, Russian and Spanish titles by the English translation.

Starting from the 992 abstracts submitted by Governments, specialized agencies and IAEA, the Scientific Secretariat, working under the guidance of the United Nations Scientific Advisory Committee, finally chose 747 papers for inclusion in the Programme of the Conference; of these, 358 were selected for oral presentation at the 42 working sessions.

In arranging the programme, the Scientific Secretariat aimed at achieving a balanced schedule, providing for the oral presentation of as many papers as possible at each session while still leaving adequate time for discussion of the material presented. Two afternoons were left entirely free, to enable informal groups to discuss matters arising out of discussions at the formal sessions of the Conference. No records were taken of such informal meetings.

Wherever possible, the author, or authors, of papers were consulted during the Conference by members of the Scientific Secretariat, who acted as secretaries of session, or by the team of editors made available for the purpose by IAEA,** to ensure maximum accuracy.

The records of discussion at the various sessions, based on notes taken in the meetings by IAEA records officers,** and checked where necessary against the sound recordings made of all sessions, were prepared by the Division of Language Services of IAEA in English, and subsequently translated into French, Russian and Spanish through the intermediary of the atomic energy authorities in the three countries concerned (see third paragraph of the present note).

The editing of the English, French and Spanish papers was carried out at the United Nations Office at Geneva under United Nations supervision by a team of editors, whose services, also, were made available by the atomic energy authorities of their respective countries, with some help from outside consultants. The editing of the Russian papers was done in Moscow in similar circumstances. The following served as editors: Mr. A. de Calmès, Dr. C. E. Granados, Mr. D. H. Hill, Mr. V. F. Kalinin, Cand. Tech. Sc., Dr. R. Lapage, Mr. E. T. Marles, Dr. J. D. C. Mole, Mr. C. Ségot, Mr. J. J. Stobbs, Mr. C. R. Symons and Mr. J. Williamson.

The task of printing this large collection of scientific information has been shared by printers in

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* The languages of the Conference were English, French, Russian and Spanish.

** The names of the scientific secretaries, editors and records officers will be found in the list of the Conference Secretariat in Annex 1, Volume 1, of this series.

Belgium, Canada, France, Switzerland, the Union of Soviet Socialist Republics and the United Kingdom.

Full titles of the sixteen volumes of these Proceedings, together with the sessions covered by each volume, are as follows:

Volume No.		*Sessions included*
1	Progress in Atomic Energy	A, B, 1.6, C, H
2	Reactor Physics	3.1
3	Reactor Studies and Performance	3.2, 3.3
4	Reactor Control	3.4, 3.5
5	Nuclear Reactors — I. Gas-cooled and Water-cooled Reactors	1.1, 1.2, 1.3
6	Nuclear Reactors — II. Fast Reactors and Advanced Concepts	1.4, 1.5, 1.7
7	Research and Testing Reactors	D, 1.9, 1.8
8	Reactor Engineering and Equipment	1.10, 1.11, 3.7
9	Reactor Materials	2.8, 2.9, 2.4
10	Nuclear Fuels — I. Fabrication and Reprocessing	2.3, 2.6, 2.7
11	Nuclear Fuels — II. Types and Economics	2.5, 2.1, 2.2
12	Nuclear Fuels — III. Raw Materials	2.11, 2.12, 2.10
13	Nuclear Safety	3.9, 3.8 3.6
14	Environmental Aspects of Atomic Energy and Waste Management	3.10, 3.11
15	Special Aspects of Nuclear Energy and Isotope Applications	E, 4.1, F, G, 4.2
16	List of Papers and Indexes	

NOTE EXPLICATIVE

Les Actes de la troisième Conférence internationale sur l'utilisation de l'énergie atomique à des fins pacifiques sont publiés ici sous la forme d'une édition unique, multilingue, en seize volumes. Cette présentation a été décidée par l'Assemblée générale lorsqu'elle a approuvé le budget de la Conférence.

En conséquence, les mémoires qui ont été acceptés pour la Conférence sont reproduits ici dans la langue originale dans laquelle ils ont été soumis et sont suivis d'un résumé dans les trois autres langues de la Conférence *.

Aux termes des dispositions budgétaires prises en vue de la Conférence, les gouvernements devaient fournir les résumés et les mémoires dans deux des langues de la Conférence. Ainsi, sur les trois résumés qui suivent chaque mémoire, un est une traduction fournie par le gouvernement intéressé. La traduction des résumés dans les deux autres langues a été faite soit par la Division des services linguistiques de l'Agence internationale de l'énergie atomique (AIEA), à Vienne, soit avec son concours, par les soins des organismes nationaux compétents en matière d'énergie atomique à Londres, Paris, Moscou et Madrid.

L'avant-propos du Secrétaire général de l'Organisation des Nations Unies, la préface du Directeur général de l'AIEA et la présente note explicative, ainsi que les comptes rendus de chacune des six séances scientifiques générales et des trente-six séances techniques de la Conférence, sont publiés dans les quatre langues. Tous les autres textes, qui pour la plupart sont d'un caractère non technique et figurent dans les volumes 1 et 16, sont publiés dans la langue dans laquelle ils ont été présentés par écrit ou oralement et sont suivis, lorsque cette langue est l'espagnol, le français ou le russe, d'une traduction en anglais.

Les gouvernements des pays dont la langue officielle n'est pas l'une des quatre langues utilisées à la Conférence ont été consultés pour savoir dans quelle langue ils préféraient voir paraître leurs mémoires.

La table des matières de chaque volume donne les titres des mémoires dans la langue originale ou dans la langue choisie; ces indications sont suivies, pour les titres en espagnol, en français et en russe, de la traduction en anglais.

Sur les 992 résumés présentés par les gouvernements, les institutions spécialisées et l'AIEA, le Secrétariat scientifique, travaillant sous la direction du Comité consultatif scientifique des Nations Unies, en a finalement retenu 747 pour les inscrire au programme de la Conférence; sur ce nombre, 358 ont été présentés oralement aux 42 séances de travail.

En établissant le programme de la Conférence, le Secrétariat scientifique a cherché à réaliser un équilibre: il s'est efforcé de ménager un temps suffisant pour la présentation du plus grand nombre possible de mémoires tout en laissant du temps pour leur discussion. Deux après-midi avaient été laissés entièrement libres afin de permettre aux participants d'organiser des réunions non officielles et de discuter en petits groupes des questions qui se posaient à la suite des séances officielles de la Conférence. Ces réunions n'ont pas fait l'objet de comptes rendus.

Toutes les fois que cela a été possible, l'auteur ou les auteurs des mémoires ont été consultés pendant la Conférence par les membres du Secrétariat scientifique, qui ont assuré le secrétariat des séances, ou par l'équipe d'« éditeurs » que l'AIEA ** avait mis à cet effet à la disposition de la Conférence, afin d'assurer l'exactitude la plus grande.

Les comptes rendus des discussions aux réunions, établis d'après les notes prises en séance par les rédacteurs de comptes rendus de l'AIEA** et comparés toutes les fois qu'il le fallait avec les enregistrements sonores, ont été rédigés en anglais par la Division des services linguistiques de l'AIEA, puis traduits en espagnol, en français et en russe par les soins des organismes compétents en matière d'énergie atomique des trois pays intéressés (voir le troisième alinéa de la présente note).

Les mémoires rédigés en anglais, en espagnol et en français ont été mis au point pour l'impression à l'Office européen des Nations Unies à Genève, sous le contrôle de l'ONU, par une équipe de rédac-

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* Les langues de la Conférence étaient l'anglais, l'espagnol, le français et le russe.

** On trouvera les noms des secrétaires scientifiques, des « éditeurs » et des rédacteurs de comptes rendus dans la liste des membres du secrétariat de la Conférence à l'annexe 1 du volume 1.

teurs mis à la disposition de la Conférence par les organismes compétents en matière d'énergie atomiques des pays intéressés, avec l'aide de quelques consultants extérieurs. La mise au point définitive des mémoires rédigés en russe a été faite à Moscou dans les mêmes conditions. Voici les noms des rédacteurs qui ont assuré la mise au point des mémoires: M. A. de Calmès, M. C. E. Granados, M. D. H. Hill, M. V. F. Kalinin, M^{lle} R. Lapage, M. E. T. Marles, M^{lle} J. D. C. Mole, M. C. Ségot, M. J. J. Stobbs, M. C. R. Symons et M. J. Williamson.

Des entreprises de Belgique, du Canada, de France, du Royaume-Uni, de Suisse et de l'Union des Républiques socialistes soviétiques se sont partagé la tâche que représentait l'impression de cette masse importante de documents scientifiques.

Les titres complets des seize volumes des Actes de la Conférence, ainsi que les numéros des séances sur lesquelles porte chaque volume, figurent ci-après:

Numéro du volume		*Séances*
1	Progrès accomplis dans le domaine atomique	A, B, 1.6, C, H
2	Physique des réacteurs	3.1
3	Etude des réseaux et performance des réacteurs	3.2, 3.3
4	Contrôle des réacteurs..	3.4, 3.5
5	Réacteurs nucléaires — I. Réacteurs refroidis par un gaz et réacteurs refroidis à l'eau	1.1, 1.2, 1.3
6	Réacteurs nucléaires — II. Réacteurs à neutrons rapides et réacteurs d'avant-garde	1.4, 1.5, 1.7
7	Réacteurs de recherche et réacteurs d'essai de matériaux.................	D, 1.9, 1.8
8	Technologie et équipement des réacteurs	1.10, 1.11, 3.7
9	Matériaux pour réacteurs	2.8, 2.9, 2.4
10	Combustibles nucléaires — I. Fabrication et retraitement	2.3, 2.6, 2.7
11	Combustibles nucléaires — II. Caractéristiques et aspects économiques	2.5, 2.1, 2.2
12	Combustibles nucléaires — III. Matières premières	2.11, 2.12, 2.10
13	Sûreté nucléaire	3.9, 3.8, 3.6
14	Influence sur le milieu de l'emploi de l'énergie nucléaire. Traitement et élimination des déchets	3.10, 3.11
15	Aspects particuliers de l'énergie nucléaire et applications des radioéléments..	E, 4.1, F, G, 4.2
16	Liste des mémoires et index	

ПОЯСНИТЕЛЬНАЯ ЗАПИСКА

Труды третьей Международной конференции по использованию атомной энергии в мирных целях представляют собой единое многоязычное издание из шестнадцати томов. Такая форма была предусмотрена Генеральной Ассамблеей Организации Объединенных Наций при одобрении ею бюджета Конференции.

Принятые к рассмотрению Конференцией доклады соответственно опубликованы здесь лишь на языке оригинала; при этом каждый доклад сопровождается аннотацией на других трех языках Конференции*.

Бюджетные постановления в отношении проведения Конференции также предусматривали, что правительства представят аннотации и доклады на двух языках Конференции. Поэтому одна из трех аннотаций, сопровождающих каждый доклад, является переводом, представленным соответствующим правительством. Аннотации были переведены на другие два языка либо Отделом переводов Международного агентства по атомной энергии (МАГАТЭ) в Вене, либо с его помощью при сотрудничестве национальных органов, ведающих вопросами атомной энергии, в Лондоне, Париже, Москве и Мадриде.

Введение и предисловие Генерального Секретаря Организации Объединенных Наций и Генерального директора МАГАТЭ, соответственно, и настоящая пояснительная записка, наряду с протоколами каждого из шести научных пленарных заседаний и тридцати шести секционных заседаний Конференции, публикуются на всех четырех языках. Все другие материалы, которые по своему характеру в основном относятся к числу официальных и содержатся в томах 1 и 16, публикуются на языке оригинала; и когда речь идет о французских, русских и испанских оригиналах, то к ним приложен английский перевод.

С правительствами стран, язык которых не относится к числу четырех языков Конференции, были проведены консультации по поводу того, на каком языке было бы желательно, по их мнению, опубликовать в настоящих трудах представленные ими доклады.

В содержании каждого тома указаны заглавия докладов на языке оригинала либо на другом избранном языке, и в том случае, когда речь идет о французских, русских и испанских заглавиях, их сопровождает английский перевод.

Из 992 аннотаций, представленных правительствами, специализированными учреждениями, а также МАГАТЭ, Ученый секретариат, работая под руководством Научного консультативного комитета Организации Объединенных Наций, в итоге отобрал 747 докладов для включения их в программу Конференции; из них 358 были отобраны для представления в устной форме на 42 рабочих заседаниях.

При составлении программы Ученый секретариат ставил целью добиться сбалансированного расписания, которое дало бы возможность представить в устной форме максимальное количество докладов на каждом заседании при обеспечении достаточного времени для проведения дискуссии по поводу представленного материала. В двух случаях имеющееся во второй половине дня время оставили нераспределенным, с тем чтобы дать возможность неофициальным группам обсудить вопросы, возникшие в ходе дискуссии на официальных заседаниях Конференции. На таких неофициальных заседаниях протоколы не составлялись.

По мере возможности, с автором или авторами докладов консультировались в ходе Конференции члены Ученого секретариата, которые выполняли функции секретарей заседаний, либо такие консультации проводились группой редакторов, которые были выделены МАГАТЭ** для этой цели, с тем чтобы обеспечить максимальную точность.

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* Языками Конференции являлись: английский, французский, русский и испанский.

** Фамилии ученых секретарей, редакторов и протоколистов приведены в перечне сотрудников секретариата Конференции в приложении 1-ом к тому 1-му настоящей серии.

Протоколы дискуссии на различных заседаниях, составленные на основе записей, сделанных в ходе заседаний протоколистами МАГАТЭ[*], и проверенные, по мере необходимости, путем сравнения со звуковой записью, которая велась на всех заседаниях, были подготовлены Отделом переводов МАГАТЭ на английском языке и впоследствии переведены на французский, русский и испанский языки при сотрудничестве национальных органов, ведающих вопросами атомной энергии, в трех заинтересованных странах (смотри третий абзац пояснительной записки).

Работа по редактированию документов на английском, французском и испанском языках была проведена в Европейском отделении Организации Объединенных Наций, в Женеве, под руководством Организации Объединенных Наций группой редакторов, услуги которых были также предоставлены по линии органов, ведающих вопросами атомной энергии в соответствующих странах, с использованием в некоторой степени помощи приглашенных со стороны консультантов. Русские документы редактировались в Москве в таких же условиях. Нижеследующие лица осуществляли работу в качестве редакторов: д-р К. Э. Гранадос, кандидат технических наук В. Ф. Калинин, г-н А. де Кальмэс, д-р Р. Лепейдж, г-н Э. Т. Марлз, д-р Дж. Д. К. Моул, г-н Ч. Р. Саймонс, г-н Дж. Дж. Стобз, г-н Ш. Сэго, г-н Дж. Уильямсон, г-н Д. Х. Хилл.

В выполнении задачи по печатанию этой обширной научной информации принимали участие типографии в Бельгии, Канаде, Соединенном Королевстве, Союзе Советских Социалистических Республик, Франции и Швейцарии.

Ниже приводятся полные заглавия шестнадцати томов настоящих Трудов, а также указывается, какие сессии охватываются каждым томом:

Номер Тома		Заседания, включенные в том
1	Прогресс в работах по атомной энергии	A, B, 1.6, C, H
2	Физика реакторов	3.1
3	Изучение реакторов и их характеристики	3.2, 3.3
4	Регулирование реакторов	3.4, 3.5
5	Ядерные реакторы — I. Реакторы с водяным и газовым охлаждением	1.1, 1.2, 1.3
6	Ядерные реакторы — II. Реакторы на быстрых нейтронах и усовершенствованные реакторы	1.4, 1.5, 1.7
7	Исследовательские и испытательные реакторы	D, 1.9, 1.8
8	Технология и оборудование реакторов	1.10, 1.11. 3.7
9	Реакторные материалы	2.8, 2.9, 2.4
10	Ядерное топливо — I. Изготовление и переработка	2.3, 2.6, 2.7
11	Ядерное топливо — II. Типы и экономика	2.5, 2.1, 2.2
12	Ядерное топливо — III. Сырьевые материалы	2.11, 2.12, 2.10
13	Ядерная безопасность	3.9, 3.8, 3.6
14	Исследование окружающей среды и удаление радиоактивных отходов	3.10, 3.11
15	Специальные аспекты применения ядерной энергии и изотопов	E, 4.1, F, G, 4.2
16	Список докладов и указатели	

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[*] Фамилии ученых секретарей, редакторов и протоколистов приведены в перечне сотрудников секретариата Конференции в приложении 1-ом к тому 1-му настоящей серии.

NOTA EXPLICATIVA

Las Actas de la tercera Conferencia Internacional sobre la Utilización de la Energía Atómica con Fines Pacíficos están constituidas por una publicación única y plurilingüe compuesta de dieciséis volúmenes, en conformidad con lo dispuesto por la Asamblea General de las Naciones Unidas al aprobar el presupuesto de la Conferencia.

Por consiguiente, las memorias aceptadas para ser examinadas en la Conferencia sólo figuran impresas en el idioma original en que se presentaron, y cada una de ellas va seguida de un resumen de la misma en los otros tres idiomas de la Conferencia *.

En los arreglos presupuestarios para la Conferencia se dispuso también que los gobiernos tenían asimismo que presentar resúmenes y memorias en dos de los idiomas de la Conferencia. En consecuencia, uno de los tres resúmenes que siguen a cada memoria es una traducción facilitada por el gobierno interesado. Los resúmenes fueron traducidos a los otros dos idiomas, ya por la División de Idiomas del Organismo Internacional de Energía Atómica (OIEA) de Viena, o, con su asistencia, por conducto de las autoridades nacionales de energía atómica de Londres, París, Moscú y Madrid.

La introducción del Secretario General de las Naciones Unidas, el prefacio del Director General del OIEA y la presente nota explicativa, junto con las actas de los debates celebrados en cada una de las seis sesiones científicas generales y las treinta y seis sesiones técnicas de la Conferencia, se publican en los cuatro idiomas. El resto del material, que reviste en su mayoría un carácter oficial y está contenido exclusivamente en los volúmenes 1 y 16, se publica en el idioma en que fue presentado o entregado, seguido para los originales en español, francés y ruso, de la traducción en inglés.

Se consultó a los gobiernos cuyo idioma nacional no es uno de los cuatro idiomas de la Conferencia para saber en cuál de ellos preferían que se publicaran sus memorias en estas Actas.

El índice de cada volumen contiene los títulos de las memorias en el idioma original, o en el idioma elegido, seguidos, cuando se trata de títulos en español, francés y ruso, de la traducción en inglés.

De los 992 resúmenes presentados por gobiernos, organismos especializados y el OIEA, la Secretaría Científica, bajo la dirección del Comité Científico Consultivo de las Naciones Unidas, escogió por último 747 memorias que debían ser incluidas en el programa de la Conferencia; de éstas, 358 fueron seleccionadas para ser presentadas oralmente en las 42 sesiones de trabajo.

Al preparar el programa de actividades, la Secretaría Científica trató de conseguir un justo equilibrio, y así se previó la presentación oral del mayor número posible de memorias en cada sesión, pero dejando todavía tiempo suficiente para examinar la información presentada. Se dejaron dos tardes totalmente libres, a fin de que los grupos oficiosos pudieran examinar las cuestiones que surgieran en las sesiones oficiales de la Conferencia. No se levantó acta de tales reuniones.

Siempre que fue posible, el autor, o los autores, de las memorias fueron consultados en el curso de la Conferencia por miembros de la Secretaría Científica, que actuaron de secretarios de sesión, o por un grupo de editores facilitado a dicho efecto por el OIEA**, a fin de asegurar la máxima exactitud.

Las actas de los debates celebrados en las diversas sesiones, basadas en notas tomadas en las reuniones por redactores de actas del OIEA**, y verificadas siempre que fue necesario mediante las grabaciones efectuadas en todas las sesiones, fueron preparadas por la División de Idiomas del Organismo Internacional de Energía Atómica (OIEA) en inglés, y traducidas después al español, el francés y el ruso por conducto de las autoridades de energía atómica de los tres países interesados (véase el tercer párrafo de la presente nota).

La preparación para la publicación del texto de los documentos en español, francés e inglés se efectuó en la Oficina de Ginebra de las Naciones Unidas, bajo la fiscalización de las Naciones Unidas, por un equipo de editores cuyos servicios fueron también proporcionados por las autoridades de energía atómica de sus respectivos países, con alguna ayuda de consultores del exterior. La preparación para la publicación de los documentos en ruso se efectuó en Moscú en circunstancias análogas. Actuaron de editores las personas siguientes: Sr. A. de Calmès, Dr. C. E. Granados, Sr. D. H. Hill,

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* Los idiomas de la Conferencia fueron el español, el francés, el inglés y el ruso.

** Los nombres de los secretarios científicos, editores y redactores de actas figuran en la lista de la Secretaría de la Conferencia, en el anexo 1, volumen 1, de esta serie.

Sr. V. F. Kalinin, Dra. R. Lapage, Sr. E. T. Marles, Dra. J. D. C. Mole, Sr. C. Ségot, Sr. J. J. Stobbs, Sr. C. R. Symons y Sr. J. Williamson.

En la impresión de esta gran recopilación de información científica han participado impresores de Bélgica, el Canadá, Francia, el Reino Unido, Suiza y la Unión de Repúblicas Socialistas Soviéticas.

Los títulos completos de los dieciséis volúmenes de estas Actas, junto con las sesiones comprendidas en cada volumen, son los siguientes:

Número del volumen		*Sesiones*
1	Progresos realizados en el dominio atómico	A, B, 1.6, C, H
2	Física de los reactores	3.1
3	Estudios sobre reticulados. Funcionamiento de reactores	3.2, 3.3
4	Control de los reactores	3.4, 3.5
5	Reactores nucleares — I. Reactores refrigerados por gas y por agua	1.1, 1.2, 1.3
6	Reactores nucleares — II. Reactores rápidos y conceptos más avanzados	1.4, 1.5, 1.7
7	Reactores de investigación y de ensayo	D, 1.9, 1.8
8	Tecnología y equipo de los reactores	1.10, 1.11, 3.7
9	Materiales de los reactores	2.8, 2.9, 2.4
10	Combustibles nucleares — I. Fabricación y tratamiento	2.3, 2.6, 2.7
11	Combustibles nucleares — II. Características y estudios económicos	2.5, 2.1, 2.2
12	Combustibles nucleares — III. Primeras materias	2.11, 2.12, 2.10
13	Seguridad nuclear	3.9, 3.8, 3.6
14	Influencia del empleo de la energía nuclear sobre el ambiente. Evacuación de residuos	3.10, 3.11
15	Aspectos especiales de la energía nuclear y empleo de los radioelementos	E, 4.1, F, G, 4.2
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Technical and economic aspects

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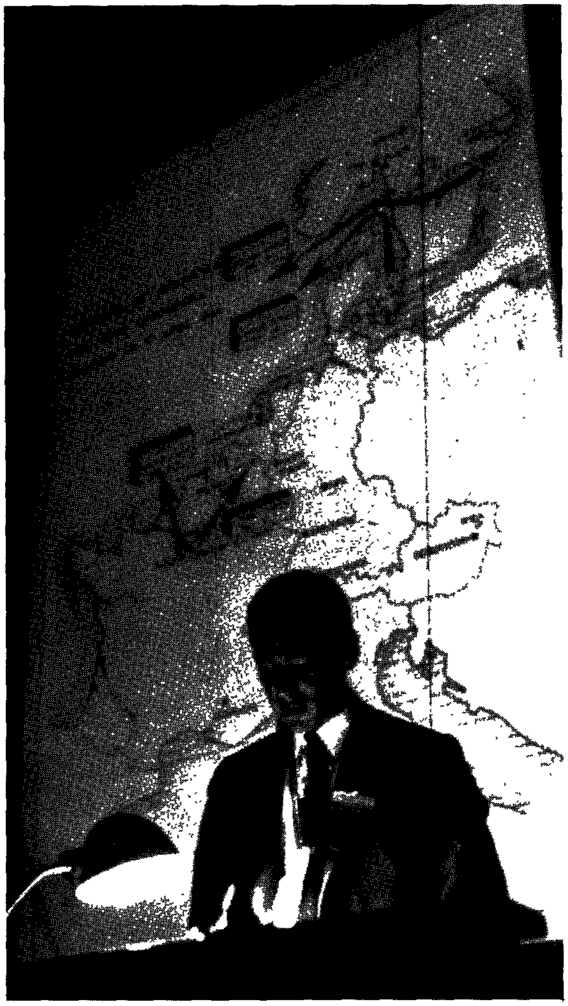

▲ Conference secretariat. Seated in front row from the left: Mr. S. W. Bailey, United Nations, Chief Conference Officer; Dr. Sigvard Eklund, Director General, IAEA; Dr. G. A. Yagodin, Deputy Director General, IAEA, Chief of the Scientific Secretariat

◀ Mr. F. R. Marcus (Denmark) at the rostrum during a technical session

▼ U Thant, Secretary-General of the United Nations (right), with Professor V. S. Emelyanov (USSR), President of the Conference

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Programme of the Conference

The programme shown here is that prepared by the Conference Secretariat. In some cases, subsequent last minute changes were necessary, but by and large the Conference proceeded as planned. The various records of session in the respective volumes show the proceedings as they actually took place.

GENERAL SESSIONS

(Sessions A-H)

Session A: 31 August, 10.30 (Vol. 1)

OPENING OF THE CONFERENCE

President: V. S. Emelyanov (USSR)

Call to order by the President of the Conference

Address of welcome by the President of the Swiss Confederation, Mr. Ludwig VON MOOS

Address by U THANT, Secretary-General of the United Nations, Chairman of the United Nations Scientific Advisory Committee

Address by the President of the Conference, Professor V. S. EMELYANOV

Address by the Director General, International Atomic Energy Agency, Mr. Sigvard A. EKLUND

Presentation of messages from Heads of State or Government of the countries represented on the United Nations Scientific Advisory Committee

Session B: 31 August, 15.00 (Vol. 1)

NEW ECONOMIC DATA. ENERGY NEEDS IN COMING YEARS AND THE ROLE OF NUCLEAR POWER IN MEETING THESE NEEDS

Chairman: H. J. Bhabha (India)
Scientific Secretaries: J. E. Shallcross (UK), R. Krymm (IAEA)

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World energy requirements and the economics of nuclear power with special reference to underdeveloped countries — H. J. Bhabha, M. Dayal

P/715 (Argentina)
The contribution of nuclear energy to solving the Argentine energy problem — J. L. Alegría *et al.*

P/559 (UK)
Nuclear power in the United Kingdom — Sir William Penney

P/31 (France)
France's nuclear power programme — J. Cabanius, J. Horowitz

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Future energy needs and the role of nuclear power — G. F. Tape *et al.*

P/294 (USSR)
Trends in atomic power development in the USSR — N. M. Sinev *et al.*

P/1 (Canada)
Electricity supply in Canada and the role of nuclear power — W. B. Lewis, T. G. Church

P/577 (Japan)
Needs of nuclear power generation and the related programme in Japan — Japan Atomic Energy Commission

Panel discussion

The role of nuclear power in meeting energy needs in other countries

Members of the Panel : Austria, Brazil, Czechoslovakia, Denmark, Pakistan, United Arab Republic

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INTERNATIONAL COLLABORATION IN NUCLEAR REACTOR PROJECTS, INCLUDING DEVELOPMENTS OF MAJOR CO-OPERATIVE INSTALLATIONS

Chairman: F. Perrin (France)
Scientific Secretaries: J. E. Shallcross (UK), R. Krymm (IAEA)

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International cooperation on nuclear power — H. D. Smyth

P/295 (USSR)
International co-operation in the field of atomic energy — I. D. Morokhov *et al.*

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The DRAGON Project — C. A. Rennie *et al.*

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Scientific Secretaries: C. B. Bigham (Canada), R. Skjoldebrand (IAEA)

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V. V. Goncharov

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A. C. Penteado Filho *et al.*

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Scientific Secretaries: S. D. Fanshenko (USSR), D. de Lacerda Coutinho (Brazil)

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Scientific Secretaries: A. Sanielevici (IAEA), J. Mehl (IAEA)

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Chairman: L. Cintra do Prado (Brazil)
Scientific Secretaries: C. Christenson (IAEA), A. Sanielevici (IAEA)

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President: V. S. Emelyanov (USSR)

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Address by the Director General, International Atomic Energy Agency, Mr. Sigvard A. Eklund

Address by the Director of the European Office of the United Nations, Mr. P. P. Spinelli

Closing by the President

TECHNICAL SESSIONS

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Chairman: T. Mukaibo (Japan)
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Scientific Secretaries: C. B. Bigham (Canada), J. M. Harrer (USA)

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Scientific Secretaries: J. M. Harrer (USA), J. D. McCullen (IAEA)

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Scientific Secretaries: J. D. McCullen (IAEA), V. G. Shevchenko (IAEA)

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Scientific Secretaries: J. M. Harrer (USA), Munir A. Khan (IAEA)

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Scientific Secretaries: J. E. Shallcross (UK), R. Krymm (IAEA)

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Scientific Secretaries: J. M. Harrer (USA), Munir A. Khan (IAEA)

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Scientific Secretaries: C. B. Bigham (Canada), B. Semenov (IAEA)

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Scientific Secretaries: B. Semenov (IAEA), R. Skjoldebrand (IAEA)

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Scientific Secretaries: Munir A. Khan (IAEA), B. Semenov (IAEA)

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Chairman: N. A. Dollezhal (USSR)

Scientific Secretaries: Munir A. Khan (IAEA), R. Skjoldebrand (IAEA)

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II. FUEL AND MATERIAL PROBLEMS

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Chairman: A. A. Bochvar (USSR)
Scientific Secretaries: J. M. Phéline (France), J. G. Boyle (IAEA)

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Chairman: M. Salesse (France)
Scientific Secretaries: J. G. Boyle (IAEA), O. Vojtech (IAEA)

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Chairman: S. Lawroski (United States of America)
Scientific Secretaries: J. M. Phéline (France), J. C. Delaney (IAEA)

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Chairman: **H. Brynielsson (Sweden)**

Scientific Secretaries: **J. C. Delaney (IAEA), A. Pushkov (IAEA)**

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***Chairman:* K. A. Mahmoud (UAR)**

***Scientific Secretaries:* J. Mehl (IAEA), C. W. Christenson (IAEA)**

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***Scientific Secretaries:* C. Christenson (IAEA), J. Mehl (IAEA)**

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MISCELLANEOUS APPLICATIONS OF ATOMIC ENERGY

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Scientific Secretaries: C. B. Bigham (Canada), A. Sanielevici (IAEA)

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Record of Session A

Opening of the Conference

President: V. S. Emelyanov (USSR)

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Messages from Heads of State or Government of other countries

Allocution de bienvenue de M. Ludwig von Moos, Président de la Confédération suisse

Monsieur le Président, Monsieur le Secrétaire général, Mesdames, Messieurs,

Pour la troisième fois en dix ans, la Suisse et Genève ont l'honneur d'avoir été choisis comme lieu de rencontre des savants et experts voués aux problèmes de l'utilisation de l'énergie atomique à des fins pacifiques. Cette rencontre a été faite sous le patronage des Nations Unies pour permettre à ses participants de procéder à un échange concluant d'opinions et d'expériences.

Laissez-moi, en évoquant les deux premières conférences analogues qui se sont tenues à Genève en 1955 et 1958 et les résultats positifs qui se sont ensuivis, vous exprimer le plaisir que j'ai à me trouver ici pour l'ouverture d'une nouvelle manifestation de même genre. Laissez-moi vous apporter le salut et les vœux du Gouvernement suisse.

Si les conférences de 1955 et 1958 sont apparues à l'opinion publique mondiale comme des normes meilleures sur la voie de l'utilisation des puissances nouvelles d'énergie qui émanent de l'éclatement et de la fusion de l'atome, elles ont été, d'autre part, pour les experts l'occasion de recueillir une précieuse moisson de connaissances et d'expériences. Cela leur a permis de vérifier le résultat de leur propre chef et leur a épargné maints efforts pénibles et coûteux. Grâce à l'abandon de la politique qui préconisait le secret absolu de la matière de développement de réacteurs civils et dans le domaine du contrôle de la fusion thermonucléaire, toutes les nations scientifiquement et techniquement avancées ont pu participer à ce développement si riche en perspectives, et ceci a donné le départ à une seconde collaboration internationale. Nous en éprouvons une vive satisfaction au regard de la grandeur des problèmes dont la solution présuppose que l'énergie atomique peut être utilisée avec succès à des fins pacifiques.

La Suisse partage cette satisfaction. Nous reconnaissons avec gratitude les impulsions données par les deux précédentes conférences de Genève pour l'utilisation pacifique de l'énergie atomique.

Précisément, dans les années 1955 et 1958, notre pays a pu faire quelques progrès importants sur la voie de sa participation à cet effort sur une base bilatérale, régionale et internationale. Le pont qu'il est possible de jeter grâce à un échange aussi positif d'idées et d'expériences rapproche les hommes des différents pays. L'humanité attend de tous ceux à qui incombe une responsabilité qu'ils s'emploient à créer et à maintenir une véritable paix entre les peuples. Le respect et la compréhension accordés dans un dialogue à un partenaire originaire d'un autre pays et parlant une autre langue sont le commencement d'une entente réelle entre les nations. Les tenants de la science atomique ont particulièrement bien compris ce sens de la rencontre internationale. Ainsi, les contacts amicaux qui se nouent entre savants et experts des divers pays sont infiniment précieux, non seulement du point de vue technique, mais aussi dans la mesure où ils servent la cause d'un véritable et mutuel accord entre les peuples.

Attendre de tels contacts qu'ils puissent porter leurs fruits suppose bien entendu que des réunions de caractère scientifique ou technique ne seront pas utilisées pour confronter et étaler des opinions politiques divergentes.

La troisième Conférence de Genève sur l'utilisation de l'énergie atomique à des fins pacifiques, qui s'ouvre aujourd'hui, devra en conséquence satisfaire à des critères exigeants si elle veut être digne des précédentes.

La situation a toutefois changé sur un point. Une revue complète de tout ce qui se rapporte à l'énergie atomique n'entrerait plus dans le cadre d'une telle conférence. La technique du réacteur a fait entre-temps de tels progrès que le passage de l'énergie atomique de la phase de la recherche et du développement à celui de la réalisation scientifique sur une grande échelle est dépassée. Si, au vu de ce développement, et tenant compte de la nécessité de se concentrer sur l'objet de la présente Conférence, une place prépondérante revient à la technique du réacteur et si, ce faisant, un pas a été accompli dans le sens de la spécialisation, ce n'est peut-être pas sans un certain regret que nous en prenons acte. Le cadre plus large des deux précédentes conférences avait permis à des experts des différentes disciplines, à des chercheurs des hautes écoles et à des ingénieurs engagés dans l'industrie de se rencontrer. Il semble d'autant plus indiqué, contraints comme nous le sommes de faire une part croissante à la spécialisation, de souligner l'importance de collaborer en toute bonne entente et de ne pas perdre de vue l'ensemble.

Un problème se pose à cet égard qui, si nous ne le considérons pas plus à fond, embrasse aussi la question des rapports entre hommes de science et ingénieurs, d'une part, et laïques, d'autre part. Nos efforts doivent aussi tendre à faire comprendre au public l'importance de nouvelles découvertes et inventions. Il sera un jour en mesure de se rendre maître de ces nouvelles motions. Il aura aussi à prendre position directement ou par l'intermédiaire du Parlement au sujet de problèmes scientifiques ou techniques dans le domaine de l'énergie atomique.

Pour que son jugement se forme, il est nécessaire de prévoir de larges et utiles contacts entre techniciens et laïques. Il appartient aux techniciens d'être auprès des laïques des interprètes compréhensifs des développements scientifiques et techniques. C'est pourquoi nous formons à l'ouverture de cette conférence le vœu que, d'une part, elle soit pour ces experts une occasion d'échanger de précieuses idées et connaissances, mais qu'elle permette aussi, d'autre part, au public de mieux connaître les perspectives de plus en plus impressionnantes qui s'ouvrent dans le domaine de l'utilisation pacifique de l'énergie atomique. Les forces enfouies dans la nature par le Créateur sont destinées au bien et au bonheur de l'humanité. La noble tâche et la haute responsabilité de faire en sorte qu'elle se développe dans ce sens et puisse être utilisée appartient à tous ceux qui s'en occupent et qui échangent des idées à ce sujet.

Je remercie l'Organisation des Nations Unies d'avoir à nouveau désigné Genève comme lieu de réunion pour cette importante conférence. Au nom du Conseil fédéral, je souhaite la bienvenue à ses dirigeants et à tous ses participants. Je vous transmets le salut du peuple suisse et notre vœu que la troisième 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.

Translation

ADDRESS OF WELCOME BY MR. LUDWIG VON MOOS, PRESIDENT OF THE SWISS CONFEDERATION

Mr. President, Mr. Secretary-General, Ladies and Gentlemen,

For the third time in ten years Switzerland and Geneva have the honour of being chosen as the place of meeting of scientists and experts engaged on the problems of the peaceful uses of atomic energy. This meeting has been arranged under the auspices of the United Nations in order to enable participants to exchange opinions and experience.

Allow me, in calling to mind the first two similar conferences held at Geneva in 1955 and 1958, and the positive results achieved, to express to you the pleasure I feel in being here for the opening meeting of a new demonstration of the same type. Allow me to offer you the greetings and best wishes of the Swiss Government.

While the conferences of 1955 and 1958 appeared to world public opinion as landmarks on the road to the use of the new sources of energy from atomic fission and fusion, they offered experts, on the other hand, an opportunity to gather a valuable harvest of knowledge and experience. That enabled them to verify the results of their own work and has spared them arduous and costly efforts. Thanks to the abandoning of a policy which advocated absolute secrecy regarding the development of civil reactors and thermo-nuclear fusion, all scientifically and technically advanced nations have been able to take part in that development so rich in prospects and this has given rise to further international collaboration. We feel great satisfaction in view of the magnitude of the problems, the solution of which will permit the successful use of atomic energy for peaceful purposes.

Switzerland shares that satisfaction. We recognize with gratitude the impetus given by the two previous conferences on the Peaceful Uses of Atomic Energy held at Geneva.

As it happens, in 1955 and 1958 our country was able to make some important progress as regards participation in that effort on a bilateral, regional and international basis. The bridge which it has been possible to build, thanks to such a positive exchange of ideas and experience, will bring men of different countries yet nearer. Mankind expects that all those who bear this responsibility will use it to build and maintain true peace among nations. The respect and understanding shown during a discussion to a partner from another country, speaking another language, are the beginning of a real *entente* between nations. Those who are engaged in atomic science are particularly well placed to understand the significance attaching to an international gathering. Friendly contacts thus made between scientists and experts of various countries are of infinite value, not only from the technical point of view but also because they serve the true cause of a real and mutual agreement among nations.

To expect that such contacts should bear fruit means of course that meetings of a scientific or technical nature will not be used to confront and display divergent political opinions.

The Third International Conference on the Peaceful Uses of Atomic Energy to be held at Geneva, which opens today, must therefore pass exacting tests if it wishes to be worthy of the previous Conferences.

However the situation has changed in one respect. A complete review of everything connected with atomic energy no longer comes within the scope of such a conference. Reactor technique has in the meantime made such progress that the transition of atomic energy from the research and development stage to scientific realization on a wide scale has already taken place. If, in view of that development, and bearing in mind the need for concentration on the purpose of the present Conference, a leading place is given to reactor technique and if, in so doing, a step has been taken on the road to specialization, it is not perhaps without some regret that we note this fact. The wider scope of the two previous conferences enabled experts in various branches, high ranking research workers and industrial engineers to meet. It appears all the more obvious, compelled as we are to allocate an increasingly important part to specialization, that emphasis should be placed on the importance of collaboration in good faith and the fact that the subject as a whole must be kept in view.

A problem arises in that connexion which, if we consider it thoroughly, includes also the question of the relations between scientists and engineers on the one hand, and laymen on the other. Our efforts must also be directed towards making the public understand the importance of new discoveries and inventions. It will one day be able to make itself master of these new ideas. It will also take a position directly or through parliament as regards the scientific and technical problems of atomic energy. To enable the public to form its opinion there must be wide and useful contacts between technicians and laymen. Technicians must act as interpreters of scientific and technical developments so far as the layman is concerned. Therefore at this opening meeting of the Conference we express the wish that it will be an occasion for experts to exchange valuable ideas and knowledge and, at the same time, enable the public to gain a better understanding of the increasingly impressive prospects offered by the peaceful use of atomic energy. The forces hidden in nature by the Creator are destined for the welfare and happiness of mankind. Those who are engaged in this noble task and have come to exchange their ideas will bear this great responsibility for the development and utilization of those forces.

I thank the United Nations for having again chosen Geneva as the place of meeting of this important Conference. On behalf of the Federal Council, I welcome the delegates and all taking part in this Conference. I bring you greetings of the Swiss people and our wish that the Third International Conference on the Peaceful Uses of Atomic Energy at Geneva may make a worthy and significant contribution to the advancement of the welfare of all peoples.

ADDRESS BY U THANT, SECRETARY-GENERAL OF THE UNITED NATIONS

Mr. President, Ladies and Gentlemen,

For the third time in less than a decade you, whom my predecessor once called from this rostrum the "master builders of nuclear science and nuclear engineering", have assembled under the auspices of the United Nations to give an account to the scientific community particularly and to the world community at large of the progress that has been achieved since the last such conference in 1958 in harnessing the atom for the promotion of peaceful human progress.

It is altogether fitting for you to turn from laboratory and office to the rostrum of a world organization which has been established for the purpose of saving succeeding generations from the scourge of war. For if science provided men with the most destructive of weapons, it also opened the door to incalculable possibilities for helping mankind in the solution of a wide range of problems. Since the time that the first atom bombs were produced, the cruel senselessness of war and the realization of the holocaust which a nuclear conflict would bring in its wake, has come to be increasingly recognized and, while disarmament is still far from reality, important steps have been taken by those principally concerned to reduce hostility and suspicion, to promote co-operation, and to reduce the dangers of an all-out war. Statesmanship and science have moved toward closing ranks, thus helping to ensure that the power which, in war, could threaten the very existence of life on this planet, should henceforth, in peace, serve man's common needs and aspirations for a life of greater well-being and larger freedom.

This accounts for the abiding interest of the United Nations in the peaceful uses of the atom. It is not a newly discovered interest. Indeed, the very first resolution adopted by the General Assembly at its first session, Resolution 1 (I) of 24 January 1946, established the Atomic Energy Commission to which was assigned the task of making proposals: for extending between all nations the exchange of basic scientific information for peaceful ends; for control of atomic energy to the extent necessary to ensure its use only for peaceful purposes; for the elimination from national armaments of atomic weapons; and for effective safeguards by way of inspection and other means to protect complying States against the hazards of violations and evasions.

Eleven years later the International Atomic Energy Agency was established as the principal instrument of international co-operation in the field of peaceful uses of atomic energy. That agency is now headed by Dr. Sigvard Eklund, the Secretary-General of the 1958 Geneva conference, under whose leadership IAEA has carried the responsibility for the scientific organization of the present conference. I wish to pay tribute to him and to the IAEA, which has been working in close harmony with the United Nations on this and many other projects. Indeed, this Conference in itself is a shining example of inter-organization co-operation.

I wish also to mention the valuable role played in the preparation of this Conference by the United Nations Scientific Advisory Committee, which counsels me on a continuing basis on action which may be required of the UN in this vital field.

Statesmanship and science join hands in the United Nations not only in seeking to prevent war and in re-directing human energies toward peaceful pursuits in general. They must, and do, join too in the positive task of building a world in which the growing needs of all countries may be met through constructive and co-operative endeavours. Statesmanship and science under the auspices of the United Nations thus unite in the vast adventure of collaboration for economic and social development to which so many of the most challenging efforts of the UN family of organizations are now devoted. This is the concerted effort against poverty, against hunger and disease, against illiteracy and want. This is the struggle that should absorb the energies of the world in a relentless quest toward the achievement of social decency and justice for all.

A historic step, of particular interest to participants in this Conference, was taken just over a year ago. I refer to the treaty banning nuclear weapons tests in the atmosphere, in outer space and under water, that was signed in Moscow at a ceremony I was privileged to attend. The unlimited potential significance of diverting efforts and resources from weapons testing to the peaceful applications of atomic energy is the very foundation of your presence and your work here.

As the half-way mark in the United Nations Development Decade is approached, this Organization seeks to assist and promote ways of transferring and adapting advanced science and technology to the vast requirements of the developing countries. It may be anticipated in this connexion that the association of the UN with the scientific world will develop along significant and perhaps unexpectedly fruitful avenues.

Eighteen months ago, in this hall, the United Nations sponsored a conference on the Application of Science and Technology for the Benefit of the Less Developed Areas. In many important ways the present Conference carries the same approach to the field of atomic energy. It is, of course, much more restricted in the range of its subject matter than UNCSAT or, for that matter, than either of the two earlier atomic conferences.

The main theme of the present Conference is nuclear power and this is a key issue for the long-term development of over half the world. If *per capita* consumption of electricity in the developing areas in one day is to compare with that now found in the major industrialized nations, the amount of additional power required will be so vast as to dwarf even the earth's immense reserves of fossil fuels and hydro-electric power. Surely, in the long run it is, as far as we can see today, only nuclear power —including perhaps power developed from fusion— that can fill these immense requirements.

In this realm, you have indeed come a long way, and I am confident that a fuller understanding of the problems involved will emerge from this Conference. When the first conference on the Peaceful Uses of the Atom gathered here in 1955, the world's first nuclear power station had been operating for only a year. Owing to fears of an impending fossil fuel shortage, a forced development of nuclear power was anticipated. The second conference in 1958 was more fully aware of the vast technical and economic difficulties involved in translating this dream to reality. That conference, moreover, coincided with the discovery of additional conventional fuel resources, which in a sense mitigated the urgency of the problem by eliminating, for the time being, the fear of immediate serious shortages.

In the long run, however, the problem of sources of energy remains as basic for economic development as ever, and over the past six years the advances achieved by you and your colleagues to solve it have been steady. These advances did not take the form of a break-through; rather, there has been a succession of solid accomplishments which entitles us to say that the problem is fully in hand technologically and is on the verge of coming under control economically.

Among the many possible uses of nuclear power, I should mention in particular the work being done in assessing its potential use for water desalination. This is a subject of particular interest for the United Nations, and, indeed, it is unnecessary to emphasize the benefits of a cheap desalination process for the developing countries, many of which contain extensive arid zones, and suffer from a chronic and growing shortage of fresh water. The UN Secretariat has just published a major study of this question, which the Economic and Social Council earlier this month asked me to bring to your attention.

I have underlined strongly that this Conference can and must—even if only in the long run—benefit the developing countries. Yet few of these countries as yet have nuclear scientists, and it is not surprising that the representatives of developing countries here today are by no means as numerous as we should have liked to see them. The key to this problem is, of course, training, and I can only repeat what I said in the statement delivered on my behalf at the opening session of UNCSAT: "In my view, development of certain scientific institutions and the training of at least a small number of scientists in some of the advanced disciplines is by no means a luxury for any of the new nations." Among these disciplines I should, of course, like to see nuclear science. The specific problem of training is not on the agenda of the Conference, but I hope you will all ponder it, both here and when you return to your homelands.

As your distinguished President, Professor Emelyanov, has pointed out, today no one doubts any more that an atomic power station or an atomic-powered ship can be built. He had said, moreover, that the next 15 to 20 years will surely witness such important developments that nuclear energy will come to play a major role in the over-all energy supply of many countries.

It is noteworthy, of course, that nuclear power reactors become economically practical when they are built on a large scale. Accordingly, it is the highly industrialized countries which have so far derived the most benefit from the atomic sources of power. If the smaller and less developed countries are to share in this advance, as indeed they must if they are to solve their development problems, they must combine their resources—human, economic, and technical. Here, as in so many other cases, effective forms of international co-operation are no luxury but an imperative necessity.

I may add that, like the peaceful exploration of outer space, the peaceful uses of the atom will eventually, albeit gradually, come to be regarded as the work of all of mankind rather than the exclusive preserve of particular nations.

Indeed, the exclusive approach was tried and failed. Before the first atomic conference in Geneva, your science had been developing on a national basis and in such secrecy that the various restrictions noticeably impeded its further progress. The first two Geneva conferences cracked many barriers of secrecy and exclusiveness and, incidentally, revealed the utter futility of trying to trying to hide science behind an insurmountable wall. These conferences revealed that the only result of these restraints had been to force scientists of various nations to make the same discovery independently over and over again, often simultaneously. Since that time, the channels of scientific communication and co-operation have been opened wider and wider. We can now say with some justification that the quest for a controlled thermo-nuclear reaction has become virtually the common endeavour of the scientific community of many nations.

Thus, as the Third International Conference on the Peaceful Uses of Atomic Energy begins its proceedings, it no longer deals with an esoteric discipline wrapped in secrecy and suspicion, yet somehow expected by the people miraculously to move mountains, swiftly to change human life and magically to solve all problems. But the harnessing of the atom remains a vastly exciting adventure, all the more so as it has passed its initial stages and now tackles complex problems soberly and realistically—yet with vastly enhanced effectiveness. The earlier promise has given way to solid accomplishment and more, vastly more, is yet to come.

Before concluding, I wish to thank the President of the Swiss Confederation for his participation in this inaugural meeting of the Third International Conference on the Peaceful Uses of Atomic Energy. Through him I should like, at the same time, to convey our thanks to the federal, cantonal and city authorities for the valuable assistance they have rendered in the preparation of the Conference, and more particularly for the Governmental Scientific Exhibition that is housed in the Palais des Expositions.

Ladies and Gentlemen, for the next few days the European Headquarters of the United Nations is your house, and you are very welcome here. I know your deliberations will be free and fruitful.

ПРИВЕТСТВИЕ ПРЕДСЕДАТЕЛЯ КОНФЕРЕНЦИИ ПРОФЕССОРА В. С. ЕМЕЛЬЯНОВА

Господин Председатель Швейцарской Конфедерации,
Господин Генеральный Секретарь,
Господин Генеральный Директор,
Господа Вице-секретари,
Господа Делегаты!

В этом году исполнилось двадцать пять лет, когда мир был оповещен о том, что ядро урана разделено. Значение этого события трудно переоценить. Труд небольших групп ученых, работавших в различных странах мира и посвятивших свои знания и энергию чисто научным исследованиям, был синтезирован и привел к результатам, которые позволяют назвать наше время веком атомной энергии.

В будущем году исполняется двадцатилетие с того дня, как атомная энергия была практически выделена и разрывами атомных бомб возвестила о наступлении новой эпохи в истории человечества. Военное использование атомной энергии наложило отпечаток на все дальнейшие процессы в науке, технике, экономике, политике.

Работы над ядерным оружием и все исследования, даже косвенно связанные с его созданием, проводились в строгой секретности, что не только затрудняло научные связи ученых, но во многих областях науки и техники сделало их невозможными.

Таким образом, период разобщенности ученых продолжался длительное время.

Девять лет тому назад по инициативе Организации Объединенных Наций была созвана Первая международная конференция по мирному использованию атомной энергии.

За год до созыва Первой конференции была введена в строй первая электростанция, производящая энергию, используя ядерный процесс деления, что практически показало возможности иного, не военного использования ядерных процессов. В текущем году было отмечено десятилетие успешной работы первой атомной электростанции.

На Первой конференции в 1955 году были восстановлены нарушенные второй мировой войной и последующим затем строгим режимом секретности научные связи. На этой Конференции со всей яркостью и убедительностью были продемонстрированы блестящие перспективы, открывающиеся перед человечеством, если атом поставить на службу миру и прогрессу.

Председатель Первой международной конференции по мирному использованию атомной энергии доктор Хоми Баба показал, какое огромное значение эта энергия будет иметь для всех стран мира и особенно для тех, которые уже испытывают недостаток в энергетических ресурсах. Он отметил также значение работ по новому направлению, тогда еще не представленному на Конференции,— процессам ядерного синтеза и высказал предположение о перспективах его развития.

Председатель Второй международной конференции профессор Франсис Перрен, подводя итоги трехлетнему периоду между двумя конференциями, обратил особое внимание на огромное значение для развития науки научных связей и сотрудничества ученых.

На Второй конференции было представлено много новых исследований, касающихся не только научных аспектов атомной проблемы, но затрагивающих также и практические вопросы различных областей использования энергии ядерного деления.

На Второй женевской конференции была показана практическая возможность использования атомной энергии не только в большой энергетике, но также и для приведения в движение судов в строительстве мирных кораблей. На Второй конференции было представлено большое количество исследований о различных путях осуществления нового источника энергии — управляемого ядерного синтеза — процесса, в силу которого изливает на Землю Солнце тепло своих лучей и светят далекие звезды.

Прошло еще шесть лет, и вот мы собрались вновь, чтобы обсудить результаты многочисленных исследований и изысканий, оценить сложившийся за эти годы опыт по практическому использованию сделанного четверть века тому назад открытия и наметить научные прогнозы на будущее.

За прошедшее шестилетие сделано много. Эти годы были годами интенсивных научных исследований. Физическая наука и атомная техника отметили это время вехами значительных достижений во всех основных направлениях ядерной физики — в области физики низких энергий, физики плазмы и физики высоких энергий.

В области физики низких энергий в настоящее время значительное место занимают работы по практическому использованию реакции деления атомных ядер. В научно-исследовательских лабораториях изыскиваются пути повышения коэффициента полезного действия сооружаемых установок, уточняются отдельные данные, необходимые для инженерных расчетов, изыскиваются средства контроля за радиоактивностью, создаются новые средства защиты от радиоактивных излучений, изыскиваются новые материалы, стойкие в полях радиации. Большинство исследовательских работ подчинено практическим целям, ибо на реакциях деления создается атомная энергетика — строятся атомные электростанции. В настоящее время уже никто не сомневается в том, что атомные реакторы можно практически использовать для производства электроэнергии.

В течение ряда последних лет в различных странах мира работают электростанции мощностью от десятков до сотен тысяч киловатт, они производят электроэнергию и служат школой для подготовки специалистов в этой новой области, позволяя также накапливать опыт и совершенствовать конструкции, аппараты и приборы регулирования процессами ядерного деления. В ряде стран ведется строительство крупных электростанций, в других странах составляются проекты их сооружения.

Вопрос в настоящее время заключается не в том, чтобы спорить, можно или нет рассматривать ядерное деление как практический источник энергии. Нет! Этот вопрос решен. На повестке дня стоят другие вопросы — как извлекать эту энергию наиболее дешевым путем и повысить ее значение в общем энергетическом балансе.

Не вызывают никаких сомнений также и перспективы практического использования атомной энергии в судостроении.

Атомный ледокол «Ленин», начавший плавание еще пять лет тому назад, успешно завершает в этом году свою пятую навигацию. Он блестяще прошел все испытания в суровых условиях Северного Ледовитого океана и показал неоспоримые преимущества атомных судов этого типа перед судами, использующими органическое топливо — уголь или нефть.

Мы можем отметить также успешное плавание товаро-пассажирского судна «Саванна», которое оно совершает в текущем году, пройдя длинный путь от берегов США до портов Европы.

Я глубоко убежден в том, что атомная энергия найдет пути также и воздушному транспорту,— слишком велики ее преимущества, чтобы не быть оптимистом.

Накопленный практический опыт проектирования, строительства и эксплуатации атомных электростанций дает основания рассчитывать на то, что в ближайшие 15—20 лет атомные электростанции, основанные на реакции деления — использовании в качестве топлива урана и плутония, получат значительное развитие и атомная энергетика будет играть существенную роль в общем энергетическом балансе многих стран мира.

Это объясняется рядом соображений, из которых наиболее важными являются два:

— во-первых, уже в настоящее время расчеты показывают, что атомные станции мощностью 500 тыс. киловатт и выше могут конкурировать с тепловыми электростанциями;

— второе соображение является не менее важным. Наше время отмечено значительными успехами в области химии и особенно органической химии. Химическая промышленность взяла на себя функции, которые раньше эта отрасль техники не выполняла.

Химия по существу вытеснила из производства натуральный шелк и заменила его искусственным.

Химия вытесняет из текстильной промышленности хлопок и шерсть, а из обувной промышленности — кожу.

Химия поставляет значительное количество самых разнообразных материалов для строительства, машиностроения, приборостроения.

Сырьем для химической промышленности, для изготовления пластических материалов, тканей, искусственной кожи и проч. являются природные газы, нефть и уголь. Органическое топливо является сырьем для химической промышленности. Если потреблять нефть в таких же темпах, как это происходит до настоящего времени, то нефть скоро будет сожжена и химия лишится важнейших источников сырья.

Сырьем для производства атомной энергии в настоящее время является уран. Пока не выявлено других крупных потребителей урана, кроме военной промышленности для производства ядерного оружия и энергетики для получения электрической и тепловой энергии, а также транспорта — прежде всего для приведения в движение судов. Насколько мы можем судить, уран может быть наиболее разумно использован в энергетике и для транспортных двигателей. Разведанные запасы урана обеспечат человечество энергоснабжением на несколько лет.

Разум подсказывает, что необходимо беречь органическое топливо, перестать рассматривать его только как топливо, а видеть в нем прежде всего сырье для химической промышленности.

Вместе с тем необходимо развивать работы по всестороннему использованию урана и продуктов его распада. Как это хорошо известно всем участникам Конференции, в результате реакций ядерного деления образуются радиоактивные изотопы и возникает излучение. Изотопы и излучения находят все более широкое применение в самых различных областях деятельности человека, и трудно найти такую область, где бы они в настоящее время с успехом не использовались, а экономический эффект от их применения в ряде стран измеряется значительными суммами.

Радиационные излучения прокладывают пути к практическому применению их в химической промышленности, позволяя совершенно по-новому проводить многие процессы, в особенности в области органического синтеза. Это направление по использованию ядерных излучений, по всей видимости, получит в ближайшие годы значительное развитие, и не исключено, что некоторые крупные реакторы будут выполнять не только роль энергетической установки, но также участвовать в проведении химических процессов. Интерес к практическому использованию изотопов и ядерных излучений в настоящее время настолько вырос, что было проведено много больших конференций, как международных, так и национальных, на которых были рассмотрены сотни докладов, посвященных отдельным исследованиям и практике их использования.

Этим объясняется, почему на нашей Конференции работы по изотопам сведены к обзорным докладам. Не потому, что здесь нечего сказать, а потому, что слишком много можно было бы еще сказать к тому, что уже высказано. Радиоактивные изотопы — это золотые россыпи, которые начали с успехом разрабатываться во многих странах мира.

Вторая проблема — проблема развития работ по физике плазмы — открывает дальнейшие страницы в области энергетики. Успешное решение этой задачи позволит включить в использование энергоресурсы мирового океана и снять с обсуждения угрозу истощения других источников энергии. Не вызывает никакого сомнения и то, что эта проблема также будет разрешена. Для ее решения необходима упорная работа ученых, поиски путей к осуществлению управляемых термоядерных процессов, которые дадут возможность практически использовать реакции ядерного синтеза.

Работы в области физики высоких энергий прокладывают пути к дальнейшему познанию тайн строения материи. За последние годы физика высоких энергий сделала много открытий. Все эти открытия пока что являются кирпичиками для построения новых теорий, которые должны дать более полную картину строения атомных ядер, изучить природу сил, действующих между отдельными частицами, дать стройную систему этих частиц и связать воедино все то, что нам известно об атоме.

Физика высоких энергий накапливает материалы и к новым процессам получения энергии, процессам аннигиляции, то есть к таким реакциям, в которых практически вся масса переходит в энергию излучения. Даже короткий перечень проблем, стоящих в повестке дня современной науки об атоме, показывает, какой размах принимают работы по изучению маленькой частицы ранее неделимого атома.

Решения о сокращении производства расщепляющихся материалов для военных целей, принятые правительствами США, Советского Союза и Соединенного Королевства, улучшают перспективы значительного развития работ по мирному использованию этих материалов.

В заявлении Председателя Совета Министров СССР Н. С. Хрущева прямо указано на решение Советского правительства «направлять больше расщепляющихся материалов для использования в мирных целях — в атомных электростанциях, в промышленности, в сельском хозяйстве, в медицине, в осуществлении крупных научно-технических проектов, в том числе в области опреснения морской воды».

Проблема обеспечения населения пресной водой становится все более острой по мере увеличения населения, освоения новых земель, роста городов и развития отраслей промышленности, потребляющих в своем производстве значительное количество воды. Без воды нет жизни. Проблему обеспечения водой необходимо решать для многих стран мира. Настало время направить силы, знания и опыт специалистов, занятых в атомной области, также и на решение этой одной из величайших проблем — превращение соленых вод в пресные.

Необходимо направить всю энергию, накопленную на военных складах в форме ядерного оружия, на то, чтобы строить мощные атомные реакторы, которые будут давать дешевую энергию и опреснять воду. Создание мощных опреснительных установок — это разумный путь использования атомной энергии.

Грандиозность открывающейся перспективы в области науки об атоме и сложность стоящих перед наукой задач требует сотрудничества, объединения сил ученых. За истекшие шесть лет в научной жизни произошло много событий, направленных на развитие научных связей и укрепление их.

Начало развивать свою деятельность Международное агентство по атомной энергии. Оно провело ряд важных научных форумов, на которых были подробно рассмотрены многие вопросы по атомной проблеме. Были организованы конференции, симпозиумы, семинары, летние школы, на которых рассмотрены и обсуждены многие вопросы по применению радиоактивных изотопов и излучений, по управляемому ядерному синтезу, по удалению радиоактивных отходов и ряд других.

Все это значительно укрепляет научные связи. Большой период между двумя конференциями — Второй и Третьей — был наполнен интенсивной деятельностью мировой научной общественности, работающей над проблемой атомной энергии. И все же все проведенные в течение последних шести лет конференции, совещания и симпозиумы не могут заменить собой международных конференций, создаваемых Организацией Объединенных Наций, ибо они, эти конференции, с особой силой и убедительностью показывают, как важно повернуть атомную энергию с тропы, ведущей к войне, и направить ее на дело мира и прогресса.

Текущий год астрофизики назвали годом спокойного солнца. Этот год можно назвать также годом надежды на то, что разум восторжествует, благоразумие одолеет силы, стремящиеся остановить прогресс человечества и ввергнуть мир в пучину войны.

К Третьей международной конференции мы пришли не только с результатами по завершенным важным и интересным исследованиям, но и с радужной перспективой плодотворного сотрудничества. Для развития сотрудничества имеются все основания: перед народами мира стоит много нерешенных проблем — поднятие экономики развивающихся стран, замена тяжелого физического труда работой механизмов, осушение болот и трясин, превращение пустынь в цветущие сады. Все это можно сделать, если приложить труд и энергию. Проблем много, и они велики. Их разумно решать только путем сотрудничества. Мы должны объединить наши усилия и направить их к тому, чтобы использовать могучие силы природы для дальнейшего развития цивилизации.

Изучая природу материи, совершенствуя наши знания об атоме и ядерных силах, мы должны научиться жить в мире, и задача ученых и, в частности, собравшихся здесь, состоит не только в том, чтобы раскрывать законы природы, но и помочь утвердить законы о том, как нам жить в мире — отвратить навсегда угрозу войны. Не допускать того, чтобы вскрытые нами силы внутриатомной энергии превратили в руины то, что создано человечеством, и не погребли бы под обломками исчезнувшей цивилизации и тех, кто содействовал и участвовал в раскрепощении могучей силы атома.

Сотрудничество должно и будет развиваться, иначе не может быть. Но для того чтобы развивалось сотрудничество, необходимо устранить главные помехи, мешающие этому. Нужен мир. Необходимо устранить угрозу войны, создать мир без оружия.

Московский договор о прекращении испытаний ядерного оружия в атмосфере, в космическом пространстве и под водой «помогает приблизиться к тем рубежам, с которых легче приняться за решение важнейшей проблемы нашего времени» — всеобщего и полного разоружения.

Под договором поставили свои подписи более ста стран.

В этом месяце исполнился год со дня подписания договора о прекращении испытаний ядерного оружия в трех средах.

СССР, США и Соединенное Королевство в совместном заявлении объявили о своем намерении «делать все возможное для урегулирования, путем переговоров, нерешенных международных проблем, с тем чтобы упрочить всеобщий мир, благами которого пользовались бы все государства — большие и малые, все народы».

Московский договор открывает пути к взаимопониманию и решению международных проблем путем переговоров.

Вслед за запрещением ядерных испытаний в трех средах удалось закрыть доступ ядерному оружию в космос и несколько уменьшить поток расщепляющихся материалов, вливающихся в ядерные арсеналы. Но это лишь первые шаги. Необходимо прикладывать дальнейшие усилия, с тем чтобы освободить мир от ужаса войн и осуществить мечту человечества — создать мир без оружия, мир без войн.

В борьбу за мир включаются все прогрессивные люди земли. Мир на земле будет утвержден.

Достижения атомной науки и техники не являются результатом труда ученого-одиночки. В сокровищницу науки об атоме сделали вклад представители многих стран и народов. Некоторых из них уже нет среди нас. За время между двумя конференциями — Второй и Третьей — физическая наука понесла невозвратимые потери.

Не стало Нильса Бора, который еще на Второй конференции радовал нас своим выступлением, развертывая панораму новых задач, стоящих перед мировой физической наукой.

Не стало Игоря Васильевича Курчатова, блестящего ученого, много сделавшего для познания тайн атома и развития науки о нем.

Нет Лео Сциларда, сделавшего значительный вклад в физическую науку и посвятившего последние годы своей жизни борьбе за запрещение ядерного оружия.

Я думаю, что все участники Конференции разделяют скорбь понесенной утраты.

Я прошу почтить их светлую память вставанием.

Мне остается теперь только выразить надежду, что наша Конференция будет плодотворно работать и активность научной дискуссии дополнит представленные на Конференцию интересные и содержательные доклады.

Разрешите пожелать успеха всем участникам Третьей конференции ООН по мирному использованию атомной энергии.

Translation

ADDRESS BY MR. V. S. EMELYANOV, PRESIDENT OF THE CONFERENCE

Excellencies, Ladies and Gentlemen,

Twenty-five years have now passed since the world heard the news that the uranium atom had been split. It is difficult to exaggerate the importance of that event. The work of a small group of scientists, working in different countries of the world and devoting their knowledge and energies to pure scientific research, was finally synthesized, leading to results which justify us in calling our times the century of atomic energy.

Next year will mark the twentieth anniversary of the date on which atomic energy was released on a practical scale, and the explosions of atomic bombs announced the advent of a new epoch in the history of mankind. The military use of atomic energy left its mark on all future developments in science, technology, economics and politics.

Work on atomic armaments and all related research, even that connected only indirectly with the development of such weapons, was carried out in the strictest secrecy, which made professional contacts between scientists not merely difficult but actually impossible in many fields of science and technology.

This isolation of scientists was of long duration.

Nine years ago, on the initiative of the United Nations, the First International Conference on the Peaceful Uses of Atomic Energy was convened.

A year before this first conference was convened, the first power station to produce electricity by nuclear fission went into service, thus giving a practical demonstration of the possibility of another, non-military application of nuclear processes. This year, the first atomic power plant completed ten years of successful operation.

The first conference in 1955 saw the restoration of the scientific contacts that had been interrupted by the Second World War and the conditions of strict secrecy that followed it. This conference provided striking and convincing evidence of the brilliant prospects that would be opened up to mankind if the atom was placed at the service of peace and progress.

Dr. Homi Bhabha, the President of the First International Conference on the Peaceful Uses of Atomic Energy, showed how important such energy would become for all the countries of the world and especially for those that were already suffering from a shortage of energy resources. He also drew attention to the importance of work in a new direction, of which nothing had previously been said at the conference, namely, that of nuclear fusion, and expressed certain assumptions about the prospects of its development.

Professor Francis Perrin, the President of the Second International Conference, summarized developments during the three-year period between the two conferences, laying particular stress on the importance of scientific contacts and co-operation between scientists for the development of science.

At the second conference many new studies were described, relating not only to the scientific aspects of the atomic problem, but also to practical questions relating to the various fields of application of the energy released by nuclear fission.

At this second Geneva conference, evidence was given of the practical possibilities of using atomic energy not only in large power plants, but also for ship propulsion—in the construction of non-military vessels. A large number of papers were presented at this conference, describing various means of creating a new potential source of power—controlled nuclear fusion—the process through which the sun bathes the earth in the warmth of its rays and distant stars light up the heavens.

Another six years have passed and we are gathered together here again to discuss the results of much investigation and research, to assess the experience acquired in the course of those six years in the practical application of the discovery made a quarter of a century ago and to hazard a scientific forecast of future developments.

Much has been done during the past six years. They have been years of intensive scientific research. During this period, physics and atomic technology have recorded substantial advances in all the fundamental disciplines of nuclear physics—in the fields of low-energy physics, plasma physics and high-energy physics.

In the field of low-energy physics, considerable attention is currently being given to work on the practical application of the nuclear fission reaction. In research laboratories, ways of increasing the efficiency of plant and equipment are being studied, the accuracy of specific data indispensable for engineering and design calculations is being improved, means of controlling radio-activity are being sought, new means of protection against radio-active radiations are being developed, and research is in progress into new materials, resistant in radiation fields. The bulk of this research is directed towards practical ends, because the fission reaction serves as the basis for atomic power engineering, for the construction of atomic power plants. Today, there is no longer any doubt that atomic reactors can be put to practical use to generate electricity.

For several years now, electric power stations with capacities ranging from tens to hundreds of thousands of kilowatts have been operating in different countries of the world. They produce electric power and serve as a school for training specialists in this new field; they also make it possible to accumulate experience and to perfect designs, equipment and devices for controlling the fission process. Large power plants are being built in a number of countries and the construction of such plants is being planned in other countries.

The question today is not whether or not nuclear fission can be regarded as a practical source of power. No, indeed! That question has been answered. Other questions have appeared on the agenda: how to extract that energy as cheaply as possible and increase its importance in the general energy balance sheet.

Neither is there any doubt today about the outlook for the practical use of atomic energy in shipbuilding.

The atomic ice-breaker *Lenin*, which went into service five years ago, is this year successfully completing its fifth cruise. It has passed all tests brilliantly in the severe conditions of the Arctic Ocean, and has shown the indisputable superiority of atomic ships of this type over vessels using organic fuels such as coal or oil.

We may also mention the successful voyage of the cargo-passenger ship *Savannah*, which it is completing this year after making the long crossing from the shores of the United States to European ports.

I am firmly convinced that atomic power will find its way into air transport too; its advantages are too great to leave room for anything but optimism on this score.

The practical experience acquired in the designing, construction and operation of atomic power stations justifies the belief that, within the next fifteen to twenty years, such plants, based on the fission reaction and using uranium and plutonium as fuel, will be very substantially developed so that atomic power will play a vital part in the over-all energy balance of many countries.

This is due to a number of factors, of which I will mention the two most important.

First, even today calculations show that atomic power stations with a capacity of 500 000 kilowatts and upwards can compete with thermal plants.

The second factor is no less important. Our times have seen significant advances in chemistry, and especially in organic chemistry. The chemical industry has assumed functions which it has never before fulfilled.

It has virtually ousted the manufacture of natural silk and replaced it by the production of artificial silk.

It is ousting cotton and wool from the textile industry and leather from the boot-and-shoe industry.

It is providing considerable quantities of the most varied materials for building, engineering and instrument-making.

The raw materials for the chemical industry, for the manufacture of plastics, fabrics, artificial leather and similar products are natural gas, oil and coal. Organic fuels provide the chemical industry with its primary materials. If we go on using oil at the present rate, all our oil will soon be burnt up, and the chemical industry will be deprived of a most important source of raw material.

At the present time, the raw material for the production of atomic power is uranium. So far, no other large users of uranium have appeared on the scene except the war industries, which use it for the production of atomic weapons, and the power industry, which uses it for the generation of electricity and heat; we must also include transport, which uses it mainly for ship propulsion. So far as we can judge, uranium can be most rationally used in the power industry and for motive power. The proved reserves of uranium are sufficient to meet mankind's power requirements for several hundred years.

Reason suggests that we must husband our organic fuels, that we must stop treating them purely as fuels and view them primarily as raw materials for the chemical industry.

We must at the same time develop work on the all-round utilization of uranium and its disintegration products. As everyone present at this Conference knows very well, the nuclear fission reaction is accompanied by the formation of radio-active isotopes and the emission of radiation. Both isotopes and radiation are finding increasingly wide application in the most varied fields of human activity, and it would be difficult to find an area where they are not at present being successfully used while, in a number of countries, the economic impact of their use, measured in financial terms, represents a substantial sum.

New ground is being broken in the practical application of radiation in the chemical industry, bringing about revolutionary changes in certain processes, especially in the field of organic synthesis. In all probability, this new trend in the use of nuclear radiation will make considerable headway in the years to come, and it is not impossible that some large reactors will not merely serve as sources of energy, but will also be used for process purposes in the chemical industry. Interest in the practical use of isotopes and nuclear radiation has currently increased to such an extent that many large conferences, both international and national, have already been held on the subject, at which hundreds of papers dealing with research and with the practical application of radiation have been considered.

This explains why, at our own Conference, consideration of work on isotopes has been confined to survey papers. This has been done, not because there is nothing to say on this subject, but because there is too much that might be added to what has already been said. Radio-active isotopes might be described as a gold field which has begun to be successfully worked in many countries.

A second problem is the development of plasma physics, which is turning over a new page in the history of energetics. The successful solution of this problem will make it possible to harness the energy of the world's oceans and to banish the threat of the exhaustion of other sources of energy. There can be no doubt that this problem, too, will be solved. Its solution calls for a sustained effort on the part of scientists to find methods of carrying out controlled thermo-nuclear processes which will make it possible to put the nuclear fusion reaction to practical use.

Work in the field of high energy physics is paving the way to a fuller knowledge of the secrets of the structure of matter. High energy physics has many discoveries to its credit during the past few years. For the time being, all these discoveries constitute bricks with which we can build up new theories that will give us a more complete picture of the structure of atomic nuclei, that will enable us to study the nature of the forces acting between individual particles, that will reveal the logical arrangement of these particles and make it possible to combine all that we know about the atom into a single whole.

High energy physics is also building up a body of material relating to new processes for obtaining energy, the annihilation processes, that is, reactions in which for all practical purposes the entire mass of the material is converted into energy in the form of radiation. Even a short list of the problems of current concern to atomic science shows the extent to which work has proceeded on the study of small particles of the hitherto indivisible atom.

The decision to limit the production of fissionable materials for military purposes, taken by the Governments of the United States of America, the Soviet Union and the United Kingdom, has improved the prospects for a substantial development of work on the peaceful uses of such materials.

In the announcement made by Mr. N. S. Khrushchev, Chairman of the Council of Ministers of the USSR, there is a direct reference to the decision of the Soviet Government to channel more fissionable material into peaceful uses in atomic power stations, industry, agriculture, medicine, and the realization of major scientific and technological projects, including the desalination of sea water.

The problem of supplying the population with fresh water is becoming more and more critical as the population of the world increases, new lands are brought into cultivation, cities grow in size and those branches of industry requiring large quantities of process water are further developed. There is no life without water. This problem of water supply calls for solution in many countries. The time has come to direct the efforts, knowledge and experience of atomic specialists towards the solution of this most important problem—the conversion of salt water into fresh water.

It is essential to channel all the energy stored up in military stockpiles in the shape of nuclear weapons into the construction of powerful atomic reactors which will produce cheap power and also desalinate water. The construction of large desalination plants is a rational method of using atomic energy.

In the light of the magnificent prospects before us in the field of atomic science and of the complexity of the problems which that science has to solve, it is essential for scientists to collaborate and to unite their forces. During the past six years, there have been many events in scientific life that have made for the development and strengthening of scientific ties.

The International Atomic Energy Agency has begun to expand its activities. It has convened a series of important scientific meetings at which many atomic problems have been discussed in detail. Conferences, symposia, seminars, and summer schools have been organized for the consideration and discussion of many questions relating to the use of radio-active isotopes and radiation, controlled nuclear fusion, the disposal of radio-active waste, etc.

All this has greatly strengthened scientific ties. The long interval between the Second and Third International Conferences has been filled with intensive activity in world scientific circles working on the problems of atomic energy. But all the conferences, meetings and symposia held during the past six years cannot replace international conferences convened by the United Nations, because the latter provide particularly striking and convincing evidence of the importance of diverting atomic energy from the path leading to war into the path of peace and progress.

The astro-physicists have called this year the Year of the Quiet Sun. It might also be called the year of hope that reason will prevail, that good sense will overcome the forces working to impede human progress and to plunge the world into the abyss of war.

We have come to this Third International Conference not only with the results of the important and interesting studies we have been making, but also with a happy prospect of fruitful collaboration. All the prerequisites for the development of collaboration are present: the peoples of the world are faced with many unsolved problems—the development of the economies of the developing countries, the replacement of heavy physical labour by mechanical devices, the reclamation of marshes and bogs, the conversion of deserts into flowering gardens. All this can be done if we apply the necessary labour and energy. The problems are many and great. They can be rationally solved only through collaboration. We must unite our forces and apply them to the utilization of the powerful forces of nature for the further development of civilization.

As we study the nature of matter and perfect our knowledge of the atom and of nuclear forces, we must learn to live in peace, and the tasks of scientists, and especially of those assembled here today, is not merely to attempt to uncover the laws of nature, but also to help to affirm the laws that should govern our life in this world, in particular, to avert the threat of war for once and for all. We must not allow our discoveries of the forces of intra-atomic energy to ruin what mankind has created, nor must we allow those who assisted and collaborated in releasing the mighty power of the atom to be buried under the fragments of a vanishing civilization.

Collaboration must and will be developed. It cannot be otherwise. But, if such development is to take place, we must remove the main obstacles standing in its way. We must have peace. It is essential to remove the threat of war, to create a world without armaments.

The Moscow treaty banning nuclear weapon tests in the atmosphere, in outer space and under water helps to bring us closer to positions from which it will be easier to grapple with the solution of the most important problem of our time—general and complete disarmament.

More than a hundred countries have already signed the treaty.

This month sees the first anniversary of the signature of the treaty banning nuclear weapon tests in these three environments.

The USSR, the United States and the United Kingdom, in a joint statement, declared their intention "to do everything possible for the solution through negotiations of unresolved international problems in order to strengthen general peace, the benefits of which would be enjoyed by all States, big and small, and by all people".

The Moscow treaty opens up the way to mutual understanding and to the solution of international problems through negotiations.

As a result of the ban on nuclear tests in the three environments, it has proved possible to prevent the penetration of atomic weapons into outer space and thereby to decrease to some extent the flow of fissionable material into nuclear arsenals. But these are only the first steps. We must make further efforts with a view to delivering the world from the horrors of war and to realizing man's dream of creating a world without weapons, a world without war.

All progressive men and women in the world are taking part in the battle for peace. Peace will be established on earth.

The achievements of atomic science and technology are not the result of the work of individuals. The representatives of many countries and peoples have contributed to the store of atomic knowledge. Some of them are no longer among us. During the period that has elapsed between the second and third conferences, the physical sciences have suffered irreparable losses.

Niels Bohr, who made such an enjoyable address at the second conference, in which he reviewed the new tasks with which the world physical scientists are confronted, is no more.

Igor Vassilevitch Kurchatov, the brilliant scientist who did so much to unveil the secrets of the atom and to develop atomic science, is no more.

Leo Szilard, who made a considerable contribution to the physical sciences and who devoted the closing years of his life to the struggle for a ban on nuclear weapons, is no longer with us.

I am sure that their death is a source of grief to all participants in the Conference.

I would ask you to honour their memory by rising.

All that remains for me now is to express the hope that our Conference will do fruitful work, and that the interesting and important papers submitted will be supplemented by active scientific discussion.

I wish success to all participants in the Third International Conference on the Peaceful Uses of Atomic Energy.

ADDRESS BY MR. SIGVARD EKLUND, DIRECTOR GENERAL OF THE INTERNATIONAL ATOMIC ENERGY AGENCY

The statement made once by an outstanding power expert that nuclear power is aiming at a moving target set by prices of conventional power has proved right throughout many years. It may not be inappropriate to recall the time when it was said with reference to theoretical studies of nuclear power costs which resulted in predictions close to conventional power prices, that the best way of decreasing the cost of nuclear power would be to reduce the price of energy units produced in the conventional way. Even recently an author referred somewhat ironically to the habit of atomic energy commissions to state in their annual reports that nuclear power is just around the corner of becoming competitive. Without anticipating the results of this Conference which has just been opened it is obvious that within the last year the competition has entered a new phase. Renewed interest in nuclear power shown by public utilities has given nuclear power such a strong position that it has probably exerted a certain influence on the price of coal, i.e., an action reversing the one I have just mentioned. It has taken some time but the specialist who at the first Geneva conference in 1955 predicted that a certain nuclear reactor system would be able to produce power at 4 mills per kWh and then was considered rather irresponsible has now proved to be right. During the forthcoming sessions we will have ample opportunity to get up-to-date information about different reactor concepts which should be helpful for utilities or power boards in making policy decisions regarding the route to follow in their future programmes. The requirement of nuclear fuel for the next few years or decades, to mention one aspect only, is so different for various systems that ultimately a policy decision will have to be taken. The problem of choosing between reactor systems may be analogous to judging the relative merits of an apple and an orange.

Progress made in the practical utilization of atomic energy, especially for production of power, will undoubtedly also be reflected in the organizations set up to foster atomic energy. I refer specifically to the fact that industry has taken over, earlier than was assumed in many quarters, part of the development work which was previously the sole responsibility of national commissions. Under such circumstances national organizations should be able to shift emphasis or undertake new duties provided that Governments are not too restrictive with regard to financial provisions. It is reasonable to expect that in many cases Governments will question the necessity of supporting to the same degree as before certain development work by their atomic energy commissions by referring to the availability on the commercial market of reactor types which have proved to be competitive or almost competitive with conventional systems. This has led to a trend to re-evaluate the role of national organizations in the field of atomic energy and such a re-evaluation will have implications also on countries' participation in schemes of international collaboration.

Let us remember that even though we are in a new phase in the utilization of nuclear power, several important questions remain to be resolved before we can make use of the larger part of the energy stored in the uranium reserves in the world; I am thinking above all of the necessity of achieving high burn-up in thermal systems or breeding. These pose tremendous tasks which can only be solved by very massive and concentrated efforts.

The economy drive by Governments will certainly foster regional and international co-operation. It is interesting to note that several bilateral agreements have been signed between countries working on similar problems whereby costly experimental facilities are better utilized in joint programmes for research and development work. Although these agreements are useful in demonstrating that through active co-operation duplication of work and investment are avoided, they cannot be compared in importance with multilateral agreements leading to regional projects in the form so successfully launched in Europe. I express the hope that wisdom will prevail so that in the future support will be given increasingly to true regional projects for the benefit of a number of countries. It is not difficult to define several such projects but I shall confine myself to mentioning only two. In areas where the use of nuclear power may grow considerably within a decade or two, agreements aimed either at using existing reprocessing plants for the reactors in the region, or the construction of a plant to be jointly used for the treatment of certain standardised fuel, may lead to considerable savings both with regard to operational and capital costs. For basic research the construction of high-energy accelerators for energies above 300 CeV on a regional or international basis should also not be forgotten. In the presence of representatives from so many countries I would again express my firm belief in the regional approach and recommend that wherever possible steps be taken to establish such collaboration.

How does the present day situation of national and regional organizations affect a world-wide organization, such as the International Atomic Energy Agency? What are the main tasks facing this seven-year-old organization in this new phase when nuclear power is becoming increasingly competitive? It is necessary to remember here that the Agency has certain functions from which all Member States benefit whereas other activities are mainly aimed at providing help for developing countries. I would like to refer first to the type of tasks of interest to all Member States.

No application of atomic energy will have the same economic impact as its use in nuclear power, whether it be for electricity production or for process heat, for example in water desalination. Several reasons could be advanced as to why the Agency has not fulfilled its role of broker for nuclear fuel, as envisaged at its foundation, but I would draw your attention to the fact that producers of enriched material and especially the United States have pledged a quantity of no less than approximately 5 000 kg of uranium-235 at the disposal of the Agency for use in nuclear reactors for peaceful purposes. Only minute quantities have yet been requested by Member States of the Agency, one reason being the slow increase in nuclear power reactors in the past, a second the fact that many Member States were supplied with enriched material through bilateral agreements and a third probably the obligation for a country receiving such enriched material to accept the safeguards system which the Agency has established to ensure that the material is used only for peaceful purposes. With the revision of the Agency's safeguards system which is now well under way, and with the transfer of safeguards responsibilities from bilateral arrangements to the Agency, I hope that in the future use will be made of this enriched material which, according to promises given, can be increased if necessary.

Time permits me to make only passing reference to the assistance which the Agency can give a Member State in estimating the role of nuclear power under the special situation prevailing in that country, in studying the siting problems and in evaluating reactor bids from manufacturers. This will constitute a major task for the Agency. Several different organs in the United Nations family deal with power questions and it is necessary to effect close collaboration between them in order to avoid unnecessary duplication and overlapping because a country embarking on a new power programme must consider the atomic energy alternative alongside the conventional means—coal, oil or hydro power. The great capital cost and foreign exchange component of power installations, especially nuclear power stations, makes it imperative for a country to examine such alternatives carefully and thus have an over-all view of its power problem and its most economical solution.

May I instead emphasise the important tasks which the Agency has to fulfil in the regulatory field, in working out international agreements on such questions as liability for nuclear damage, etc., which may be less familiar to you. With the rapidly growing number of power reactors it is very essential to find a solution for these problems and I take this opportunity to draw your attention to the importance of ratifying the Vienna Convention on Civil Liability for Nuclear Damage of May 1963. By channelling all liability to the operator of a nuclear installation and placing a ceiling on his liability, this Convention makes it possible to avoid a cumulation of insurance. It thereby contributes to reducing the costs for nuclear energy and of transport of nuclear materials. At the same time the Convention accords adequate protection to possible victims by offering them substantive and procedural advantages which they do not have under existing law.

At the present Conference we shall hear reports on the operational experience from the Soviet icebreaker *Lenin*. Recently, the United States nuclear ship *Savannah* has made visits to European ports. In this connection authorities in the countries visited have made extensive safety evaluations and it is probably true to say that no reactor including auxiliaries has been scrutinised by so many independent experts as that of the *Savannah*. It may not be unreasonable to expect that the Agency, in co-operation with the Intergovernmental Maritime Consultative Organization (IMCO) will be asked to perform evaluations of this type in the future. Similarly, it was necessary to conclude special agreements with the countries to be visited by *Savannah* providing for liability for any damage which might be caused. It is conceivable that the conclusion of special agreements in the countries to be visited by nuclear ships could be dealt with on an international basis when the Brussels Convention on Liability of Operators of Nuclear Ships established by the Agency and the Belgian Government enters into force.

International regulations are important also in respect of the safe transport of nuclear materials. The Agency's Regulations for the Safe Transport of Nuclear Materials, approved in 1960, were revised in June of this year, and the uniform application of these Regulations in all countries and to all means of transport is of great importance, for example, in order to avoid the need of packaging and labelling the same consignment of nuclear materials in different ways to satisfy different sets of regulations.

With an increasing number of large power reactors coming into operation, regulations covering the disposal of radio-active waste become increasingly important. Considerable effort has been devoted to this problem especially the disposal of waste into the sea. It has not yet been possible to find an acceptable formula for this but the problem is under constant study and a possible first step towards a general agreement would be the opening of an international registry by the Agency by which Member States would indicate the amount and location of their deposits.

It would not be proper for me to leave the regulatory field without referring to the importance of establishing and having accepted an international safeguard system *now* when the number of power reactors is still small. The Agency's statutory activity in this field has gained considerable momentum in the past year, as the Agency has assumed rightfully the responsibilites formerly covered under bilateral arrangements.

Fostering the use of isotopes in different branches of science and technology has always been prominent on the Agency's programme. The development which has taken place as reflected in the survey lectures at this Conference, whereby isotopes have become a common tool in medicine and agriculture, just to mention two fields, require organizational steps to meet the developing situation. One such step is the proper establishment of a joint division between the Food and Agriculture Organization (FAO) and the Agency. Through this division, to be located in Vienna with access to the Agency's laboratory, it is hoped to increase the efficiency of the services of the two organizations to their Member States, particularly in those fields of radioisotope applications in which they have a common interest.

I shall not refer to the technical assistance activities of the Agency other than to mention that the Agency has an explicit statutory obligation to provide assistance to developing countries. In a number of such countries research reactors exist, surrounded by fine experimental facilities and in other countries installations are under construction. The importance of maintaining this momentum towards creation of scientific and technological centres is obvious and the Agency is trying to assist as much as its means allow. In this too, a regional approach is favoured by the Agency.

In this brief survey, Mr. President, I have tried to show how the present situation may affect especially the work of the International Atomic Energy Agency in the future. Some of you will agree with me, I hope, that satisfactory progress in several of these tasks of common importance is essential for a sound development in the fields to which the first, second and third Geneva conferences have been devoted. Progress however can only be achieved by a sustained, wholehearted support by the Member States of the Agency which are represented at this Conference.

Messages from Heads of State or Government of the countries represented on the United Nations Scientific Advisory Committee

MESSAGE DE M. HUMBERTO DE ALENCAR CASTELLO BRANCO, PRÉSIDENT DE LA RÉPUBLIQUE DES ETATS-UNIS DU BRÉSIL

Dans l'intervalle des six années qui se sont écoulées entre la deuxième Conférence atomique de 1958 et celle qui s'ouvre aujourd'hui, d'importants développements dans le domaine de la science et de la technologie nucléaires ont été accomplis, en particulier en ce qui concerne la réduction du prix de revient des centrales nucléaires.

C'est donc dans un climat d'optimisme, qui rappelle l'atmosphère de la première Conférence de

1955, que les représentants des pays du monde entier se retrouvent à Genève, unis dans le même esprit de coopération, en vue d'échanger des informations tendant à faire disparaître les inégalités dans le développement des différentes régions du globe.

Il faut espérer que, de cette rencontre internationale, naîtront de nouvelles initiatives fondées sur les expériences vécues au cours de ces dernières années. Le Gouvernement brésilien, porte-parole d'un pays encore jeune, qui peut tant espérer de l'énergie nucléaire, veut exprimer sa certitude que les résultats obtenus à cette conférence marqueront une étape décisive dans la voie du progrès scientifique et technologique, en vue d'accroître toujours davantage le bien-être de tous les peuples.

Translation

MESSAGE FROM MR. HUMBERTO DE ALENCAR CASTELLO BRANCO, PRESIDENT OF THE REPUBLIC OF THE UNITED STATES OF BRAZIL

The six-year interval, between the second conference in 1958 and this one which is being inaugurated today, gave place to important developments in nuclear science and technology, particularly with regard to decreasing the cost of atomic power plants.

Consequently, it is in a climate of optimism, which recalls the atmosphere of the first conference in 1955, that the representatives of all nations in the world meet again in Geneva, united by the same spirit of cooperation, with the objective of exchanging information towards diminishing the development gap between different regions of the earth.

We do hope that from this international gathering new initiatives will spring, based upon effective experience during the last years. On behalf of a country still young, having so much to expect from nuclear power, the Brazilian Government expresses its confidence that the results achieved in this Conference will mark a decisive phase in the history of scientific and technological progress towards the goal of achieving a constant rise in the well-being of all peoples.

MESSAGE FROM THE RT. HON. LESTER B. PEARSON, PRIME MINISTER OF CANADA

In the name of Canada I send this message of greetings and goodwill to accompany the technical contributions my country's delegation will make to the Third International Conference of the United Nations on the Peaceful Uses of Atomic Energy. It is fitting that this Conference should be convened at a time when the world has recognized not only the terrible destructiveness of nuclear energy in war, but also its value as a source of power for the peaceful, economic and industrial development of nations.

The world remembers the enthusiasm that sprang from the great sharing of scientific knowledge which took place at the First International Conference on the Peaceful Uses of Atomic Energy, and the exchanges in depth that marked the second conference. Now that the hopes there raised are gaining in strength and engineering substance, we look to this third conference for an open exchange of that growing knowledge on which the engineers of all nations can build, for what they build can hasten the prosperity so greatly desired by so many.

For its part Canada will present to the Conference the knowledge gained from the experience and studies that have enabled Canadian companies to embark with confidence on the construction of giant nuclear-electric power stations to be built and operated under normal commercial conditions.

We hope that we will be able to measure up to the challenge issued by the late Dag Hammarskjold, when he described the gathering nine years ago in Geneva as the conference of master builders of nuclear science and nuclear engineering.

MESSAGE DU GÉNÉRAL CHARLES DE GAULLE, PRÉSIDENT DE LA RÉPUBLIQUE FRANÇAISE

La fission de l'atome, désormais exploitée à l'échelle industrielle, peut contribuer de plus en plus au progrès et au bien des hommes. De là la grande importance de la troisième Conférence internationale organisée par les Nations Unies pour l'étude de l'utilisation de l'énergie atomique à des fins pacifiques. La France y participe avec confiance.

J'adresse à tous les délégués des nations représentées à ces assises internationales de l'énergie atomique mes vœux les plus sincères pour le plein succès de leurs travaux.

Translation

MESSAGE FROM GENERAL CHARLES DE GAULLE, PRESIDENT OF THE FRENCH REPUBLIC

Nuclear fission, which is to be used in future for industrial purposes, can contribute increasingly to the progress and welfare of mankind. The Third International Conference on the Peaceful Uses of Atomic Energy, organized by the United Nations, is therefore of great importance. France participates in the Conference with full confidence.

I send to the representatives of all the nations attending this international gathering for the study of atomic energy my sincere wishes for the complete success of their work.

MESSAGE FROM SHRI LAL BAHADUR SHASTRI, PRIME MINISTER OF INDIA

The first conference on the Peaceful Uses of Atomic Energy, organized by the United Nations in 1955, was the most important and historic scientific conference ever held. Never before was such a vast and significant amount of scientific knowledge, developed separately by a few nations in the strictest secrecy, thrown suddenly open to all for the benefit of mankind. This conference engendered great optimism about the peaceful uses of atomic energy, in particular, for the generation of electrical power.

The second conference, organized by the United Nations in 1958, was even larger, as a result of the great impetus given by the first conference to the development of atomic energy in many countries.

The work of the third conference is likely to be of immense importance for power development in the world. As a result of the vast scientific effort put in by many countries, atomic power will be a boon to all power and water hungry areas in the world.

India believes today, as it has always believed, that atomic energy should only be used for peaceful purposes and for the welfare of humanity and has resolved to use it only in this manner as far as its own efforts are concerned. I wish the Conference great success and hope that it will give a further impetus to the peaceful uses of atomic energy for the welfare of mankind.

Послание Н. С. Хрущева, Председателя Совета Министров Союза Советских Социалистических Республик

Мне доставляет большое удовольствие от имени Советского правительства и от себя лично горячо приветствовать участников Третьей Международной конференции ООН по мирному использованию атомной энергии.

Две предыдущие конференции 1955 и 1958 гг. продемонстрировали важность обмена идеями, знаниями и опытом между учеными и специалистами различных стран мира в области мирного использования атомной энергии. Проведение таких конференций стало хорошей традицией.

Позвольте выразить надежду, что Третья Женевская конференция внесет новый большой вклад в дело международного научно-технического сотрудничества. Такое сотрудничество тем более необходимо, что ширится фронт использования атомной энергии, которое стало возможным и практически целесообразным во многих отраслях экономики и науки. Атомная энергия должна найти широкое применение в самых различных областях — в промышленности, сельском хозяйстве, на транспорте, в медицине. Особенно перспективным в ближайшие годы станет использование чудодейственных свойств ядерного горючего в производстве электроэнергии, а также в строительстве атомных судов типа ледокола «Ленин». Атомная энергия призвана решить среди многих других проблем и проблему нехватки пресной воды, которая сегодня стоит перед многими странами, в том числе и перед развитыми промышленными государствами.

В Советском Союзе проводятся большие работы по мирному использованию атомной энергии. Советские ученые из года в год расширяют сотрудничество с учеными других стран. Мы приветствуем такое сотрудничество и будем всемерно развивать его дальше.

Говоря о расширении областей и масштабов использования атомной энергии в мирных целях, мы не можем закрывать глаза на то, что мешает этому. Военный атом препятствует полнокровному развитию атома мирного. Вот почему важно решение проблемы всеобщего и полного разоружения и отказ от любых шагов, которые вели бы к расползанию ядерного оружия по нашей планете.

Выступая за скорейшее решение проблемы всеобщего и полного разоружения, Советский Союз добивается, чтобы атомная энергия использовалась исключительно в целях дальнейшего технического прогресса и подъема благосостояния всех народов и стран.

Желаю ученым и специалистам, собравшимся на Третью Женевскую конференцию, больших успехов в работе.

Translation

Message from Mr. N. S. Khrushchev, Chairman of the Council of Ministers of the Union of Soviet Socialist Republics

It gives me great pleasure, on behalf of the Soviet Government and on my own behalf, to send warm greetings to the participants in the Third International Conference on the Peaceful Uses of Atomic Energy.

The two preceding conferences, held in 1955 and 1958, have shown the importance of an exchange of ideas, knowledge and experience with regard to the peaceful uses of atomic energy among scientists and experts from the various countries of the world. The convening of such conferences has become a praiseworthy tradition.

I should like to express the hope that the third Geneva conference will make a new and considerable contribution to the cause of international scientific and technical co-operation. Such co-operation has been made particularly necessary by the widening of the scope of the utilization of atomic energy which has become possible and practically feasible in many branches of economy and science. Atomic energy is destined for extensive use in a wide variety of sectors—in industry, agriculture, transport and medicine. Particularly favourable prospects are offered in the near future for the utilization of the miraculous properties of nuclear fuel in electric power production and in the construction of atomic vessels of the type of the icebreaker *Lenin*. Among the many other problems that can be solved by atomic energy, there is the problem of the shortage of fresh water, which confronts many countries, including developed industrialized States.

The Soviet Union is conducting extensive work on the peaceful uses of atomic energy. Soviet scientists are annually expanding their co-operation with the scientists of other countries. We welcome this co-operation and intend to develop it further in every possible way.

In speaking of the expansion of the sectors and scope of the peaceful uses of atomic energy, we cannot ignore the factors hampering this expansion. The military uses of the atom represent an obstacle to the full development of its peaceful uses. Hence the importance of solving the problem of general and complete disarmament and refraining from any measures which might lead to the dissemination of nuclear weapons on our planet.

In championing the rapid solution of the problem of general and complete disarmament, the Soviet Union is endeavouring to ensure that atomic energy should be used exclusively for further technical progress and for promoting the well-being of all peoples and nations.

I wish the scientists and experts attending the third Geneva conference the greatest success in their work.

Kremlin, Moscow, 31 August 1964 (transmitted by telegram)

MESSAGE FROM THE RT. HON. SIR ALEC DOUGLAS-HOME, PRIME MINISTER OF THE UNITED KINGDOM

It gives me great pleasure to send the warm greetings and good wishes of Her Majesty's Government in the United Kingdom to the Third Geneva Conference on the Peaceful Uses of Atomic Energy.

The theme of the Conference is progress in nuclear power. This is particularly appropriate at a time when scientists and engineers in the leading countries have built up an industry equipped to utilise economically the tremendous forces of the atom, in competition with older forms of power generation.

The enthusiasm which greeted the conclusion of the nuclear test ban treaty a year ago showed how widespread is the desire to avoid the horrors of a nuclear war. Her Majesty's Government hope that the Conference will, like its predecessors, effectively demonstrate that scientists of all nations can co-operate to share their knowledge of the peaceful uses of nuclear energy for the advantage of all.

MESSAGE FROM THE HON. LYNDON B. JOHNSON, PRESIDENT OF THE UNITED STATES OF AMERICA

I would like to extend my best wishes to all the delegates at this Third International Conference on the Peaceful Uses of Atomic Energy. A great challenge confronts you. You can hasten the day when the atom will be harnessed to hard labour for man's welfare. You can reduce the risk that the atom will be used for man's destruction.

We stand at the threshold of the age of nuclear power. But whether nuclear power will meet our needs tomorrow depends on our work and our wisdom today.

In the United States we have been working and learning. We have now learned how to build large-scale reactors whose electric power will be economically competitive in many parts of our country and the world. Our utility companies now aim to build or purchase reactors producing electricity at between four and six mills per kilowatt-hour.

This achievement has come from fifteen years of concentrated research and development. The US Government has spent more than 1.6 billion dollars on this effort. American private enterprise has spent an additional half billion dollars.

These expenditures are an investment by our people in the future of all mankind. Through our Government and through private enterprise, we are prepared to use this vast new technology to help other countries to meet their energy needs.

At present, the large-scale reactor offers the best hope of economic production of electricity. Not every country and not every community can use this large size. But our rapid rate of progress should soon lead to economic production in smaller reactors too.

A further application of nuclear energy will be large-scale desalting of water. The time is coming when a single desalting plant, powered by nuclear energy, will produce hundreds of millions of gallons of fresh water—and large amounts of electricity—every day.

Our Government is proceeding with an aggressive program of nuclear desalting. What we learn in this program will be shared with other nations. Already we have begun cooperative exchanges with Mexico, with Israel, and with the Soviet Union. Today I invite all of you to join with us in this enterprise.

As we move ahead, we look to the International Atomic Energy Agency to play an ever larger role in these peaceful efforts. Already it has set standards for the care and keeping of nuclear materials. This achievement has raised our hopes for a workable system of world law on nuclear energy.

For almost twenty years, we have known the atom's terror as a weapon of war. Today, we begin to know its hope as a powerhouse of peace. Today, at last, we have good reason for belief that the atom can be made the servant, not the scourge, of mankind.

Messages from Heads of State or Government of other countries

MESSAGE FROM MR. LUDWIG ERHARD, CHANCELLOR OF THE FEDERAL REPUBLIC OF GERMANY

The United Nations are holding the Third International Conference on the Peaceful Uses of Atomic Energy at a significant time. The efforts of science and technology have led to the threshold of the economical use of this source of energy. The Conference will be focused on the development of power reactors, and scientists and engineers from all over the world will again be communicating their knowledge to each other and exchanging views on the best way to achieve further progress. The Federal Republic of Germany, too, will co-operate as best it can towards the realization of this objective. May also this Third International Conference on the Peaceful Uses of Atomic Energy emit a strong impulse for international co-operation, for the solution of scientific and technological problems, and thereby for the prosperity and peace of nations.

MESSAGE FROM FIELD MARSHAL MOHAMMED AYUB KHAN, N.PK., H.J., PRESIDENT OF PAKISTAN

Never before and not since has a scientific discovery so profoundly affected the course of human history and international relationship as the discovery of atomic energy. Its potential for the promotion of human welfare is immense. Its power to destroy mankind and civilization is equally great. To balance its use is one of the key problems of our age. It is tragic that nations which pioneered the discovery of atomic energy and development of nuclear technology have ploughed their resources of men and money on a massive scale to build a huge stockpile of atomic bombs and weapons. What is more tragic is the fact that countries which are now acquiring or which have since acquired the know-how, think of diverting the fissionable materials for military purposes. Let us hope that sanity will dawn upon us all and there will be not only international agreement to ban the testing of nuclear weapons but an agreement not to produce them at all.

As time goes on, the benefits of peaceful uses of atomic energy will be reaped by an ever-growing number of nations and nuclear power reactors will become as common as thermal stations fired by coal, oil or gas. It is, therefore, of utmost importance to bring all such reactors under a workable system of safeguards, international inspection and control.

It is heartening to note that the United Nations attach the highest importance to exchange of information on the development of peaceful uses of atomic energy and periodically bring leading scientists and experts from different parts of the world together to review the progress made. I am sure that the scope of the application of radioisotopes and radiation sources in the fields of agriculture, medicine and industry will receive a great impetus as a result of this Conference. I wish it every success.

MESSAGE ADRESSÉ PAR M. HABIB BOURGUIBA, PRÉSIDENT DE LA RÉPUBLIQUE TUNISIENNE

Nous adressons nos chaleureuses salutations à tous les savants et techniciens réunis à l'occasion de la troisième Conférence internationale sur l'utilisation de l'énergie atomique à des fins pacifiques. Dans l'intervalle de neuf ans, trois conférences de cette nature se sont tenues. Nous accordons la plus grande attention à vos travaux, dont les résultats contribueront à l'avènement de l'énergie atomique dans les pays en voie de développement. Un des sujets que vous étudierez préoccupe tout particulièrement la Tunisie. Il s'agit de la désalinisation de l'eau de mer par l'énergie atomique.

La Tunisie a fait des études assez avancées dans ce domaine. Il résulte des calculs effectués que dans certaines régions de la Tunisie l'énergie atomique peut économiquement produire de l'électricité et de l'eau douce qui contribueront à leur développement économique et social. La collaboration internationale dans ce domaine est de nature à concrétiser de tels projets. Nous adressons tous nos vœux de pleins succès à vos travaux en formulant le souhait le plus ardent pour que vos discussions puissent aboutir à des conclusions fructueuses, réalisant ainsi les objectifs de cette importante conférence.

Translation

MESSAGE FROM MR. HABIB BOURGUIBA, PRÉSIDENT OF THE REPUBLIC OF TUNISIA

We send our warmest greetings to all scientists and experts meeting on the occasion of the Third International Conference on the Peaceful Uses of Atomic Energy. This is the third conference in nine years. We shall follow your work with the greatest interest, for it will help to bring atomic energy to the developing countries. One of the subjects that you will be studying—the desalination of sea-water by atomic energy—is of special importance to Tunisia, which has made some advanced studies in that field. The surveys show that in certain areas of Tunisia electricity and fresh water can be cheaply produced by atomic energy thus contributing to the economic and social development of those regions. International co-operation in this sphere would give practical effect to such projects.

We send our wishes for the complete success of your work and express the fervent hope that your discussions may lead to useful conclusions and fully achieve the purposes of this important Conference.

MESSAGE FROM PRESIDENT GAMAL ABDEL NASSER, PRESIDENT OF THE UNITED ARAB REPUBLIC

On the occasion of the meeting of the Third International Conference on the Peaceful Uses of Atomic Energy I wish to convey my greetings and sincere sentiments to all the scientists participating in this Conference, on which the whole world is focusing its attention.

In the domain of science, the UAR has always sought the great promise of a better tomorrow for its people among all the peoples of the world. What mankind anticipates is not merely the provision of the necessities to sustain life but rather the realization of what can be truly termed an "age of plenty and abundance". To this end we are always ready to bear our full share of the responsibility in co-operation with all scientists of all nations, and to the limit of our capacity.

This basic concept of the "internationalization of science" which underlies the whole of our thoughts and actions, derives from our firm belief and deep conviction that science owes its obligations equally to each and every member of the family of man regardless of race, colour or creed.

There is no doubt in my mind that the vast potentialities inherent in atomic energy, when entirely directed towards peaceful ends, would furnish unlimited opportunities for the constructive co-operation of the scientists of the world to be manifested in achievements surpassing our farthest dreams.

The Moscow treaty for the limited banning of nuclear tests concluded last year, and which the UAR was one of the first nations to ratify, has revived the hope in their complete banning. This is our goal and we shall spare no effort until all forms of nuclear weapons are totally abolished.

Only then will humanity witness the full scale miracles that atomic energy can do, and also then will atomic energy on earth be synonymous with prosperity, and in the truest sense.

May I, on behalf of the people and the Government of the UAR, thank you for your continuous and generous contributions to the cause of humanity, and wish you all success.

Session B

NEW ECONOMIC DATA. ENERGY NEEDS IN COMING YEARS AND THE ROLE OF NUCLEAR POWER IN MEETING THESE NEEDS

LIST OF PAPERS

General aspects and the needs of under-developed countries

National programmes

World energy requirements and the economics of nuclear power with special reference to underdeveloped countries

By H. J. Bhabha and M. Dayal

The energy resources and energy requirements of the world were reviewed in the 1955 and 1958 Geneva Conferences on the Peaceful Uses of Atomic Energy and separate attention was also devoted to the needs of atomic energy in the underdeveloped areas [1]. This paper brings these reviews up to date and studies likely demands for nuclear power in relation to present economics. Special attention is again devoted to the energy resources and requirements of the underdeveloped areas, and their need for atomic energy. The same approach is followed as in the previous work, namely, to consider the population and energy resources of certain large regions into which the world can be divided naturally, either for geographical or for other pertinent reasons.

To estimate the energy demand and supply position on a global basis, it is convenient to divide the world into nine regions as follows [2]:

(*a*) North America, comprising essentially the United States and Canada;

(*b*) Latin America including Mexico and countries south of it;

(*c*) Western and Eastern Europe;

(*d*) USSR;

(*e*) Africa excluding Egypt;

(*f*) The Middle East, including Iran, Turkey, Egypt and other Arab countries;

(*g*) South Asia and the Far East (SAFE), including all countries of Asia excepting the Middle East and China;

(*h*) China;

(*i*) Oceania, consisting of Australasia and the Pacific Ocean islands.

Some of the latest United Nations statistics [3], on the population in these areas, the installed electrical capacity, electricity production and total energy consumption from commercial sources as well as the *per capita* value for each of these three items, are given in Table 1. The annual energy consumption *per capita* for North America is about 8 tons of coal equivalent, and that for Europe, Oceania and the USSR is about 3 tons. In general these areas contain the industrially advanced countries of the world. On the other hand, Latin America, Africa, SAFE, the Middle East and China, which comprise areas that may be termed underdeveloped, have a *per capita* consumption of less than 0.7 ton coal equivalent per annum. The table also shows the correlation between electricity production and total energy consumption. The underdeveloped regions of the world contain the bulk of the world's population, i.e., 2 200 million out of a total of 3 069 million, or 71.8%, but consume only 20.6% of the energy and produce only 14.8% of the world's electricity.

GROWTH OF DEMAND

There can be no certainty in the projection of future demands, but orders of magnitude can be arrived at based on general considerations. The total consumption of commercial sources of energy in the world was over 4 200 million tons of coal equivalent in 1960. Table 2 indicates the manner in which the consumption of energy has increased in the various areas of the world during the period 1957 to 1960. World consumption increased on average at about 6% per annum in this period, while it rose in the underdeveloped areas of SAFE and the Middle East at about 8 to 9% per annum, i.e., considerably faster than the world average. Energy consumption in Africa increased at about 3% per annum only, but with the changing economic conditions this rate may go up. As the total energy consumption of the underdeveloped areas becomes greater, their higher growth rate will push up the world average rate of rise of demand. Another factor of great importance is the rapid growth in population, the impact of which is most pronounced in the underdeveloped areas of the world, which contain over 70% of the world's population. Thus the average rate of increase in total energy consumption for the world as a whole is not likely to fall below 5% for many years and may indeed be higher. On the assumption of a 5% per annum increase, the total consumption of commercial sources of energy in the world, which was 4 200 million tons per annum in 1960, will rise to about 30 000 million tons per annum in the year 2000.

The world demand in the year 2000 can also be estimated by assessing the growth in demand for each region. Table 3 indicates the position based on present trends according to UN statistics for both population increase and increase in consumption *per capita* *. According to this, the demand from the developed regions of the world will be about 13 500 million tons by the year 2000. This agrees closely with other estimates arrived at from more detailed considerations [4] [5].

At the rate of increase which prevailed between 1957 and 1960, the energy consumption *per capita* of the underdeveloped regions in the year 2000 will be about 3 tons per annum or more on the average. Multiplying this by the expected population at that time, the total demand in these regions will be about 16 000 million tons, thus bringing the total world demand to about 30 000 million tons which checks with the overall estimates given above. Other estimates have placed the consumption of the underdeveloped regions at about 8 000 million tons with a *per capita* annual consumption of only 1.5 tons by 2000 A.D. [4] [5]. When we consider that the value for *per capita* consumption in Europe *today* is about 3 tons (see Table 1), it becomes clear that for the underdeveloped countries we should at least aim to arrive at such a target by the year 2000, particularly since this will be achieved by following or slightly increasing the present rates of growth in these areas. It should also be pointed out that now much of the energy consumption in the underdeveloped regions comes from non-commercial sources such as bagasse, dung, wood, etc., the proportion for India in 1960 being over 60%. As development proceeds, the swing will be more towards commercial sources and the demand for such sources will increase sharply.

WORLD ENERGY RESOURCES

Hydro-power

It has been estimated that, if all the sites of the world which have been surveyed are utilized, it will be possible to generate 5 million million kWh of electricity per annum [6]. This potential is equivalent to roughly 625 million tons of coal equivalent per annum—based on the conversion factor used for the UN statistics—which is a small portion of the present total world energy consumption and less than 3% of the likely consumption 30 to 40 years hence. The economically exploitable hydro-resources will be even less. The total water power resources cannot therefore make a substantial contribution to the overall long-term energy picture.

Fossil fuel

Perhaps the most authoritative recent estimation of fossil fuel reserves is that by the World Power Conference Survey of Energy Resources [6]. According to this, the total reserves of fossil fuel in the world that could be recovered economically are about 3½ million million tons of coal equivalent. If the rate of world consumption continues to rise beyond 2000 A.D., also at 5% per annum, these resources would be exhausted in about 75 years. Even if the rate of growth tends to slow down somewhat, it is clear that all the economically exploitable resources would be exhausted within a limited, foreseeable time. The figure of 3½ million million tons of economically exploitable reserves is based on the assumption that one third of all the estimated resources including indicated and inferred reserves could be recovered economically. The World Power Conference survey points out that the measured reserves are considerably less and, assuming that half can be recovered economically, the total amount available will be about 400 000 million tons. If in fact this turns out to be correct, the fossil fuel reserves that are economically recoverable will be exhausted in about 30 years.

Nuclear energy

Nuclear energy has been developed and now can supply power in several areas of the world more economically than conventional sources, and since the latter cannot meet total world demands an increasing contribution will be called for from nuclear energy. Even if it contributes electric power equivalent to 1 000 million tons of coal in the year 2000, i.e., less than 5% of the total, it will require the generation of 8×10^{12} kWh and an installed capacity of the order of 1 600 million kW, that is 2.8 times the present installed capacity in the world. In fact, in the USA alone a nuclear capacity of 734 000 MW and electricity generation of 4.5×10^{12} kWh will be required in 2000 A.D. [7]. If the same relation exists between world figures and US figures in the year 2000, as in 1961, world requirements will be of the order of 2 160 million kW nuclear capacity and 12.6×10^{12} kWh of electricity generation.

Another general factor which will increase the utilisation of nuclear energy is the insensitiveness of nuclear fuel costs to the effect of transportation. Over the past three decades, the relative importance of solid and liquid fuels has changed markedly, the latter's share of the total world consumption increasing from about 15% in 1929 to about 31% in 1960. The proportion of solid fuels declined from 80% to about 52%. Mainly this swing occurs because oil can be transported over long distances more cheaply than coal [4]. This factor applies even more to nuclear fuel, since the cost of transportation is an extremely small fraction of total fuel costs in nuclear power stations.

REGIONAL DISTRIBUTION OF ENERGY RESOURCES

Table 4 gives the total reserves of conventional resources, both measured and inferred, for different regions of the world [5]. A striking fact is that the

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* The total world population of 6 600 million in the year 2000, arrived at in the Table 3 projection, agrees with most other projections.

Table 1. Total and *per capita* installed capacity, electricity production and consumption of commercial energy in various regions of the world in 1961 [a]

Region	Population		Total installed capacity 10^6 kW	Total electricity production 10^6 kWh	Commercial energy consumption		Installed capacity *per capita* kW	Electricity production *per capita* kWh	Commercial energy consumption *per capita* (tons coal equivalent)
	Millions	% of total			Total (10^6 tons coal equivalent [b])	% world total			
North America	204	6.64	236	992 981	1 581	36.55	1.16	4 870	7.824
Oceania	17	0.56	8.5	34 765	47.8	1.105	0.5	2 050	3.024
Western and Eastern Europe	430	14.01	186	734 313	1 171.36	27.04	0.431	1 705	2.72
USSR	218	7.1	74.1	327 611	636.84	14.72	0.34	1 501	2.921
Latin America	218	7.1	19.42	73 360	148.25	3.42	0.0894	337	0.679
Africa	196	6.38	8.77	37 512	61.2	1.41	0.0447	191	0.310
SAFE	942	30.67	34.4	183 113	237	5.47	0.0365	194	0.262
Middle East	146	4.76	3.522	12 537	38.27	0.885	0.0242	86.0	0.272
China	698 [c]	22.78	—	58 500 [d]	407.31	9.4	—	84	0.528
World	3 069	100.00	570.712	2 454 692	4 328.42	100.00	0.186	800	1.40

NOTE. — The conversion factor for electricity does not make any allowance for thermodynamic efficiency in the conversion of heat to electricity.

[a] *Source: UN Statistical Yearbook,* 1962.

[b] The conversion factors have been taken, according to present UN practice, as · 1 tonne of brown coal and lignite = 0.5 tonne of coal; 1 tonne of peat = 0.445 tonne of coal; 1 000 m³ of natural gas = 1.33 tonne of coal; 8 000 kWh = 1 tonne of coal; 1 tonne crude petroleum and shale oil = 1.3 tonnes coal.

[c] Semi official estimate.

[d] 1960.

Table 2. Growth of energy consumption [a]

Total consumption of commercial sources in million tons coal equivalent

Region	*1957*	*1958*	*1959*	*1960*	Annual % increase between 1957 and *1960*
North America	1 428.06	1 424.32	1 486.09	1 549.31	2.8
Oceania	39.26	40.65	42.98	45.62	5.2
Western and Eastern Europe	1 043.99	1 033.67	1 048.75	1 134.14	2.8
USSR	514.40	550.55	583.74	610.61	5.8
Latin America	116.00	122.46	129.85	139.37	6.3
Africa	54.33	56.86	57.52	59.35	3
SAFE	169.75	169.79	185.68	213.51	8
Middle East	28.75	30.32	33.27	36.91	8.7
China [b]	141.36	286.20	369.64	446.83	46.8
World	3 535.90	3 714.82	3 937.52	4 235.65	6.25

[a] *Source: UN Statistical Yearbook,* 1961.

[b] The figures for China are subject to verification.

Table 3. Projection of energy consumption in 2000 A.D.

Region	*Per capita* consumption of energy in 2000 A.D. at present rate of increase (tons coal equivalent)	Population in 2000 A.D. at present rate of increase 10^6	Total energy consumption in 2000 A.D. (10^6 tons coal equivalent)	
North America	11.62	407	4 740	
Eastern and Western Europe	5.81	609	3 540	
USSR	14.4	332	4 780	
Oceania	9.18	55.6	511	13 571
Latin America	3.0	541.9		15 626.7
Africa		530.0		
SAFE		2 140		
Middle East		312		
China		1 685		
World	4.42	6 612.5		29 197.7

Table 4. Absolute and *per capita* reserves of coal, brown coal, lignite, peat, petroleum, shale oil, natural gas and water power [a]

Fuel quantities in million tons of coal equivalent

							Water power		
								Per capita/yr	
Country or region	Total solid fuel	Total liquid fuel [b]	Total gaseous fuel	Total solid, liquid and gaseous fuel	Population in 2000 A.D. (millions)	*Per capita* (tons coal equivalent)	10^6 MWh/yr	MWh	Tons coal equivalent
North America	1 380 720	285 000	50 000	1 715 720	407	4 200	999.30	2.45	0.306
Oceania	62 036	42	4	62 082	55.6	1 120	29.24	0.526	0.066
Western and Eastern Europe	618 213	1 760	488	620 461	609	1 020	601.05	0.99	0.124
USSR	5 375 265	4 290	31 550	5 411 105	332	16 300	2 100.00	6.3	0.79
Latin America	20 916	7 600	2 330	30 846	541.9	56.8	453.60	0.839	0.105
Africa	75 906	1 740	660	78 306	530	148	450.62	0.850	0.106
SAFE	82 046	1 660	1 620	85 326	2 140	40	476.01	0.223	0.028
Middle East	1 739	30 600	950	33 289	312	106	61.33	0.196	0.024
China	1 011 350	91	–	1 011 441	1 685	600	–	–	–
World	8 628 191	332 783	87 602	9 048 576	6 612.5	1 363	5171.15	0.78	0.098

NOTE. — UN conversion factors have been used (as given in Table 1) for converting to coal equivalents.

[a] *Source:* World Power Conference Survey of Energy Resources 1962.

[b] There may be additional amounts of shale oil in various countries which have not been estimated or reported to the World Power Conference.

underdeveloped areas are also those which possess the least resources *per capita* of conventional energy. With a consumption of 3 tons coal equivalent *per capita* and the estimated population which will be reached by the turn of the century, the entire conventional fuel resources of Latin America would be exhausted in about 19 years, of the Middle East in 35 years, of SAFE in 13 years, and of Africa in 49 years. The economically recoverable reserves would be much less. The table shows that the water power resources of the underdeveloped regions are insignificant compared with other reserves, and cannot, by themselves, provide for the energy needs of the regions even to-day. Also if energy has to be imported it is cheaper to do this as nuclear rather than as conventional fuels. It is clear, therefore, that the underdeveloped areas will have to turn to nuclear power to develop and maintain standards of living comparable with those in the industrially advanced countries today.

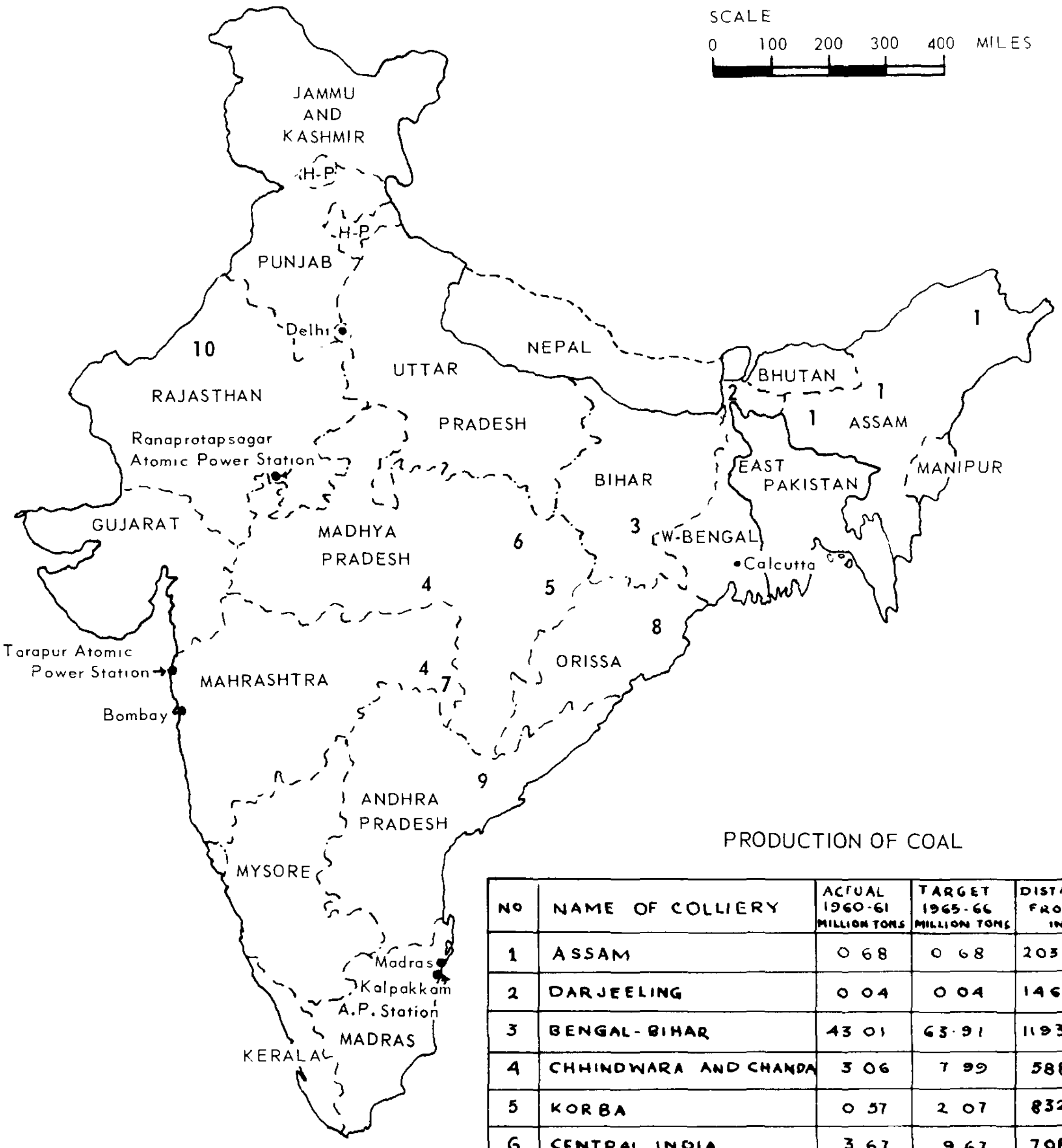
Table 4 also shows that the area which is worst served with conventional resources is SAFE. This region with a present population of over 940 million will therefore require to use nuclear energy at the earliest date. Even at the present increase in the rate of energy consumption, the cumulative consumption between now and the year 2000 will be 61 500 million tons, which amounts to 72.5% of the entire fossil fuel reserves of this region, and means that probably *all* the economically exploitable reserves will be exhausted before the turn of the century. For this region, therefore, one can foresee that within the next three decades a situation will arise when all additional power capacity may well have to be from nuclear power stations.

Of the population of 940 million in the SAFE region, Japan, which is already an industrialised country, accounts for 95 million. Of the balance, India alone accounts for about 450 million, i.e., more than half. We shall, therefore, discuss India's energy requirements in greater detail.

INDIA'S POWER REQUIREMENTS

At the present rate of growth, India's population will reach something of the order of 700 million by 1986. The hydro-power potential in the country is only about 225 000 million kWh, which for a population of 700 million would amount to 325 kWh *per capita* or 0.04 tons of coal equivalent *per capita*. This potential cannot, therefore, make any appreciable impact on the long term energy requirements. As regards oil, India has to import large quantities even today, and any increase for power production purposes is not desirable because of the difficult foreign exchange situation. India's largest resource is coal, but this too will be inadequate to support the development needed to achieve and sustain the levels that prevail today in the industrially advanced countries [8] [10]. It is accepted, therefore, that nuclear energy must play a part in the future.

Nuclear power is immediately attractive in certain areas of the country because coal resources are concentrated only in certain regions. Figure 1 shows the distribution of coal reserves. For several areas such as the west coast, southern and northern regions, coal has to be hauled from collieries over distances of 500 to 1 400 miles. This increases the price of coal and also puts a heavy load on the transportation system, which is already burdened with the needs of a rapidly developing economy [8]. The problem is further accentuated by the acute shortage of better grades of coal which are required for steel and other industries, leaving only the poorer



PRODUCTION OF COAL

NO	NAME OF COLLIERY	ACTUAL 1960-61 MILLION TONS	TARGET 1965-66 MILLION TONS	DISTANCE BY RAIL FROM BOMBAY IN MILES
1	ASSAM	0 68	0 68	2037 FROM LEDO
2	DARJEELING	0 04	0 04	1463
3	BENGAL-BIHAR	43 01	63·91	1193 FROM JHARIA
4	CHHINDWARA AND CHANDA	3 06	7 99	588 FROM CHHINDWARA
5	KORBA	0 57	2 07	832
6	CENTRAL INDIA	3 67	9 67	708 FROM UMARIA
7	SASTI	0 14	0 14	570
8	ORISSA	0 88	2 88	1387 FROM TALCHER
9	SINGARENI	2 52	5 52	653
10	BIKANER	0 05	0 05	746
	TOTAL	54 62	92 95	

Reference Third 5-Year Plan, Government of India

Figure 1. Location of coal deposits in India

grades (calorific value 9 000 Btu/lb or less) for power purposes. The railway budget for 1964 has introduced another increase in the freight rates for coal. Coal prices, effective from 1st April 1964, for power generation in areas far from coalfields are given in Table 5. They range from about Rs.2.4 to Rs.4.5 (51 to 94 US cents) per million Btu, and the fuelling cost ranges from 2.4 nP (5 mills) to about 9 nP (19 mills) per kWh. In comparison, the fuelling cost for nuclear power stations of the CANDU type now being set up in Rajasthan will be about 0.65 nP (1.36 mills) per kWh. The minimum cost of power from a thermal station using coal delivered to these areas from the nearest collieries therefore works out as indicated in Table 6.

Pit-head generation plus EHV transmission

Recently attention has also been given to the possibility of supplying power to regions remote from coalfields by having pit-head stations and using high voltage transmission. In working out the cost of power delivered by such means, we have to take

Table 5. Cost of conventional fuels in certain regions of India

	Cost Rs/ton	Cost per million Btu		Fuelling cost per kWh sent out (net efficiency 35%)	
		Rs	US cents	nP	mills
1. Bengal-Bihar coal ex-colliery	20.14	1.02	21.4	0.99	2.08
2. M.P. coal ex-colliery	23.58	1.19	25.0	1.16	2.44
3. Singareni coal ex-colliery	29.73	1.5	31.5	1.46	3.06
4. M.P. coal at Bombay transported by rail	56.59	2.86	60.1	2.79	5.86
5. Bengal-Bihar coal at Bombay transported by rail	62.96	3.18	66.7	3.10	6.51
6. Bengal-Bihar coal at Bombay transported by rail-cum-sea route	88.66	4.47	94.0	4.36	9.05
7. Singareni coal at Madras transported by rail	52.30	2.64	55.5	2.58	5.42
8. Bengal-Bihar coal at South Indian ports transported by rail-cum-sea route	77.11	3.9	81.9	3.8	7.97
9. Bengal-Bihar coal at Delhi transported by rail	53.22	2.69	56.5	2.62	5.5
10. M.P. coal at Delhi transported by rail	52.56	2.66	55.9	2.59	5.44
11. M.P. coal at Kotah transported by rail					
12. Bengal-Bihar coal at Kotah transported by rail	48.23 56.47	2.44 2.85	51.2 59.9	2.38 2.78	5.0 5.84
13. Furnace oil in Bombay area without duty	80-90	2.03 to 2.27	42.5 to 47.6	1.97 to 2.22	4.13 to 4.66
14. Furnace oil in Bombay area with duty	140-150	3.55 to 3.8	74.5 to 79.5	3.44 to 3.69	7.21 to 7.75

NOTE. — Conversion factor of Rs.1 = 21 US cents is assumed; items 1-12 refer to grade III A coal of calorific value 9 000 Btu per lb.; items 13-14 refer to furnace oil of calorific value 18 000 Btu per lb.

Table 6. Cost of power from coal burning station in Bombay-Gujarat, Madras and Delhi-Punjab-Rajasthan regions[a]

	Cost of power nP/kWh[b]					
	Interest rate 5%			Interest rate 10%		
Capital charges	0.97	0.97	0.97	1.51	1.51	1.51
Fuelling costs:						
(*a*) Minimum in Bombay-Gujarat	2.79	–	–	2.79	–	–
(*b*) Minimum in Madras	–	2.58	–	–	2.58	–
(*c*) Minimum in Delhi	–	–	2.59	–	–	2.59
Operation and maintenance	0.20	0.20	0.20	0.20	0.20	0.20
	3.96	3.75	3.76	4.50	4.29	4.30
Interest during construction[c]	0.09	0.09	0.09	0.27	0.27	0.27
	4.05	3.84	3.85	4.77	4.56	4.57

[a] Assumptions made are:

Capital cost	Rs 900/kW* sent out ($189/kW)
Life	25 years
Load factor	75%
Net thermal efficiency	35%
Calorific value of coal	9 000 Btu/lb

* Even if this is reduced to Rs 800/kW, the reduction in power costs will be about 0.12 nP/kWh for 5% interest and 0.2 nP/kWh for 10% interest.

[b] To convert from nP to mills multiply by 2.1.

[c] 9% of capital charges for 5% interest rate and 18% of capital charges for 10% interest rate.

into account costs of generation at the pit-head, of the transmission losses and the additional installed capacity required to meet these losses, and the costs involved in installing and operating the transmission system terminal equipment, etc.

The cost of power per kWh delivered in this manner at Madras, Bombay, Delhi and Rajasthan has been estimated, based on a careful assessment of the general design of the lines and of the terminal equipment required at each end for satisfactory transmission. The results for the minimum transmission distance involved in any of the cases concerned are given in Table 7. The capital investment in the pit-head station plus transmission facilities for delivering 400 MW to the areas examined amounts to about Rs.1 350/kW. While it may be argued that high tension transmission lines would have to be installed in any case in order to interconnect regional grids, this is not the same as installing lines and terminal equipment specifically for bulk transmission of power in one direction only, and if large amounts of power have to be so transmitted unidirectionally then clearly the capital investment on the lines and terminal equipment will in general increase with the power to be transmitted.

Oil-fired station

Table 8 gives the cost of power from an oil-fired station located near a port. For a location inland such as Rajasthan, costs will be much higher.

Nuclear power

Tables 9 and 10 give the cost of power from nuclear power stations of 400 MW (2 × 200 MW) capacity which are actually being set up now in the Bombay-Gujarat and Rajasthan regions respectively. The relative costs of power have been summarised in Table 11. At the prevailing interest rate for public plants, which is less than 5%, nuclear power is considerably cheaper than all the conventional alternatives. Even with a hypothetical interest rate as high as 10%, nuclear power is competitive. The tables show that for the regions considered, pit-head generation and EHV transmission will produce cheaper power than local coal stations using coal transported by rail, but nuclear power is cheaper still.

As previously stated, imports of large quantities of oil for an oil-fired station will involve an undesirable foreign exchange drain. In view of the availability of natural uranium in India as well as

Table 7. Costs of transmitting power from pit-head thermal stations (nP/kWh) over 350 miles[a, b]

	5% interest rate				10% interest rate			
	400 MW		500 MW	1 000 MW	400 MW		500 MW	1 000 MW
	220 kV	380 kV	380 kV	380 kV	220 kV	380 kV	380 kV	380 kV
Generating station								
(1) Fixed cost including effect of interest during construction	1.06	1.06	1.06	1.06	1.78	1.78	1.78	1.78
(2) Fuel cost	1.38	1.38	1.38	1.38	1.38	1.38	1.38	1.38
(3) O and M	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Total cost of pit-head generation	2.64	2.64	2.64	2.64	3.36	3.36	3.36	3.36
Transmission								
(1) Fixed cost	0.382	0.660	0.525	0.298	0.676	1.16	0.93	0.503
(2) O and M	0.053	0.091	0.073	0.039	0.053	0.091	0.073	0.039
Total	0.435	0.751	0.598	0.337	0.729	1.251	1.003	0.542
Transmission losses								
(1) Fixed	0.11	0.046	0.054	0.107	0.180	0.077	0.091	0.181
(2) Fuel cost	0.129	0.054	0.065	0.130	0.129	0.054	0.065	0.130
Total cost of transmission losses	0.239	0.100	0.119	0.237	0.309	0.131	0.156	0.311
Total transmission costs	0.674	0.85	0.717	0.574	1.038	1.382	1.159	0.853
TOTAL cost of power delivered	3.31	3.49	3.36	3.21	4.4	4.74	4.52	4.21

[a] This will apply for transmission from the nearest collieries to Madras and Kotah (Rajasthan). Cost of transmitting power to Delhi will be higher (nearest colliery distance is about 450 miles) and to Bombay higher still (nearest colliery distance = 500 miles); this however is compensated by the present lower fuel costs at the collieries supplying power to these areas, as compared with those supplying Madras. Coals costs are however rising.

[b] The following assumptions were made:

(1) Cost of coal/ton = Rs.28/ = ($5.90);
(2) Life of switchgear, transformers, transmission lines etc., according to the schedule prescribed in the Indian Electricity Supply Act (1948);
(3) Annual loss factor = 70%;
(4) Annual operation and maintenance charges for transmission = 1% of capital cost of transmission system;
(5) Cost of 380 kV line = Rs.3 lakhs ($63 000) per mile/circuit;
Cost of 220 kV D.C. line = Rs.2.2 lakhs ($46 200) per mile;
(6) Other assumptions as in Table 6.

Table 8. Cost of power from oil burning station [a]

Capital cost — Rs.850 ($179) per kW sent out

	Cost of power nP/kWh			
	5% interest rate		10% interest rate	
Capital charges	0.92	0.92	1.43	1.43
Fuelling cost: [b]				
(*a*) Including duty and taxes	3.46	–	3.46	–
(*b*) Excluding duty and taxes	–	1.98	–	1.98
Operation and maintenance	0.2	0.2	0.2	0.2
	4.58	3.10	5.09	3.61
Interest during construction [c]	0.08	0.08	0.26	0.26
TOTAL	4.66	3.18	5.35	3.87

[a] Assumptions made are:

Load factor	75%
Life	25 years
Net thermal efficiency	35%
Calorific value of oil	18 000 Btu/lb.

[b] This applies to the west coast region with present prices of furnace oil about Rs.140/tonne including, and about Rs.80/tonne, excluding duties; the price in Madras is about Rs.15/tonne higher and in Delhi about Rs.35/tonne higher.

[c] 9% of capital charges for 5% interest and 18% for 10% interest rate.

Table 9. Cost of power from Tarapur Nuclear Power Station [a, b]

	Cost of power nP/kWh sent out	
	5% interest rate	10% interest rate
Capital charges	1.38	2.14
Fuelling costs	1.20	1.41
Operation and maintenance	0.25	0.25
	2.83	3.80
Interest during construction [c]	0.19	0.56
TOTAL	3.02	4.36

NOTE. — The same unit costs for fabrication and reprocessing in India have been used as in the USA. Actual costs in India are expected to be considerably lower. It is expected that on this account alone the actual power cost will be about 0.2 nP/kWh less than that given above.

[a] This is a boiling water reactor station using slightly enriched uranium oxide fuel. The capacity will be 380 000 kW (net) supplied from two reactors of equal capacity.

[b] Assumptions made are:

Capital cost	Rs.1 271 ($267) per kW sent out
Load factor	75%
Life of plant	25 years
Equilibrium fuel burn-up	16 500/tonne
Enriched uranium prices	According to present USAEC schedule
Plutonium value	$9.50/g of metal

[c] At 13% of capital charges for 5% interest rate and 26% for 10% rate.

Table 10. Cost of power from 400 MW (2 × 200 MW) CANDU type station [a, b]

	Cost of power nP/kWh	
	5% interest rate	10% interest rate
Capital charges:		
On plant	1.33	2.06
On D_2O	0.20	0.40
Fuelling costs	0.64	0.70
Operation and maintenance	0.26	0.26
	2.43	3.42
Interest during construction [c]	0.21	0.69
TOTAL	2.64	4.11

NOTES. — (1) Interest during construction is based on a conservative six-year construction schedule. This could be compressed, effecting significant reductions in the power costs.

(2) In the second case, a 10% interest rate is assumed to apply both during construction and thereafter. If 10% is the total return on capital, with interest during construction at 5%, total power costs would be reduced by 0.35 nP/kWh to 3.76 nP/kWh.

(3) No credit has been taken for plutonium in calculating the fuel costs.

[a] Plant cost: Rs.1 235/kW; D_2O inventory cost: Rs.265/kW; total: Rs.1 500/kW.

[b] Assumptions:

Load factor	75%
Life of plant	25 years
Burn-up	9 000 MWd/tonne
Cost of fabricated fuel	Rs.137/lb

D_2O bears interest charges only.
Half initial fuel charge is capitalised.

[c] 14% of capital charges at 5% interest rate, 28% at 10% interest rate.

coal, the choice for meeting thermal power needs during the next few years will, by and large, lie * between nuclear stations based on natural uranium and coal-based stations.

It can be calculated that the nuclear stations will give cheaper power for meeting base load (75% load factor) requirements than conventional thermal power in all areas where coal costs are about Rs.40/ton or more; in areas where coal costs are higher, they will be competitive even at lower plant utilization. It is a feature of the three regions far from collieries discussed above that a certain amount of hydroelectric capacity can be installed to operate at low plant utilization for the next few decades in order to meet the requirements of the system. Thus, for future growth in these regions beyond the end of the Fourth Five Year Plan (1970-1971), an attractive scheme of development is to increase utilisation of hydroelectric energy designed for low plant utilization operation to meet the variations and peaks of the system, with the base load supplied in the main by increasing the capacity of nuclear stations supplemented by some pit-head generation together with EHV transmission.

Tables 9 and 10 are based on 200 MW reactor units. In time, larger sized reactor units can be installed. This is also true of conventional stations; however, the capital costs of nuclear stations fall much more sharply with increasing size than conventional stations. Nuclear power costs are also falling rapidly with advances in technology.

In the light of this situation, the likely growth rates in electrical energy demand and the potential requirements for nuclear power during the next decades may be estimated. The growth of electrical energy production according to the recently completed First Annual Power Survey of India [9] is

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* A certain amount of oil-fired capacity based on residual oil from refineries could also be installed.

given in Table 12. It will be seen that production increased by about 100% during the Second Five Year Plan and is expected to increase by almost 175% during the Third Plan and about 112% during the Fourth Plan, reaching a figure of about 95 TWh (1 TWh = 10^9 kWh) by 1970-1971. Since electricity is one of the basic commodities for industrialisation, its rate of growth has to be maintained at a high level and indeed it would be desirable for it to remain at approximately the same level as in the Fourth Plan during several future Five Year Plans. Then, the electrical energy requirements in 1986 will exceed 750 TWh. With a population of 700 million, this will mean a *per capita* production of 1 070 kWh. A comparison with Table 1 shows that India will still be far below the present levels in industrially advanced countries. Even if we consider that the average rate of increase over each of the three Five Year Plan periods after 1971 is reduced to 75%, the electrical energy requirements in 1986 will reach over 500 TWh.

As mentioned above, the entire hydroelectric energy potential in the country is around 225 TWh per annum. Moreover, of the total potential of 43 million kW at 60% load factor, 7.5 million can be exploited best in Nepal and about 13.3 million lie in the extreme eastern and north-eastern parts of India, for example, NEFA, Assam, etc., which, for a considerable time to come, will consume not more than a small fraction of this potential. Of the balance, a fair proportion is again situated right on or close to the coal belts where exploitation for power generation will be slow unless it forms part of some multipurpose scheme for both irrigation and power. For these reasons, it is unlikely that more than 150 TWh of hydro-power will become available by 1986. There is thus a balance of at least 350 TWh on Estimate 1 and 500 TWh on Estimate 2 which would have to be met from either conventional thermal sources or nuclear fuels.

Because of this position on coal and oil and the present favourable economics of nuclear power in some of the industrial and rapidly developing regions, it is probable that at least 120 TWh on Estimate 1 and 200 TWh on Estimate 2 would be most economically supplied by nuclear fuels. Even assuming that most of this will be base load power operating at 75% annual plant utilization, the potential demand for nuclear capacity in 1986 will be of the order of 20 million kW on Estimate 1 and over 30 million kW on Estimate 2.

The likely growth rates can also be checked from a regional analysis. A detailed analysis has been carried out for the west coast region (States of Maharashtra and Gujarat) and southern zone (States of Madras, Andhra, Mysore and Kerala). In these regions the estimated increase in energy and capacity requirements will be met economically by following the scheme suggested earlier. On this basis the potential demand for nuclear power in these two regions alone will amount to about 3 million kW in 1975-1976, about 8-10 million kW in 1980-1981 and about 20 million kW in 1986.

The latest estimate of the growth of total installed capacity for India as a whole, together with the contribution expected from nuclear power is as follows:

	Nuclear power (10^6 kW)	Total installed capacity (10^6 kW)
1966	—	12[a]
1971	1.2	24
1976	3	38
1981	8–10	60
1986	18–20	about 90

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[a] 380 MW at Tarapur, Maharashtra State; 400 MW at Rana Pratap Sagar, Rajasthan State; 400 MW at Kalpakkam, Madras State.

The increasing nuclear power programme does not in any way reduce the need also for a rapid expansion in conventional power capacity; for the country as a whole, the major share of power capacity up to 1986 will still come from conventional sources, and a considerable effort will be required, both in the hydroelectric and conventional thermal fields, to meet India's targets. The total installed hydro-power capacity in 1966 will be about 5 million kW, and the total thermal capacity about 7 million kW only.

AVAILABILITY OF NUCLEAR FUELS IN INDIA

Recent investigations have established considerable new reserves of uranium. These could support the entire capacity of nuclear power expected in 1975-1976, even based on natural uranium stations. However, in order to meet the needs of the programme beyond 1975-1976, it is essential to develop methods of extracting energy from India's vast thorium reserves. This will be possible with the help of the plutonium produced in the initial stages of the programme and one way of doing so has been discussed earlier [10] [11]. However, there are a number of alternatives which can be followed and the final choice will depend on technological developments. Of the 1.2 million kW nuclear power to be installed by 1970-1971, 800 MW will be of the natural uranium type using heavy water as moderator and coolant. Plutonium from these reactors and the additional reactors built between 1971 and 1976 can be used either in plutonium-uranium or in plutonium-thorium reactors. A discussion of the various alternatives is not relevant to this paper.

SUMMARY

Analysis shows that world energy consumption will probably reach about 30 000 million tons of coal equivalent per annum by 2000 A.D., and the contribution of nuclear power is expected to be over 2 000 million kW by that date. The under-developed countries have the lowest reserves *per capita* of

Table 11. Comparative costs of delivering power (400 MW) to Bombay, Delhi, Kotah (Rajasthan) and Madras (nP/kWh)

	5% interest				10% interest			
	Bombay	Delhi	Kotah	Madras	Bombay	Delhi	Kotah	Madras
Local coal based station using coal transported by rail	4.1	3.9	3.6	3.8	4.8	4.6	4.4	4.6
Pit-head coal station + EHV transmission	3.3	3.3	3.1	3.3	4.8	4.5	4.2	4.4
Local oil station:								
(*a*) Including present duty and taxes	4.7	5.5	5.4	5.0	5.4	6.2	6.1	5.7
(*b*) Excluding duty and taxes. . . .	3.2	4.0	3.9	3.5	3.9	4.7	4.6	4.2
Nuclear (CANDU)	2.6	2.6	2.6	2.6	4.1	4.1	4.1	4.1

Table 12. All India electrical energy requirements (TWh = 10^9 kWh)[a]

	1955/56		1960/61		1965/66		1970/71		1975/76		1980/81		1985/86
Estimate 1[b]	8.27		16.38		44.92		95.15		170		300		510
% rise		98		175		112		79		77		70	
Estimate 2[c]	8.27		16.38		44.92		95.15		190.39		380.6		761.18

[a] Figures from 1955/61 to 1970/71 according to First Annual Electric Power Survey.
[b] Estimate 1: % rise after 1970/71 reduced to an average of 75% for each five-year plan period.
[c] Estimate 2: rise after 1970/71 continued at 100% for each five-year period.

conventional fuels and will require nuclear energy even to reach and maintain the same living standards as the developed countries now have. The region of South Asia and the Far East will have exhausted its economically exploitable reserves by the end of the century even at the present rate of increase of energy consumption.

It appears that in three widely separated and important regions of India, which are more than 350 miles from the coal fields, nuclear power is likely to be competitive with thermal power produced by coal transported by rail, by pit-head generation with high voltage transmission, or by oil, even with an assumed interest rate of 10%. An expanding programme of nuclear power is envisaged, rising from 1.2 million kW by 1971 to about 3 million kW by 1976, 10 million kW by 1981 and about 20 million kW by 1986. Apart from economics, basic factors in embarking now on the programme are the need to build up experience and produce plutonium to meet future nuclear power needs. The situation in India has been studied in some detail as it constitutes a large under-developed area. It highlights the need for similar studies in other under-developed countries. Only general conclusions can be made on long term expectations, and the immediate scope for nuclear power will depend on the specific situation in each country.

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ABSTRACT - RÉSUMÉ - АННОТАЦИЯ - RESUMEN

A/741 Inde

Les besoins du monde en énergie et l'économie de l'énergétique nucléaire en ce qui concerne plus particulièrement les pays sous-développés

par H. J. Bhabha et M. Dayal

Le mémoire examine des données récentes touchant l'accroissement de la demande d'énergie dans le monde, et les ressources en combustibles traditionnels et combustibles nucléaires. De cette analyse on peut retenir que les programmes devront être élaborés en tenant compte du fait que les ressources traditionnelles dont l'exploitation est rentable ne pourront satisfaire les besoins d'énergie au-delà de l'avenir prévisible, et qu'il faudra recourir, dans une large mesure, à l'énergie nucléaire. Le mémoire donne aussi des évaluations quantitatives. Il contient une étude des diverses parties du monde et montre que dans les régions dites sous-développées les besoins spécifiques en énergie d'origine nucléaire seront encore plus grands que dans les autres régions, car la pénurie relative de combustibles classiques y est plus marquée par rapport à la demande potentielle. Le mémoire fournit aussi de nouvelles données économiques sur les diverses catégories de centrales nucléaires et de centrales de type classique.

Il examine enfin en détail les plus récents éléments de la situation de l'Inde en matière d'énergie traditionnelle et d'énergie d'origine nucléaire, et il traite des prix de revient comparatifs dans les diverses régions du pays, ainsi que de l'évolution de la demande de force motrice et d'énergie dans ce pays. Il fournit des données sur les prix de revient à la centrale atomique de Tarapour, ainsi qu'une ventilation des frais de production et du coût de l'énergie à la centrale atomique du Rajasthan et en d'autres centrales équipées de réacteurs à eau lourde qui doivent être construites en Inde et qui constitueront, pour l'essentiel, la première tranche du programme d'équipement énergétique nucléaire. Le mémoire traite aussi de l'évolution possible du coût de ces réacteurs. Il apparaît qu'à l'heure actuelle l'électricité nucléaire est nettement plus rentable dans certaines régions du pays que l'énergie thermique de type classique, produite soit à partir du fuel, soit à partir du charbon acheminé par rail ou transformé à la mine en énergie électrique qu'il faut transporter sous haute tension. Il est prévu que la puissance installée nucléaire passera de 1, 2 million de kilowatts à la fin du quatrième plan (1970-1971) à 10 millions de kilowatts à la fin du sixième plan (1980-1981) et à quelque 20 millions de kilowatts en 1986 pour augmenter encore par la suite. [Le rythme d'équipement nucléaire serait de près de 400 MW par an pendant la période du cinquième plan (1971-1976) et approcherait un million de kilowatts par an entre 1976 et 1981.] Le mémoire examine les moyens nécessaires à cet effet ainsi que l'approvisionnement en combustibles nucléaires en Inde, et aussi la mise sur pied des installations connexes voulues.

A/741 Индия

Мировые потребности энергии и роль атомной энергии в слаборазвитых странах

Х. Дж. Баба и М. Дайал

В докладе дается анализ некоторых последних данных, касающихся роста потребностей в электроэнергии во всем мире в целом и ресурсов обычного и ядерного топлива. Установлено, что планирование в этой области следует проводить исходя из того, что экономически выгодные для разработки запасы обычного топлива не в состоянии будут обеспечить потребности в энергии в недалеком будущем и что потребуется большое количество атомной энергии. Приводятся некоторые количественные оценки. Затем дается региональный анализ по различным частям мира и устанавливается, что так называемые слаборазвитые районы будут испытывать даже бóльшую необходимость в использовании атомной энергии по сравнению с другими районами из-за относительного недостатка обычного вида топлива с точки зрения потенциальных потребностей. Анализируются новые экономические данные, касающиеся различных типов атомных и обычных электростанций.

И наконец, дается детальный анализ положения на сегодня в Индии в отношении использования обычной и атомной электроэнергии, сравнительных стоимостных оценок обычной и атомной электроэнергии в различных районах и роста потребностей в электроэнергии в Индии. В докладе приводятся стоимостные данные для Тарапурской атомной электростанции, а также статьи расходов и значения стоимости электроэнергии для Раджастанской атомной электростанции и других станций, основанных на тяжеловодных реакторах, которые планируются построить в Индии и которые удовлетворяют основные потребности страны, предусмотренные первой стадией программы развития атомной энергетики Индии. Обсуждаются также перспективы развития стоимостей реакторов этого типа. В докладе показано, что в некоторых районах Индии электроэнергия, производимая атомными электростанциями, несомненно, более экономична, чем

электроэнергия, производимая в результате сжигания нефти и угля, транспортируемых на электростанции по железной дороге, или непосредственного строительства станций вблизи шахт с последующей передачей электроэнергии на большие расстояния по высоковольтным линиям. Полагают, что доля атомных электростанций повысится с 1,2 млн. *квт* установленной мощности, планируемой к концу четвертого плана (1970—1971 годы), до 10 млн. *квт*, запланированных согласно будущим потребностям к концу шестого плана (1980—1981 годы), достигнет приблизительно 20 млн. *квт* к 1986 году и будет затем непрерывно увеличиваться. Полагают, что скорость развития атомной энергетики будет равна приблизительно 400 *Мвт* в год в течение пятого плана (1971—1976 годы) и достигнет 1 млн. *квт* в год в период с 1976 по 1981 год. Обсуждаются пути удовлетворения этих потребностей, доступность ядерного топлива в Индии, а также разработка вспомогательного оборудования.

A/741 India

Demanda mundial de energía y estudio económico de la energía nuclear aplicado especialmente a países subdesarrollados

por H. J. Bhabha y M. Dayal

Se examinan algunos de los datos más recientes sobre el aumento de la demanda de energía en todo el mundo y sobre los recursos de combustibles clásicos y nucleares. Se estima que la planificación en esta materia habrá de basarse en el supuesto de que los recursos clásicos económicamente explotables no puedan satisfacer la demanda más tiempo de lo que en la actualidad se prevé y de que se necesitarán grandes cantidades de energía de origen nuclear. Se formulan algunas previsiones de tipo cuantitativo y se hace un análisis regional de las diferentes partes del mundo, llegándose a la conclusión de que en las denominadas regiones insuficientemente desarrolladas la necesidad específica de energía nuclear será mayor que en otras regiones debido a la escasez relativa de combustibles clásicos en comparación con la demanda potencial. Se examinan los nuevos datos económicos de diferentes tipos de centrales nucleares y clásicas.

Por último, se hace un estudio detallado de la situación actual en la India en lo que respecta a la energía de origen clásico y nuclear, a sus costes relativos en las diferentes regiones del país y al aumento de la demanda y de la potencia instalada. Se facilita información sobre el coste de la central nucleoeléctrica de Tarapur y se detallan los costos de instalación y de producción de la central nuclear de Rajasthan y de otras centrales de reactores de agua pesada que se construirán en la India y que completarán, prácticamente, la primera fase del programa de energía nucleoeléctrica. Se examina también la posible evolución del coste de estos reactores y se demuestra que la energía de origen nuclear es ya sensiblemente más económica en ciertas regiones del país que la energía termoeléctrica clásica a base de fuel-oil o carbón transportado por ferrocarril, o que la generada a bocamina pero con largas líneas de transporte a muy alta tensión. Se prevé que la energía nucleoeléctrica pasará de 1,2 millones de kilovatios de potencia instalada a fines del cuarto plan (1970-1971), a una demanda de 10 millones de kilovatios para fines del sexto plan (1980-1981), y a unos 20 millones de kilovatios en 1986 para alcanzar después una cifra superior (se prevé que el ritmo de instalación de potencia nuclear será de unos 400 MW anuales durante el quinto plan (1971-1976) y se aproximará al millón de kilovatios anuales entre 1976 y 1981). Se estudia la manera de satisfacer estas necesidades desde el punto de vista de la disponibilidad de combustibles nucleares en la India, así como el desarrollo de las instalaciones auxiliares.

Electricity supply in Canada and the role of nuclear power

By W. B. Lewis and T. G. Church*

To discuss the future role of nuclear power in Canada implies that we have evaluated both the reactors we have and the development program for their further improvement. These evaluations are, in fact, presented to this Conference in a series of papers. Together they cover most aspects of a program based on reactors moderated by heavy water and fuelled with natural uranium in pressure tubes. Our belief in this type of reactor has been verified by the operation of the 20MW NPD station [1, 2], and the technical [3] and financial [4] aspects of the construction of the 200MW Douglas Point station. It is supported by extensive testing in in-reactor loops [5]. Conference papers report on safety studies [6], supporting physics data [7, 8], irradiation of important materials [9, 10, 11, 12, 13], fuel engineering [14], experience with heavy water [15], alternative coolants [16, 17, 18] and plans for improved reactors [19, 20]. These evaluations bear out the technical assumptions presented at the 1958 Conference which were based on the much more limited data available at that time.

It is of interest to compare in some detail the electrical energy situation in Canada, as it exists today and as it will probably develop in the short term, with forecasts made at previous conferences. This is done in the next three sections of this paper.

In the fourth section long-range trends in electrical demand and supply are indicated and the role nuclear power will play in meeting Canada's requirements is estimated. The world-wide trends most likely for the economic long-term development of nuclear power are discussed in the last Section. It should be noted that all costs are in 1964 Canadian dollars and that 1 mill = 0.1¢ = $0.001.

ELECTRICAL ENERGY DEMAND, 1955-1980

In 1955 [21] past trends indicated an annual rate of growth of 6%. At that time the forecast was for a decreasing growth rate of 5.5% per year during 1956-60 falling to 4% per year by 1980. Recent estimates are considerably higher. Now records show that actual firm demand for electrical energy increased at an average annual rate of some 6.7% from 1926 to 62 (6.1% for 1952-62). A preliminary forecast to 1980 reflects an average annual growth rate of some 6.4%. Data for the years 1962 and 1980 are shown by province in Table 1.

ELECTRICAL ENERGY SUPPLY, 1955-1980

Table 1 also shows that the fraction of energy supplied by non-hydroelectric sources is expected to increase from 12% in 1962 to 28% in 1980. Even now the increase in conventional thermal plant capacity is greater than forecast in 1955 as shown in Table 2. This table compares the growth of electrical capacity as forecast then [21] with actual growth and our forecast today.

In recent years there have been significant developments which affect the economics and potential supply of all three types of electrical generating stations as follows:

Hydro-electric supply

It is now realized that many earlier forecasts of undeveloped available water power in Canada, based on incomplete preliminary data, tended to be too low. As power surveys are extended, detailed information on new sites will become available and, undoubtedly, substantial additions to present figures of available power will result. Estimates of available power have been based upon existing river flows and do not take into account the benefits of streamflow regulation that would result from the development of storage potential. In addition, it should be pointed out that the figures of available power do not include the power potential of major river diversions that have been investigated but not developed [22]. With this proviso, today's best estimate of undeveloped water power in Canada shows at ordinary six-month flow** about 41 000 MW of available continuous power.

In addition to increased potential hydro-supply, the competitive position of large remote hydro-generating stations (which make up a large fraction of undeveloped resources) is now greatly improved by the successful development of extra-high-voltage transmission lines of 800 to 1 100 km in length.

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** "Ordinary six-month flow" represents continued operation which can be assured during six months of the year on the assumption that the deficiency in power during the remainder of the year can be profitably provided from storage or other means.

Table 1. Firm electrical energy demand and supply — Canada by province

	Energy 1962 (actual)			Present annual load factor, per cent	Energy 1980 (estimate)		
		Supply				Supply	
	Demand 10^6 kWh	Hydro 10^6 kWh	Thermal [a] 10^6 kWh		Demand 10^6 kWh	Hydro 10^6 kWh	Thermal [a] 10^6 kWh
Newfoundland	1 473	1 363	110	65	3 700	3 000	700
Other Atlantic	3 978	1 723	2 255	61	13 300	4 500	8 800
Quebec	40 389	40 059	330	69	125 000	124 500	500
Ontario	39 631	35 244	4 387	66	115 000	48 000	67 000
Manitoba	5 003	4 871	132	65	12 000	11 800	200
Saskatchewan	2 064	86	1 978	51	8 000	4 000	4 000
Alberta	4 121	975	3 146	53	18 000	5 500	12 500
British Columbia	14 222	13 293	929	69	47 000	46 000	1 000
(incl. Yukon and N.W.T.)	(162)	(134)	(28)				
Canada	111 043	97 748	13 295	66	342 000	247 300	94 700
Per cent of total		88	12			72	28

[a] Thermal = conventional-fuelled and nuclear-fuelled.

Plans are now under way to install 500 or 735 kV a.c. transmission lines from three areas of Canada. The design of one of these lines indicates that, at 60% load factor, a 735 kV circuit carrying 1 900 MW over a distance of up to 960 km will transmit power at a cost of 1.4 mills/kWh [23]. It appears that large blocks of power can be delivered over these distances to load centres for a total cost of about 4 mills/kWh (based on provincial government financing) if capital costs at the power generation site are in the $200-225/kW range [24]. This condition may exist at several additional very large hydro-power sites in Canada.

Coal-fired thermal plant supply

Significant changes since 1958 are:

(*a*) Coal prices are showing no tendency to increase. Southern Ontario prices for large long-term supplies from the United States seem to have fluctuated from 33¢ to 31¢ per million kj over the past few years. Because of changing foreign-exchange rates, this represents a reduction in revenue to the supplier of about 10%.

(*b*) Much larger steam-raising and generating units are being used. These tend to reduce capital and operating costs to the low side of the ranges quoted for 200 MW stations in 1955 [21]. Estimates for multi-unit generating stations, using 300 MW units, being constructed in southern Ontario, where nuclear power is likely to be competitive first, showed in 1962 [25]:

Capital cost of coal-fired plant, $110/kW installed.

Unit energy cost at 80% capacity factor and 5.9% for interest plus depreciation:

Fixed charges	1.0
Operating and maintenance	0.3
Fuel	3.1
Total	4.4 mills/kWh

The expectation is that future plants with 500 MW units will deliver power at about 4.0 mills/kWh.

(*c*) The use of other thermal plants designed primarily to operate during periods of low supply from hydroelectric plants is becoming widespread and tends to result in more flexible and adaptable generating systems.

Natural gas

Large efficient natural-gas distribution systems have now been built up. Although generally considered a premium fuel, gas could be made available

Table 2. Comparison of estimates of installed capacity made in 1955 and 1964

(Millions of kilowatts)

	Total		Hydro		Coal, oil, gas		Nuclear	
Date	1955	1964	1955	1964	1955	1964	1955	1964
1951	11.1		10.0		1.1		Nil	
1956	16.0		14.0		2.0		Nil	
1961	22.5	24.9[a]	20.0	20.0[a]	2.4-2.3	4.9[a]	0.1-0.2	
1966	28.0		24.5		3.7-2.9		0.2-1.0	0.22[a]
1971	34.0		27.4	30.5	6.0-4.9		0.6-1.7	0.7-1.2
1976	41.		30.2		8.8-7.5		2.0-3.3	2. -3.
1981	48.	70-80[b]	33.	50-58	11. -8.	15-17	4. -7.	5. -7.

[a] These figures represent actual capacity.

[b] Subject to major corrections resulting from possible power exports and system interconnexions.

for less than 28¢ per million kj to almost any location in western Canada having a large sustained demand. Costs for an efficient generating station made up of 150 MW units have been published [26]. Of course much of this area also has cheap coal available, so the usage of natural gas, except perhaps for supplying peaking power, should not develop. However its presence does put a ceiling on allowable fuel costs over a wide area.

Nuclear contribution

The 1955 prediction was slightly modified when, in 1957, the new and highly promising CANDU design of reactor was adopted. The change set back the first 200 MW(e) reactor to 1965. In August 1964 however the decision was made to construct two 500 MW(e) reactors as a first installment in a projected 2 000 MW(e) nuclear plant for the Ontario system. There is therefore no need to revise the 1955 projection for nuclear power unless possibly upwards in the late seventies.

General

One important change has occurred that affects forecasting. For the last thirty or forty years industry was facing the prospect of an ever rising cost of electric power. Now this is reversed. Thermal-electric stations whether conventional or nuclear now promise lower cost power the greater the demand. Uses for electricity previously thought extravagant are appearing, such as heating of houses and buildings and driveway deicing in winter, balanced by air conditioning in summer. We may still see wider applications of temperature control in cities. From these and other new uses may come an upswing in the demand for electricity. On the other hand, there is new competition from natural gas now piped across the country as a convenient source of heat. We cannot tell what balance will emerge, but so far the demand for electricity is still rising.

NUCLEAR POWER

Most of Canada's electrical energy is now generated and supplied by provincial government organizations. In recent years some large privately owned power systems in British Columbia and Quebec have been absorbed and most new construction has been by provincial agencies. The resulting trend towards larger systems and lower over-all financing costs favours plants with relatively high capital and low operating costs as providing lowest total energy cost, i.e., large nuclear or hydro-generating stations. In addition, the Canadian Government's new policy of allowing the export of power to the USA makes practical the efficient utilization of the very large blocks of power now visualized from these stations.

In the past few years interest rates on new financing for government utilities have risen significantly but it is not known if this will make a major change in the long-term interest rate. The owner for a specific plant under consideration will use his own methods of estimating and meeting capital cost charges. However, we have changed our assumptions for evaluating the capital portion of nuclear plant generating costs as follows:

	1955-58	1964
Life-time interest rate	4½%	5½%
Plant or capacity factor	80%	80%
Initial fuel loading	Interest only	½ depreciated
Reactor life—for depreciation	15 years	30 years
Other structures—depreciation	30 years	30 years
D_2O inventory—depreciation	40 years	30 years
Resulting annual-charge rate against capital	6.35%	6.88%

There now appears to be good reason for following conventional thermal power-station depreciation practice. A lifetime plant factor of 80% might be bettered. In any case, though actual operating practice will not be determined for many years, continuing supplies of nuclear fuel at or below initial costs should result in an increase in the actual lifetime load factor to the advantage of nuclear plants.

Other significant changes since 1958 indicate that nuclear power is more than holding its own with the competition. Much larger reactors and generating units are now envisaged. This scale factor is the largest single reason for the reduction of capital and operating costs below the ranges previously quoted. 500 MW(e) output from a single reactor is considered the norm for use in the early seventies; larger units may predominate after that time.

Reduction in D_2O cost

In 1955-58 D_2O was estimated at $62/kg. First Canadian production in 1966 will cost $45.20/kg and is estimated to fall below $41/kg by 1970 or soon after. These reductions represent a decrease in capital outlay per reactor of roughly 5%. Larger-scale production after that time should result in costs of less than $37/kg of D_2O.

Reduction in fuel costs

The total cost for fabricated CANDU fuel quoted in 1958 [27] is now considered to be much too high. At that time an estimate of $80/kg uranium was made; the 1964 actual cost for first production is $73.20/kg uranium, and the 1970 estimate is $50.00/kg uranium with $32.00 of this for UO_2 pellets. Further reductions in 1958 CANDU fuelling cost data are now evident from the latest estimates of increased net thermal efficiency of 29.1% (25.2% previously) and burn-up of 8 800 MWd/tonne uranium (8 100 previously).

Here is a summary of comparative energy cost estimates in mills/kWh which shows the trend of fuel costs.

	200 MW(e) CANDU [27]	203 MW(e) CANDU [28]	457 MW(e) D_2O Cooled [20]
Date of estimate	1958	1963	1964
Fixed charges	3.18	3.56	2.50
Fuel costs	1.85	0.9	0.60
Operation, maintenance and supplies	0.75	1.0	0.73
Total (mills/kWh)	5.78	5.46	3.83

Regional variations

It will be noted from Table 2 that our forecasts of nuclear capacity installed up to 1980 lie within the ranges given in 1955 [21]. Essentially all this capacity represents plants for southern Ontario to be built in competition with imported coal-burning stations of large size. (Ontario uses 35% of Canada's power output.) There is no clear requirement for nuclear-electric generating stations to be in operation elsewhere much before 1980 unless the province of Quebec (which uses 38% of Canada's power output) is unable to develop all the large remote hydroelectric sites available to it at costs resulting in delivered power at load centres competitive with nuclear power. If engineering studies on the development of watersheds draining into the east side of James Bay are available in a few years, this situation can then be properly evaluated.

The Maritime Provinces are a high-cost power area by Canadian standards. However, system interconnexion plus the resulting development of large (for the local area) hydroelectric sites and construction of thermal plants using local coal and the fact that for many years the size of the annual load growth will be too small to accommodate efficiently large nuclear-electric units, all lead to the conclusion that not much more than a prototype nuclear plant will be in operation before 1980.

The possibility of nuclear-electric plus steam plants in the Canadian North has intrigued many people. Such occurrences will be so rare that they are not considered in this paper.

THE CANADIAN SCENE AFTER 1980

Electricity demand

Due to the increasingly extreme competition between types of energy in Canada and also rapidly changing technologies, forecasts beyond 1980 are extremely difficult to make. A projected increase of 6% per year may be valid for a few years.

Electricity supply

Developments show that nuclear generating stations can be called upon to meet demands other than a base load at 80% capacity factor. It is therefore assumed that, in the next 15 years, the fraction of generating capacity in a system which can be made nuclear to advantage will grow and be in excess of this base-load requirement.

After 1980 most of the new plants being constructed in Ontario should be nuclear, i.e., up to 1 200 MW(e) per year. The same situation should exist in Quebec. New plants in the Maritime Provinces should also be nuclear, the annual capacity required being about 300 MW(e). In western Canada the first nuclear generating station will probably be under construction in the Province of Manitoba. Therefore the total Canadian annual requirement for new nuclear plants in operation in the early 1980's should be about 2 000 to 2 500 MW(e).

Multi-unit CANDU-type stations

When the costs we forecast for large multi-unit CANDU-type generating stations have been realized, further development of remote hydroelectric sites will be uneconomic. Estimates from preliminary evaluation studies are about 3.5 mills/kWh for a station consisting of four 457 MW(e) reactors and about 3.0 mills/kWh for two 750 MW(e) reactors [28, 20]. These forecasts are based on the annual-charge rate against capital quoted above, on conditions in southern Ontario, and on a natural uranium fuel cost estimate which allows \$17.60/kg of U_3O_8 as yellow cake.

There has been much discussion of, and interest in, the wisdom of basing a long-term power program on known "reserves" of uranium. Estimates of uranium required for large-scale utilization of the CANDU-type reactor were made in 1958 [29]. These are still valid, although conservative for today's more efficient designs.

Until a large and expanding international commercial market has existed on a normal industrial base for a considerable number of years, no meaningful long-term estimates of mineral reserves are feasible. The uranium mining industry should be in this position in the mid-1980s. The long-term view of the spectacular rise and fall of this industry in Canada is to conclude that, as a result of only six years of prospecting by normal techniques, we have now developed reserves [30] which will provide uranium at reasonable prices to meet foreseeable demands for decades.

THE WORLD SCENE IN THE LONG TERM

The future of economic nuclear power will involve changes of practice dictated by changes of prices and costs. In particular, the following changes of circumstances are expected:

(*a*) Rapid and extensive growth of nuclear power will demand an inventory of the fissile uranium-235 that exceeds the known reserves of low-cost uranium ores, so the cost of uranium will rise.

(*b*) Discovery of further uranium ores, if extensive, would at least check the rate of rise in the cost of uranium.

(*c*) Technically improved processes will reduce the cost of extracting uranium from the lower-grade ores.

(*d*) As the application of nuclear power extends, the unit costs of reprocessing and refabricating fuel will fall because of the increased scale of such operations.

(*e*) Although to a considerable degree subject to government control, the value of the artificial fissile materials U^{233} and plutonium will follow the cost of U^{235} as it rises.

(*f*) The availability of separated U^{233} and plutonium from fuel reprocessing will lead to the economic utilization of thorium for nuclear power. (Even if thorium becomes the major source of nuclear power, the price of thorium will not rise proportionally with the price of uranium.)

(*g*) Provision of the large inventories required for any extensive introduction of fast breeders would cause a large demand for fissile material extending over several times the doubling time of the breeders. Afterwards the demand for uranium would be much less than in the absence of the breeder reactors.

(*h*) A ceiling will be set to the value of uranium by the development of processes for the production of neutrons or of nuclear power by physical techniques other than the fission chain reactions. The two independent techniques already foreseen are (i) high-energy excitation of heavy nuclei and (ii) thermonuclear fusion of deuterium. The first produces neutrons and the second both neutrons and power (unless the neutrons have to be consumed in the intermediate step of producing tritium).

At intervals, over periods of ten years or more, major changes of practice are likely to result from these changes of circumstances that will succeed one another in a manner and at times that cannot be determined long in advance.

Several forecasts of the future of nuclear power have been published and there is a risk that action may be taken on the conclusions without regard to the restrictive assumptions that were necessary in order to allow for possible changes of circumstances.

Although the future possibilities are many and varied, there are some close relations between circumstances and economic practice that may be recognized.

Assuming the yield of U^{235} from an isotope separation plant is 4.74 g/kg U (i.e., 2/3 of the content in the natural-uranium feed), the recent low market price of $13/kg U would contribute $3.64/g U^{235}. Processing and separative work in large plants adds about $6/g U^{235}.

The residual plutonium in spent fuel from natural uranium at 10 000 MWd/tonne uranium burn-up in CANDU reactors is about 2.75 g fissile plutonium/kg U. When the scale of reprocessing is sufficiently great to bring the cost down to $20/kg U, this would contribute $7.3/g to the cost of plutonium, and provided fuel fabrication costs are not much higher than for separated U^{235}, such plutonium would compete with separated U^{235} as a seed or spike fuel in thermal reactors in which the neutron spectrum is cool enough to preserve a high fission neutron yield (η) from plutonium.

It has been shown [31, 32] that U^{235} + thorium fuel cycles are close to competing with natural uranium fuel at the present time and even a doubling of the cost of natural uranium ore could change the balance in favour of U^{235} + Th with or without recycling. The position cannot be stated more definitely because it depends on relative costs of fuel fabrication and reprocessing methods that are not yet established on an adequate scale to have reached any economic balance.

In several nuclear power systems of widely different types the contribution to the cost of power attributable to the cost of the uranium ore concentrates is now very low. For example, at the present low market price of $13/kg U the contribution may be less than 0.2 mill/kWh, and details of fuel financing methods are not very important. A price rise by a factor of, say, four would make the contribution significant and the financing details important. Typical relevant costs for three widely different fuel cycles are given in Table 3. It will be noted that for the CANDU system of natural-uranium fuelling without reprocessing the inventory charges are almost negligible. In systems obtaining a higher energy yield by recycling the inventory charges are larger and are likely to predominate.

Since it appears from this table that even the high suggested price of $250/kg U would not contribute a crippling component to the cost of power using a well chosen fuel cycle, it is necessary to consider the time when such high costs may prevail. Here there is extreme uncertainty. Uranium is abundant in the earth's crust at 4 parts per million and the amount within 1.6 km of the surface of the land mass is 2.5×10^{12} tonnes. There is also 4.5×10^{9} tonnes of uranium in the oceans.

For a world population of 14 000 million supplied at 1 kW *per capita* (or 7 000 million at 2 kW *per capita*) and 50 000 MWd/tonne burn-up at 35% efficiency, the demand is only 24 million tonnes per century. At present the world enjoys low-cost uranium separated by geochemical processes into relatively rich ores. Their extent is largely unknown. It is conceivable that techniques could be developed to process rocks averaging 4 ppm recoverable uranium for $1/tonne and thereby contribute only $250/kg U, but the incentive for developing such techniques has not yet arisen. It seems likely that the demand for many centuries can be met from somewhat higher grade deposits for less than $250/kg U. When the price rises, a ceiling may be set by the development of other nuclear processes for the generation of neutrons that can produce U^{233} and plutonium from the abundant isotopes of thorium and uranium.

In summary it appears that the economic optimum fuel cycle will change as nuclear power extends;

Table 3. Examples of contribution of uranium cost to power cost

	Power rating of total fuel in inventory r kW(th)/kg U	Burn-up B MWd/kg U	Efficiency e	Contribution of uranium cost at $P/kg U to power cost[a] c mill/kWh	Annual charge rate on inventory a %/year	Contribution of uranium cost at $P/kg U to power cost			
						c mill/kWh	$P = 13$ c mill/kWh	$P = 42$ c mill/kWh	$P = 250$ c mill/kWh
CANDU (natural uranium no reprocessing)	15	10	0.3	$\frac{P}{0.3}\left[\frac{1}{240}+\frac{a^*}{10\,500}\right]$	7	$0.0151P$	0.195	0.63	3.75
					10	$0.0155P$	0.20	0.65	3.9
CANDU (with plutonium recycle)	15	25	0.3	$\frac{P}{0.3}\left[\frac{1}{600}+\frac{a^*}{10\,500}\right]$	7	$0.0073P$	0.095	0.31	1.83
					10	$0.0081P$	0.105	0.34	2.02
U^{235}-Th-U^{233} (with exhaustive recycle)	6	50	0.35	$\frac{P}{0.35}\left[\frac{1}{1\,200}+\frac{a}{4\,200}\right]$	7	$0.0071P$	0.093	0.30	1.78
					10	$0.0092P$	0.119	0.385	2.29
Fast breeder plutonium cycle for 20-year inventory doubling time (i.e. 3.53%/year increase)	2.2	700	0.4	$\frac{P}{0.4}\left[\frac{1}{16\,800}+\frac{a-3.53}{1\,540}\right]$	7	$0.0058P$	0.075	0.24	1.45
					10	$0.0107P$	0.138	0.45	2.66

[a] c = Make-up contribution + inventory contribution $= \frac{P}{e}\left(\frac{1}{24B}+\frac{a}{700r}\right)$. For CANDU without reprocessing the effective inventory is halved, so $a^* = 0.5a$; with plutonium recycle the inventory is reduced, so $a^* \simeq 0.8a$.

at present fuel reprocessing does not necessarily confer any advantage. When the demand for the inventory of fissile material becomes so large that the cost rises and at the same time the cost of reprocessing falls because of the increased scale of operations, economics will favour reprocessing. Still later it will become important to keep inventories to a minimum, and eventually burn-up may be sacrificed when a ceiling value is set on fissile material by the artificial production of U^{233} or plutonium. The changes of economic balance are likely to be quite significant, and it will not pay at any time to employ the process that was optimum ten years ago or will be optimum ten years or more later. The same applies to the working of uranium ores.

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ABSTRACT - RÉSUMÉ - АННОТАЦИЯ - RESUMEN

A/1 Canada

L'approvisionnement en électricité au Canada et la place des centrales nucléaires

par W. B. Lewis et T. G. Church

La mise au point, la construction et l'exploitation des centrales nucléaires utilisant l'uranium naturel comme combustible et l'eau lourde comme modérateur et comme caloporteur ont été poursuivies avec succès, conformément aux plans indiqués lors de la Conférence de 1958. Le prix de revient nouvellement calculé, de même que les détails de la construction des génératrices du type CANDU ont fait l'objet de mémoires qui seront présentés à cette Conférence. La pratique ainsi que les résultats des calculs les plus récents ont donc fourni les bases de ce mémoire.

Il est intéressant de rappeler les prévisions d'offre et de demande faites lors des conférences antérieures en ce qui concerne l'électricité au Canada et de les comparer aux dernières prévisions établies en fonction des nouvelles conditions économiques. La capacité installée est supérieure aux prévisions et d'importants changements se sont produits dans les différents systèmes de production de l'électricité (hydroélectriques, combustibles fossilifères et nucléaires), changements qui ont fortement modifié les facteurs économiques de chaque système.

Les techniques modernes de l'aménagement hydroélectrique des cours d'eau ont permis d'augmenter le potentiel des projets individuels. Par ailleurs, les lignes de transmission à longue distance étant moins coûteuses, il est possible d'implanter, dans des emplacements appropriés et lointains, des centrales hydroélectriques géantes qui desserviront les grands centres à des prix concurrentiels, c'est-à-dire à raison de 4 millièmes de dollar par kilowattheure, avec les méthodes de financements accordées aux gouvernements provinciaux.

Le combustible fossile destiné aux centrales thermiques est maintenant moins coûteux et on peut se le procurer plus facilement dans la plupart des régions canadiennes. Des systèmes de production de vapeur plus grands et plus efficaces rendent aussi possible la production d'une électricité d'origine fossile à un coût d'environ 4 mills/kWh.

Notre programme d'implantation de centrales nucléaires a, lui aussi, fait des progrès en ce qui concerne le prix de revient du kilowattheure. Nous prévoyons que la construction et l'exploitation de très grandes centrales permettront des économies; celles-ci, ajoutées aux diminutions des prix du combustible et des matériaux spéciaux, donnent lieu de croire qu'il sera possible de produire de l'électricité à raison de moins de 4 mills/kWh. L'implantation des grandes centrales nucléaires canadiennes se réalisera, comme prévu, au cours des années 70.

Plusieurs raisons permettent de croire que vers 1980 la proportion des centrales nucléaires par rapport aux autres types de centrales électriques augmentera très rapidement.

Les prévisions révèlent que les besoins en électricité s'intensifieront de plus en plus dans le futur et que vers 1980 toutes les régions canadiennes verront leurs besoins accrus d'année en année.

Vers 1980, la mise en valeur des ressources hydrauliques les plus accessibles aura atteint son point culminant. De plus, les centres importants sont éloignés des sources de combustibles fossiles bon marché.

Par contre, la réduction du prix des matériaux et des frais d'exploitation permettra aux grandes centrales nucléaires de produire de l'électricité à meilleur compte que prévu originellement, et le coût des nouvelles centrales continuera à diminuer. Les prix des matériaux spéciaux seront inférieurs et le coût du combustible restera à la fois modique et stable pendant très longtemps après 1980.

Il ne sera pas possible d'établir des prévisions pourvues de sens, quant à l'obtention du combustible à un bas prix, tant qu'une demande vraiment commerciale n'aura pas été établie et n'aura pas été satisfaite pendant au moins quelques années (c'est-à-dire après 1980). Le prix de l'uranium, cependant, ne représente qu'une petite fraction du coût total

de la production de l'électricité dans une centrale ayant un réacteur du type CANDU. De plus, si ce prix augmentait au point de multiplier par deux les chiffres prévus pour les années 80 il serait avantageux de recourir au recyclage du combustible et à des convertisseurs uranium-thorium pour stabiliser le coût de l'électricité produite dans ces centrales nucléaires. De cette façon le coût total ne serait guère plus élevé que celui prévu pour l'uranium naturel non recyclé.

A/1 Канада

Энергоснабжение и роль атомной энергетики в Канаде

У. Б. Люис, Т. Дж. Черч

Успешно продолжаются (в тех масштабах, о которых сообщалось на Женевской конференции 1958 года) разработка, строительство и эксплуатация тяжеловодных энергетических реакторов на природном уране, в которых в качестве замедлителя и теплоносителя используется тяжелая вода. В других докладах, представленных на данную конференцию, приводятся последние оценки по стоимости электроэнергии и подробные данные о строительстве реакторов типа CANDU. В данном докладе освещаются в основном проблемы эксплуатации и строительства в свете упомянутых оценок и применительно к вышеуказанной конструкции реакторов.

Интересно сравнить прогнозы в отношении потребностей в электроэнергии и производства электроэнергии в Канаде на период 1955—1980 гг., сделанных на предыдущих Женевских конференциях, с последними аналогичными оценками и пересмотренными экономическими данными. Установленная мощность оказалась выше предсказываемой; значительные успехи были достигнуты в использовании гидроэнергии, ископаемых видов топлива и атомной энергии, что оказывает большое влияние на экономику каждой системы.

Современный технический подход к каскаду гидроэлектростанций увеличил потенциальные возможности отдельных гидроэнергетических систем, и возможность использования в настоящее время экономичных дальних линий высоковольтных передач позволяет разрабатывать очень крупные блоки гидроэлектростанций для отдаленных районов с использованием вырабатываемой ими электроэнергии в центрах с большими потребностями в электроэнергии по конкурентной стоимости, например ~ 0,4 *цент/квт · ч* при условии обеспечения финансирования со стороны правительственных органов на местах.

В настоящее время ископаемые виды топлива для тепловых электростанций дешевле и более доступны в большинстве районов Канады, чем раньше. Поэтому более крупные и эффективные парогенераторные установки также будут производить электроэнергию по стоимости порядка 0,4 *цент/квт · ч*.

Работы в Канаде в области разработки ядерных энергетических реакторов продолжают успешно развиваться. Снижение стоимости ядерного топлива и специальных материалов в сочетании с предполагаемой экономией, обусловленной строительством и эксплуатацией очень крупных атомных электростанций, дает возможность добиться производства атомной электроэнергии по стоимости ниже 0,4 *цент/квт. · ч*. В 70-е годы сооружение атомных электростанций должно продолжаться согласно ранее разработанным планам.

По некоторым причинам приблизительно к 1980 году представляется вероятным очень быстрое увеличение доли атомных электростанций в общем числе строящихся электростанций других типов.

Перспективные оценки свидетельствуют об увеличении в будущем потребностей в электроэнергии, и к тому времени ежегодное увеличение этих потребностей во всех районах страны будет значительным.

Освоение основных известных источников гидроэнергии будет по существу завершено. Важные районы страны расположены далеко от источников дешевого ископаемого топлива.

С другой стороны, снижение эксплуатационных расходов и стоимости материалов приведет к тому, что крупные атомные электростанции будут производить более дешевую электроэнергию, чем планировалось первоначально, и стоимость электроэнергии, производимой новыми станциями, будет продолжать падать. Снизится стоимость специальных материалов, и в течение значительного периода времени после 1980 года должна стабилизироваться и стать более низкой стоимость ядерного топлива.

Дать перспективные оценки относительно будущих поставок ядерного топлива по таким низким ценам будет невозможно до тех пор, пока не будут установлены и проверены в течение по крайней мере нескольких лет например, после 1980 года действительные коммерческие потребности в ядерном топливе. Однако уран образует лишь небольшую составляющую общей стоимости электроэнергии, производимой реакторной энергетической системой CANDU. Более того, если стоимость урана возрастет вдвое по сравнению с цифрами, предсказываемыми на 1980 год, то к этому времени станет конкурентоспособным использование повторного топливного цикла и уран-ториевых реакторов-конвертеров, что приведет к стабилизированию стоимости электроэнергии, производимой этими атомными энергетическими установками, на уровне, не превышающем значительно уровня, предсказываемого для цикла на природном уране без повторной переработки топлива.

A/1 Canadá

Suministro de energía eléctrica en Canadá y misión de la energía nuclear

por W. B. Lewis y T. G. Church

El desarrollo, la construcción y la explotación de los reactores de potencia de uranio natural moderados y refrigerados por agua pesada han continuado con éxito, de acuerdo con las líneas ya indicadas en la Conferencia de Ginebra de 1958. En otros informes presentados a esta Conferencia de 1964 se da cuenta de las últimas estimaciones de costes de la energía y de los detalles de construcción de esta familia de reactores del tipo CANDU. La experiencia de funcionamiento y de construcción, juntamente con las estimaciones y proyectos, proporcionan las bases para esta memoria.

Es interesante comparar los pronósticos de demanda y producción de energía eléctrica en Canadá que se hicieron en las Conferencias anteriores para el período 1955-1980 con las últimas estimaciones y datos económicos revisados. La potencia instalada está por encima de las previsiones y ha habido progresos importantes en la producción de energía, tanto hidroeléctrica como térmica de combustible fósil y nuclear, que tienen un gran efecto sobre la economía de cada sistema.

El moderno enfoque técnico de los sistemas fluviales ha incrementado el potencial de los sistemas hidroeléctricos individuales, y el uso, ahora posible, de líneas de transmisión económicas a larga distancia, ha asegurado el aprovechamiento de grandes cantidades de energía hidroeléctrica de localización muy remota, para su uso en los centros de consumo a precios de competencia, del orden, por ejemplo, de 4 milésimas de dólar por kWh, con financiación por los gobiernos provinciales.

El combustible fósil para centrales térmicas es ahora más barato y más fácilmente asequible que antes en una gran parte del Canadá. Por este motivo, con unidades más grandes y con mayor rendimiento en la generación de vapor se producirá energía eléctrica a precios del orden de las 4 milésimas por kWh.

Nuestro desarrollo en reactores nucleares de potencia ha continuado a ritmo creciente. Los precios más bajos del combustible y de los materiales especiales, unidos a las economías que se espera resulten de la construcción y explotación de centrales de gran capacidad, prometen una producción de energía a precios inferiores a 4 milésimas por kWh. Es de esperar que, durante el decenio 1970-1980, la instalación de centrales nucleares de potencia prosiga de acuerdo con los pronósticos previos. Parece probable, por varias razones, que hacia 1980 el número de centrales nucleares aumente muy rápidamente con respecto al de centrales de otros tipos que se construyan.

Los pronósticos muestran demandas crecientes de energía eléctrica y, para entonces, los incrementos anuales en cada una de las regiones del país habrán de ser considerables. El aprovechamiento de los recursos hidroeléctricos naturales más importantes estará prácticamente terminado y habrá aún importantes regiones alejadas de las fuentes de combustible fósil a bajo precio. Por otro lado, la reducción en los costes de los materiales y en los de explotación permitirá que las grandes centrales nucleares produzcan energía más barata que lo que se pensó al principio y el coste de las nuevas centrales aún bajará más. Los costes de los materiales especiales serán más bajos y los precios del combustible habrán de ser bajos y estables durante un período considerable de tiempo, después de 1980.

No será posible hacer pronósticos sensatos con respecto a los suministros de combustible nuclear a tales bajos precios hasta que se haya creado y puesto en práctica una verdadera demanda comercial durante algunos años por lo menos (esto es, después de 1980). El uranio, sin embargo, representa solamente una pequeña fracción del coste total de la producción de energía eléctrica en una central tipo CANDU. Además, si su coste duplica las cifras previstas para los años posteriores a 1980, el reciclado del combustible y los reactores convertidores de uranio-torio se harán competitivos y estabilizarán el coste de la energía producida en esas centrales nucleares a un nivel que no será muy superior al estimado para el ciclo de uranio natural sin recuperación.

Le programme nucléaire français

par J. Cabanius* et J. Horowitz**

Le programme nucléaire français est conditionné par des données permanentes qui, au-delà des aléas de la conjoncture, déterminent la politique énergétique à long terme. Ce sont: l'augmentation régulière de la consommation d'énergie électrique, la limitation des possibilités hydroélectriques et la limitation des ressources du sol national en charbon, lignite, pétrole et gaz naturel.

Dès 1955, il était évident que l'augmentation inéluctable et relativement très rapide des besoins en calories pour la production d'énergie électrique imposerait à très court terme des importations régulièrement croissantes. A la même époque, il était possible d'envisager la construction de centrales électro-nucléaires à partir des réalisations industrielles du Commissariat à l'énergie atomique: mise en service en 1952 du premier réacteur expérimental refroidi au gaz sous pression, EL2 et construction des réacteurs plutonigènes de Marcoule, refroidis au gaz et modérés au graphite, G1, G2, G3, à laquelle Electricité de France fut associée pour les installations de production d'électricité.

Electricité de France prit alors position sur un programme nucléaire de 850 MW(e) (y compris G2 et G3) dont l'achèvement était envisagé pour 1966-1967 et qui était susceptible de fournir à cette date environ 5% de la production nationale totale. Cette fraction était suffisamment importante pour que l'expérience acquise puisse être considérée comme significative; elle n'était pas trop élevée pour éviter une augmentation notable du volume des investissements annuels et une dégradation trop sensible du compte d'exploitation, compte tenu des coûts de premier établissement et des prix de revient finaux que l'on pouvait évaluer alors.

Des décisions ultérieures, prises notamment à l'occasion du quatrième Plan de modernisation, portèrent à 7,5% ou 8% en 1970–1971 la part de l'énergie nucléaire dans la production nationale, le but essentiel du programme restant celui qui avait été défini dès l'origine et rappelé par MM. Ailleret et Taranger à la Conférence de Genève de 1955, à savoir la mise au point aussi rapide que possible d'un modèle de centrale nucléaire compétitif avec les centrales thermiques classiques, tout en conservant la préférence initiale vers les réacteurs à uranium naturel. Le développement des études n'a fait que confirmer l'intérêt de l'utilisation de l'uranium naturel, dû non seulement à la multiplicité des sources d'approvisionnement et aux avantages qui en résultent, mais aussi à la simplicité de son cycle de combustible qui n'exige que des investissements modérés, des installations peu complexes et dont l'économie ne comporte que très peu de facteurs d'incertitude.

L'objet du présent mémoire est d'abord de rappeler les prévisions de consommation d'électricité en France dans les vingt prochaines années, de faire ensuite le point sur l'état d'avancement actuel du programme français de centrales nucléaires et d'indiquer enfin ses perspectives de développement à court et moyen terme.

ÉVOLUTION DE LA CONSOMMATION D'ÉLECTRICITÉ EN FRANCE

Le bilan ci-dessous a été établi à partir des hypothèses de travail de base considérées dans les études préliminaires de la Commission de l'énergie du Commissariat au Plan:

L'augmentation de la consommation totale d'énergie électrique serait de 7,2% par an, en tenant compte de l'évolution probable de la population et de celle de la production intérieure brute.

Le développement de l'hydraulique se poursuivrait au rythme actuel jusqu'à épuisement à peu près total des sites actuellement considérés comme rentables.

Le thermique "fatal" correspond à la production des charbonnages de France, de la sidérurgie et des tiers, et à la production d'Electricité de France à partir des combustibles pauvres — lignite, gaz de hauts fourneaux — et du gaz de Lacq.

L' "autre thermique" correspond à la production à partir de combustibles riches — charbon marchand, fuel ou gaz naturel importé — et au nucléaire (voir tableau 1).

En ce qui concerne la puissance installée, le bilan est moins simple à établir. Le tableau précédent correspond sensiblement à un accroissement de la puissance mise en service en thermique de 6 900 MW entre 1965 et 1970, 10 000 MW entre 1970 et 1975 et de 35 000 MW entre 1975 et 1985. Il est rappelé que les décisions concernant ces équipements sont généralement prises cinq ans à l'avance.

Le tableau 2 résume la comparaison des besoins

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* Electricité de France, Direction de l'équipement.

** Commissariat à l'énergie atomique, Direction des piles atomiques.

Tableau 1. Prévisions d'évolution de la consommation

TWh	1965	1970	1975	1985
Consommations (pertes comprises)	103	150	205	410
Importations nettes	2	2	1	0
Hydraulique	43,5	51	59	70
Thermique	57,5	97	145	340
Thermique "fatal"	26,1	28,4	29	30
"Autre thermique"	31,4	68,6	116	310

en énergie et des ressources nationales, sans tenir compte du nucléaire.

Il résulte des tendances indiquées dans ce tableau, d'une part, qu'il s'ouvre un champ très vaste aux centrales nucléaires en raison du développement probable de la demande d'électricité et des possibilités limitées de l'hydraulique et, d'autre part, que l'introduction de l'énergie nucléaire pourrait avoir une influence très importante sur le taux de couverture des besoins en énergie par les ressources nationales.

LE DÉVELOPPEMENT DES CENTRALES NUCLÉAIRES EN FRANCE

Rappel du programme en cours

Les réalisations actuellement en service ou en construction sont reportées dans le tableau 3.

La filière uranium naturel-graphite-gaz carbonique

Le programme français est essentiellement axé sur le développement en priorité des réacteurs à uranium naturel modérés au graphite et refroidis au gaz carbonique. Avec les réacteurs G2 et G3, respectivement en service depuis avril 1959 et avril 1960, la France dispose d'une expérience précieuse du fonctionnement de réacteurs de ce type. Cette expérience peut être considérée comme extrêmement satisfaisante, après quelques difficultés initiales de mise au point, tant pour la disponibilité générale de la centrale et le comportement du combustible que pour le fonctionnement des équipements dont certains étaient mis en œuvre pour la première fois au monde: caisson en béton précontraint, installations de chargement-déchargement du combustible fonctionnant réacteur en marche.

Le programme d'Electricité de France, qui bénéficie de la collaboration technique du CEA, comprend actuellement la réalisation des trois tranches de la centrale de Chinon et de la première tranche de la centrale de Saint-Laurent-des-Eaux. Ces quatre réacteurs représentent un montant total de dépenses de 1 900 millions de francs, formant l'essentiel du programme nucléaire d'EDF.

D'un réacteur au suivant, le développement général a été dans le sens de l'économie, de la simplification et de la sécurité. Cependant dans le même temps on a voulu, dans la mesure du possible, explorer des solutions techniques différentes; en particulier en ce qui concerne le caisson, une solution "acier" a été adoptée pour EDF1 et EDF2 et a d'ailleurs conduit, après quelques difficultés, à des réalisations qui comptent parmi les plus remarquables dans ce domaine. G2, G3, EDF3 et EDF4 ont au contraire des caissons en béton précontraint, solution qui présente plus de possibilités d'adaptation.

Mais la caractéristique essentielle dans l'évolution des projets est incontestablement l'augmentation des puissances unitaires, qui s'est effectuée en un nombre minimum d'étapes qui ont également permis un alignement sur les puissances normalisées des centrales classiques. C'est ainsi qu'après EDF1 (70 MW(e) net avec un groupe de 83 MW), EDF2 a été équipé de 2 groupes turbo-alternateurs de 125 MW et EDF3 et EDF4 sont équipés de 2 groupes de 250 MW. Il est apparu que la diminution du prix par kW installé est importante lors-

Tableau 2. Evaluation des besoins nouveaux

(Tonnes d'équivalent charbon)

	1960	1965	1970	1985
A. Consommation totale d'énergie	130	160	190	330
B. Ressources nationales				
Charbon [a]	58,2	55,3	50	30-40 (?)
Pétrole	2,8	4,0	17	25-40 (?)
Gaz naturel	4,2	7,8		
Hydraulique	16,1	17,4	20,5	30
Total B	81,3	84,5	87,5	85-110
Rapport B/A	62,5%	53%	46%	26 à 33%

[a] Y compris lignite EDF.

Tableau 3. Réacteurs de puissance français

Nom	G2	G3	EDF1	EDF2	EDF3	SENA	EL4	EDF4
Emplacement	Marcoule	Marcoule	Chinon	Chinon	Chinon	Chooz	Brennilis	St-Laurent-des-Eaux
Date de mise en service[a]	1959	1960	1963	1965	1966	1966	1967	1968
Type								
Combustible	U nat.	U nat.	U nat.	U nat.	U nat.	U enr.	U nat.[b]	U nat.
Modérateur	Graphite	Graphite	Graphite	Graphite	Graphite	H_2O	D_2O	Graphite
Refroidisseur	CO_2	CO_2	CO_2	CO_2	CO_2	H_2O	CO_2	CO_2
Puissance électrique nette (MW)	40	40	70	200	480[c]	266[d]	75	480

[a] Date de couplage au réseau électrique.

[b] Le premier jeu sera en uranium légèrement enrichi.

[c] Puissance correspondant à la saturation des groupes.

[d] A moitié avec des producteurs belges d'électricité.

qu'on accroît la puissance unitaire, et que cette filière serait plus vite compétitive pour des unités de grande puissance: un réacteur nucléaire de 400 à 500 MW(e) est bien à l'échelle des grands réseaux modernes interconnectés. Cette évolution vers de grandes puissances unitaires a été ensuite suivie dans la plupart des autres pays.

Pour que cette augmentation de puissance ne se traduise pas par une augmentation de la complexité des structures et en particulier par une multiplication excessive du nombre de canaux, il a été nécessaire parallèlement de développer des éléments combustibles qui conservaient la simplicité fondamentale de la conception des combustibles de la filière — élément unique, massif, constitué par un barreau d'uranium métallique dans une gaine d'alliage de magnésium — mais qui permettraient un accroissement de l'énergie dégagée par élément. Alors que dans G2/G3 un élément combustible ne pèse que 4 kg et ne produit, en moyenne, qu'un peu plus de 300 kW(e) par tonne, dans EDF3 et EDF4, l'élément combustible pèse 10 kg et produit 1 200 kW(e) par tonne. Ceci permet de n'augmenter le nombre de canaux que dans un rapport de 3, alors que la puissance électrique est multipliée par un facteur supérieur à 10.

Enfin un nouveau pas dans le sens de la simplification a été fait avec EDF4: en utilisant les possibilités techniques de réalisation de grandes enceintes en béton précontraint, il a été décidé d'incorporer la totalité du circuit de gaz carbonique dans le caisson, ce qui conduit à une architecture de centrale très compacte, plus économique et présentant une sécurité intrinsèque accrue.

Aboutissement d'un important effort de développement technique et de simplification industrielle, tenant compte de l'expérience acquise dans la réalisation des unités précédentes, EDF4 devrait se présenter ainsi comme une "tête de série" susceptible d'être reproduite à plusieurs exemplaires, si elle se confirme comme économiquement rentable.

EDF3 constitue actuellement la référence la plus valable pour le coût d'investissement d'une centrale nucléaire de 500 MW(e), car toutes les commandes sont passées et la construction est suffisamment avancée pour que le devis initial puisse être considéré comme respecté.

Pour EDF4, le coût n'est pas défini avec la même précision; cependant une grande partie des équipements sont identiques à ceux d'EDF3, et l'adoption du concept intégré doit permettre une réduction du prix; dans le cas particulier de la centrale de Saint-Laurent-des-Eaux, cette réduction risque d'ailleurs d'être compensée en partie par les dépenses inhérentes à l'installation d'une première tranche sur un site nouveau. Tenant compte de ces facteurs, on peut évaluer actuellement le coût de construction d'une centrale de 480 MW(e) net identique à EDF4 et établie sur un site moyen à moins de 2 fois celui d'une centrale à fuel de même importance.

Dans cette évaluation, on n'a pas pris en compte la charge de combustible. Le coût du cycle de combustible, y compris les intérêts sur la charge en pile, est évalué actuellement à moins de 1 ¢/kWh, soit 2,5 fois moins que les charges de combustible d'une centrale classique. Les coûts EDF4 seraient d'ailleurs inférieurs si l'on tenait compte de la baisse actuelle de l'uranium naturel, que nous avons compté au prix de 8 dollars par livre d'U_3O_8.

Une comparaison complète des prix de revient de l'énergie demande que soient faites des hypothèses sur les taux d'intérêt, les durées de vie, etc. Elles sont exposées en détail par ailleurs*. Il en résulte que dans l'état actuel de nos connaissances et sous certaines hypothèses, une centrale de ce type doit produire de l'électricité à un coût nettement compétitif avec les centrales françaises les plus modernes.

Malgré ces perspectives très favorables, de nouvelles solutions techniques sont actuellement à l'étude tant au CEA qu'à EDF et dans l'industrie, en vue d'arriver à une plus grande simplification de la centrale et à une nouvelle diminution des investissements. Les études qui ne remettent pas en cause les principales options de la filière — uranium naturel métallique, gainage magnésium — portent en

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* J. Gaussens, B. Leo et P. Tanguy, *Quelques aspects économiques de la filière U naturel-gr[illegible]ite-gaz carbonique.* Voir les présents Actes, P/37, vol. 5.

particulier sur la mise au point d'un élément annulaire, tube refroidi extérieurement et intérieurement, qui permet d'envisager l'accroissement des performances intrinsèques du réacteur, tirant ainsi parti des possibilités des caissons en béton précontraint. Une telle solution, qui entraîne une réduction des dimensions du réacteur et une notable simplification — le nombre de canaux est divisé par 3 ou 4 — doit conduire à une réduction du coût de construction de la centrale, d'autant qu'elle devrait permettre de passer dans l'avenir à la réalisation d'unités plus puissantes, 1 000 à 1 200 MW(e) par réacteur, avec un gain économique supplémentaire important. Le développement actuel des études permet d'envisager l'engagement d'une unité de 500 MW dès l'année 1965. Leurs promesses constituent une raison supplémentaire de poursuivre l'effort engagé dans la filière uranium naturel-graphite.

La filière eau lourde

Compte tenu des perspectives favorables de développement présentées par la filière graphite-gaz, on pourrait être tenté de penser qu'il n'est pas nécessaire de chercher à mettre au point un deuxième type de réacteur thermique. Le développement d'une nouvelle filière exige en effet pour aboutir une masse énorme d'efforts, de personnel qualifié, de moyens d'essais. Par ailleurs, la France a également entrepris l'étude des réacteurs à neutrons rapides; ceux-ci pourraient ultérieurement relayer les réacteurs à graphite, tout en étant alimentés par ces derniers en plutonium.

La France n'a pas estimé raisonnable d'adopter une telle attitude. Même si l'on croit à un succès relativement rapproché des réacteurs rapides, le développement industriel des centrales surrégénératrices ne peut avoir pour conséquence l'arrêt prochain de l'équipement en réacteurs de puissance à neutrons thermiques, surtout si ceux-ci peuvent se prévaloir d'une excellente économie neutronique qui les rend peu sensibles à une augmentation éventuelle du prix du concentré d'uranium naturel qui proviendrait d'un excédent des demandes.

C'est dans cet esprit qu'a été décidée en France l'étude des réacteurs modérés à l'eau lourde dont le réacteur EL4, de 75 MW(e), construit par le Commissariat à l'énergie atomique avec la participation d'Electricité de France pour la partie conventionnelle, doit être le prototype. L'eau lourde, grâce à ses excellentes propriétés neutroniques, doit permettre de conserver la forme d'économie du cycle de combustible à uranium naturel et même d'en exploiter à fond les avantages tout en autorisant des performances plus poussées que dans les réacteurs à graphite, en particulier en densité de puissance et taux de combustion.

On ne reviendra pas ici sur les raisons qui ont conduit à choisir le gaz carbonique comme fluide de refroidissement: outre le fait qu'il prolonge le programme gaz-graphite, il permet d'obtenir des températures de sortie élevées et des conditions de vapeur proches de celles mises en jeu dans les centrales classiques. Le souci d'améliorer les conditions de vapeur apparaît d'ailleurs chez les tenants du refroidissement par liquide lorsqu'ils envisagent pour l'avenir des améliorations telles que l'ébullition, la surchauffe et éventuellement le cycle direct. Il a semblé au Commissariat à l'énergie atomique que l'emploi de gaz carbonique fournissait une approche plus directe et une solution en définitive meilleure. La mise en œuvre des cycles directs avec le gaz n'est d'ailleurs pas totalement exclue dans un avenir plus éloigné.

C'est en juin 1962 que le Commissariat à l'énergie atomique a autorisé la construction d'EL4, en acceptant que l'essentiel de la première charge soit constitué par de l'oxyde d'uranium enrichi gainé d'acier. Cette solution évitait que la mise au point d'un gainage peu absorbant, nécessaire à un fonctionnement avec de l'uranium naturel, ne retarde l'expérience attendue de la construction et du fonctionnement du prototype. EL4 est en effet un projet assez ambitieux dont on espère tirer un enseignement valable pour apprécier pleinement les possibilités de ce type de réacteur: bien loin de chercher à esquiver les problèmes fondamentaux, on a demandé au contraire au réacteur de comporter au moins les amorces des solutions définitives.

La divergence d'EL4 est prévue pour la fin de 1966. Parallèlement les études se poursuivent sur les gainages peu absorbants, béryllium ou alliages zirconium-cuivre, et des résultats décisifs ont été acquis. L'étape suivante pourrait être la construction d'une centrale d'environ 300 MW(e) dont la date d'engagement n'a pas encore été fixée. L'existence et le développement satisfaisant de la filière graphite rendent plus aisé le développement de la filière eau lourde en lui laissant le temps de s'épanouir normalement. Les résultats actuellement disponibles permettent de penser qu'à moyen terme la filière eau lourde présente de très intéressantes possibilités.

La filière à neutrons rapides

Les perspectives de surrégénération présentées par les réacteurs à neutrons rapides, qui permettent à long terme la meilleure utilisation des ressources mondiales en combustible nucléaire, ont conduit la France à lancer, comme bien d'autres pays, un vaste programme d'études et d'essais.

Si la surrégénération est le principal atout des réacteurs à neutrons rapides, ce n'est pas le seul. La forte densité de puissance, la grande latitude dans l'emploi des matériaux de structure (par opposition aux réacteurs thermiques), le rendement élevé à pression modérée (sodium), etc., devraient conduire à des investissements intéressants.

De nombreux problèmes techniques restent encore à résoudre et c'est dans ce but que le Commissariat à l'énergie atomique a entrepris la réalisation, au Centre d'études nucléaires de Cadarache, de la pile expérimentale RAPSODIE qui répond à un triple objectif: RAPSODIE doit à la fois être une expérience de physique, apporter un enseignement industriel directement utilisable dans la conception d'une pile de puissance — la puissance de RAPSODIE a été fixée à 20 MW(th) — et permettre l'essai des combustibles des piles futures de la filière. La divergence est prévue pour 1966.

Depuis juillet 1962, l'ensemble du programme français d'étude des réacteurs à neutrons rapides est effectué en collaboration avec EURATOM. Un contrat d'association EURATOM-CEA couvre l'étude, la réalisation et l'exploitation de RAPSODIE, ainsi que d'une installation pour expériences critiques constituée par un assemblage critique MASURCA et un réacteur source HARMONIE. L'association EURATOM-CEA disposera ainsi à Cadarache d'une solide infrastructure pour poursuivre le développement de cette nouvelle filière.

Autres types de réacteurs

Comme il a été rappelé au début de cette communication, le programme nucléaire français est axé sur l'utilisation de l'uranium naturel comme combustible dans les réacteurs de puissance à neutrons thermiques. Mais cette orientation préférentielle n'a pas empêché le Commissariat à l'énergie atomique et l'Electricité de France de s'intéresser aux types de réacteurs utilisant un combustible enrichi. C'est ainsi qu'Electricité de France s'est associée avec la société belge "Centre et Sud" groupant des sociétés privées belges de production et de distribution d'électricité pour constituer la SENA, Société d'énergie nucléaire franco-belge des Ardennes, dont l'objet est la réalisation de la centrale de Chooz, d'une puissance électrique nette de 266 MW, équipée d'un réacteur de type PWR.

C'est en septembre 1961 que le contrat pour la fourniture de l'ensemble du matériel nécessaire au fonctionnement de la centrale a été passé au groupement international: Ateliers de constructions électriques de Charleroi, Métallurgie et mécanique nucléaires, Cockerill-Ougrée, Framatome, Westinghouse Electric International Company (AFW).

La réalisation de la centrale de Chooz entre dans le cadre du programme commun d'énergie nucléaire EURATOM—Etats-Unis et fait de plus l'objet d'un contrat de participation d'Euratom.

L'un des buts de cette entreprise était de permettre aux constructeurs français et belges d'acquérir de l'expérience dans une technique nouvelle et la majeure partie des équipements tant nucléaires que conventionnels est construite en Europe; c'est en particulier le cas de la cuve réalisée en France, la plus importante actuellement pour ce type de réacteur avec celle de la centrale de SELNI.

Les travaux de génie civil ont débuté en janvier 1962 et la mise en service est prévue pour 1966.

On signalera par ailleurs que la France participe en tant que membre d'EURATOM aux études et réalisations de la filière ORGEL (modérateur eau lourde, refroidisseur organique) et suit les travaux du projet DRAGON (graphite-gaz à haute température). Il est prématuré de faire des pronostics sur l'avenir industriel de ces types de réacteur.

CONCLUSION

Si l'expérience confirme les performances prévues pour les installations actuellement en construction en France, les réacteurs uranium naturel-graphite-gaz carbonique pourront à partir d'EDF4 être considérés comme compétitifs sur le plan français et constituer un excellent point de départ pour un équipement électro nucléaire important capable de contribuer à la sécurité d'approvisionnement en énergie de notre pays.

Les ébauches du cinquième Plan d'équipement actuellement en cours d'élaboration et qui couvrira les équipements à engager entre 1966 et 1970 envisagent une moyenne de 500 MW(e) par an de centrales nucléaires, avec une option de 1 500 MW(e) supplémentaire pour la fin de cette période.

Il est probable que la grande majorité des réacteurs inclus dans ce plan seront du type uranium naturel-graphite-gaz carbonique, du type EDF4 tout d'abord, le type "avancé" à élément combustible annulaire et pression de gaz élevée s'y substituant dès que l'expérience industrielle de la première unité, engagée probablement en 1965, sera considérée comme satisfaisante.

Il n'est pas encore possible de prévoir à quel moment les autres filières, en particulier eau lourde et surrégénérateur, prendront une importance industrielle comparable.

ABSTRACT - RÉSUMÉ - АННОТАЦИЯ - RESUMEN

A/31 France

France's nuclear power programme

By J. Cabanius and J. Horowitz

The development prospects of France's electricity requirements will increase the shortage of her national energy resources.

Nuclear power stations should enable this deficit to be reduced, provided a number of the uncertainties prevailing today are resolved.

The first programme, presented by Ailleret and Taranger at the 1955 Geneva Conference, aimed at commissioning 850 MW(e) by 1965; the programme was devoted to developing the natural uranium,

graphite-moderated, gas-cooled type of reactor and was completed by the construction of EDF3, the world's first unit capable of achieving 500 MW(e).

Before leaving the prototype stage and duplicating this type, Electricité de France decided, in agreement with the Commissariat à l'énergie atomique, to build EDF4. This reproduces the EDF3 reactor, together with the refuelling equipment, the entire control equipment and various other units, and also pioneers an important innovation by incorporating the heat exchangers and fans inside the pre-stressed concrete pressure vessel housing the core.

Concurrently, studies are being carried out with the same type of reactor to develop a new annular-shaped fuel element, whose use would considerably improve the performance of EDF5.

In the heavy water reactor field, the construction of EL4 at Brennilis jointly by the Commissariat à l'énergie atomique and Electricité de France is continuing. Design work on a 500 MW(e) reactor of this type has already started.

As regards pressurized water reactors, the Chooz power station is being built jointly by Electricité de France and Belgian Utilities.

Finally, the Commissariat à l'énergie atomique is continuing the construction of RAPSODIE, the fast reactor at Cadarache, together with studies for a larger power reactor.

Thus from the knowledge of technical and economic aspects gained on these different types of reactor, it will be possible to plan an installation programme in which nuclear power stations will play an increasingly significant part, using the country's resources of natural uranium, and later plutonium, to the best advantage.

A/31 Франция

Французская программа по атомной энергетике

Ж. Кабаниус, Ж. Горовиц

Перспективы роста потребления электроэнергии во Франции свидетельствуют об увеличении дефицита энергетических ресурсов в стране.

Атомные электростанции позволят уменьшить этот дефицит при условии, если будут устранены некоторые существующие сомнения.

Первая программа, представленная Айере и Таранже на Женевской конференции в 1955 году, имела целью добиться в 1965 году мощности 850 *Мвт* (эл.) за счет использования атомной энергии; эта программа предусматривала разработку реактора на природном уране с графитовым замедлителем и газовым теплоносителем с последующим строительством энергетического реактора EDF-3, первого в мире реактора мощностью 500 *Мвт* (эл.).

До перехода от стадии прототипов к стадии серийных промышленных электростанций фирма «Электрисите де Франс» совместно с Комиссариатом по атомной энергии Франции приняли решение построить реактор EDF-4, основанный на конструкции реактора EDF-3, с аналогичными машинами по перегрузке топлива, приборами управления и различным другим оборудованием, но отличающийся существенным новшеством, а именно расположением теплообменников и газодувок внутри реакторного корпуса из предварительно напряженного бетона.

Одновременно продолжаются исследования реактора этого типа с целью использования нового трубчатого тепловыделяющего элемента, что позволило бы заметно улучшить характеристики реактора EDF-5.

Комиссариат по атомной энергии и фирма «Электрисите де Франс» продолжают строительство тяжеловодного реактора EL-4 в Бреннили. Начались проектно-конструкторские работы по реактору такого типа мощностью 500 *Мвт* (эл.).

Фирма «Электрисите де Франс» совместно с бельгийскими предприятиями коммунального энергоснабжения построила в Шузе электростанцию с реактором на воде под давлением.

Наконец, Комиссариат по атомной энергии продолжает в Кадараше строительство реактора на быстрых нейтронах RAPSODIE и ведет исследование с целью создания более мощного энергетического реактора этого типа.

Таким образом, технические и экономические данные, полученные в результате исследования этих различных типов реакторов, позволяют разработать такую программу, в которой все более и более важное место будет предоставляться атомным электростанциям с широким использованием национальных ресурсов природного урана, а позднее и плутония.

A/31 Francia

El programa nuclear francés

por J. Cabanius y J. Horowitz

Las perspectivas de evolución del consumo de energía eléctrica en Francia confirman la agravación del déficit de recursos energéticos metropolitanos.

Las centrales nucleares permitirán aminorar este déficit si se disipan algunas incertidumbres actuales.

El primer programa, presentado por los señores Ailleret y Taranger en la Conferencia de Ginebra de 1955, tenía por objetivo la producción de 850 MW(e) en 1965; se ha consagrado al perfeccionamiento del concepto uranio natural-grafito-gas y concluye con la construcción del reactor EDF3, primera unidad de 500 MW(e) puesta en servicio en el mundo.

Antes de pasar de la etapa de los prototipos a la de construcción en segunda serie, Electricité de France ha decidido, de acuerdo con el Commissariat à l'énergie atomique, construir la central EDF4, que, si bien estará provista de reactor, aparato de carga y descarga, dispositivos de control y diversos materiales análogos a los de la EDF3, representa una innovación importante al incorporar los intercambiadores y los sopladores en el interior de la envoltura de hormigón pretensado que contiene el cuerpo del reactor.

Al mismo tiempo, la prosecución de los estudios sobre reactores de este concepto deja entrever la posibilidad de utilizar un nuevo elemento combustible anular que mejoraría notablemente las características de EDF5.

En cuanto al concepto agua pesada, el Commissariat à l'énergie atomique y Electricité de France prosiguen la construcción del reactor EL4 en Brennilis. Ya han comenzado los estudios sobre un reactor de esta clase, de 500 MW(e).

En cuanto al concepto agua a presión, Electricité de France y los Productores Belgas están construyendo en asociación la central de Chooz.

Por último, el Commissariat à l'énergie atomique prosigue en Cadarache la construcción del reproductor RAPSODIE y los estudios acerca de un reactor de mayor potencia.

Así, pues, los conocimientos técnicos y económicos adquiridos sobre estos sistemas permiten concebir un programa de construcción que concederá a las centrales nucleares un lugar de creciente importancia a fin de aprovechar los recursos nacionales de uranio natural y, más adelante, de plutonio, en las mejores condiciones posibles.

Future energy needs and the role of nuclear power

By G. F. Tape,* F. K. Pittman** and M. F. Searl**

CHANGING PATTERN OF ENERGY SOURCES

This history of energy sources has been one of constant replacement of one energy source by another. New and better fuels have come into use long before resources of then existing fuels were depleted. In the early days of the American economy, fuel wood supplied most of the energy. In the United States as late as 1850, it supplied over 90 per cent of the nation's energy, but by the early 1880s coal had become the dominant fuel supplying over one-half of the total energy market and over 90 per cent of the non-fuel wood market. By the late 1940s, the fluid fuels — oil and natural gas — supplied over one-half, and now supply about three-quarters, of total energy. Hydroelectricity, although regionally important, has never become an important factor in the total United States energy supply.

In view of this history of constant change and emergence of new energy sources, the appearance of a major new source of power, nuclear power, and its rise to prominence in the coming decades seems most natural. The basic purpose of nuclear power research and development in the United States is to provide an additional and alternate energy source to meet present and future demands thereby providing timely protection for the nation against rising power costs and eventual fuel shortages. The long-term objective will be met through the development of commercial breeder reactors capable of utilizing the vast potential of the world's nuclear resources. We also hope to reduce power costs in high fuel cost areas, achieve the economic advantages of competition in parts of the country where electric utilities are dependent on one fuel, reduce air pollution, and contribute to the solution of energy problems in other countries.

It is appropriate to note in passing that energy developments around the world do and will continue to affect the American situation. Historical examples are the Suez crisis, the emergence of North Africa as a major petroleum province, the further penetration of oil into world energy markets, and the increase in export markets for American coal. For the future, we see factors such as the development of European oil and gas resources, for example the discovery of Slochteren, one of the world's major gas fields in the Netherlands, the nuclear and especially breeder research and development programs here in Europe, and the world production of natural uranium all having an influence on energy availability and costs in the United States.

The situation in the United States has been dynamic in recent years. Total energy requirements have been increasing about 3.5 per cent per year during the last five years after several periods of stagnation during the 1950s. Electricity generation has grown even more rapidly, averaging about 7 per cent per year.

On the supply side, historic production and price trends in the fossil fuel industries have been reversed or greatly altered, and nuclear power has become a significant competitive factor in the electric utility market. Production in the coal industry which had been in a long-term downward trend since 1947 was abruptly reversed in 1962. There is good reason to believe that a long-term upward trend in coal production has started. Coal prices at the mine, which were at a historic peak in 1957, have been dropping gradually and are now back to about the 1954-1955 level.

Major, although somewhat less dramatic, changes have occurred in the petroleum industry. Crude petroleum production, which had been increasing at an average annual rate of about 4 per cent during the postwar period, levelled off in 1957 and did not significantly exceed 1957 levels until 1962. Increasing competition from domestic natural gas and natural gas liquids and from foreign crude oil were chiefly responsible for breaking the upward trend of crude oil production. The levelling of domestic oil production was soon followed by major declines in exploration and development activity and by some reduction in crude oil prices.

Only natural gas and natural gas liquids have shown a continuing growth pattern during the postwar period. However, even in the natural gas industry there have been significant changes. The assumption of control of most field prices of natural gas by the Federal Government has brought about a levelling of prices, and producer's expectations that future gas prices will be lower than under a free market have been reflected in a sharp drop in gas exploration and development.

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Competition from nuclear power

The changing patterns and trends in the energy supply industries are now beginning to be affected by the emergence of nuclear power as a strong competitor for major portions of the electric utility fuel market. Developments in the nuclear field have been particularly rapid. In 1959, there was hope that the costs of nuclear power could be lowered to about 7 mills per kilowatt-hour in plants commencing operation in 1970. Today, it appears that large nuclear plants coming on the line around 1970 will be capable of producing power in the range of 4-6 mills.

One of the most unexpected developments since the 1958 Geneva Conference has been the rapid drop in unit capital costs of both nuclear and conventional plants. Even though there are great variations in the cost of generating plants depending upon location, optional design features and type of construction, a reasonable figure for the cost of a nuclear power-plant in 1958 was about $320 per net kilowatt of electricity for a 200-megawatt plant and about $180 per kilowatt for a comparable alternative coal-fired plant. In the case of the coal-fired plant, a utility could have ordered a plant of perhaps twice this size for a somewhat lower unit cost.

Early this year, a major utility contracted for a nuclear plant with a guaranteed capacity of 515 megawatts of electricity and an expected capacity of over 640 megawatts. At its expected capacity, this plant would cost about $105 per net kilowatt, roughly one-third of the corresponding cost in 1958. Major equipment manufacturers now are offering plants in the range of 500-600 MW(e) at costs in the $140 per net kW(e) range, and are projecting prices in the range of $100-$110 per net kW(e) for 1 000 MW(e) plants. Plants as small as 200 MW(e) are being offered at prices in the $170 per net kW(e) range.

Although costs vary between areas and utilities and with pricing policies, these figures are indicative of the drastic reductions in initial costs in recent years. Even more important, the capital costs of nuclear plants are approaching the capital costs of comparable coal fired plants, thus overcoming a major disadvantage of nuclear plants. Although we anticipated such reductions in capital costs and the convergence of nuclear and coal fired plant costs in our 1962 report on nuclear power [1], they have been occurring much more rapidly than was projected there.

Several factors are responsible for these downward cost trends. A major cause has been substantial increases in unit sizes with accompanying economies of scale. In 1958, 200 megawatts was the largest strictly nuclear unit under construction, although conventional units of up to 500 megawatts were being built. Today, nuclear units of over 600 megawatts capacity are being designed and conventional units have reached the 1 000 megawatt stage. In effect, maximum unit sizes of nuclear plants tripled while the maximum size of conventional units was doubling. Furthermore, nuclear design studies indicate that 1 000 megawatt nuclear units are feasible although none is actually under construction.

The ability of manufacturers to offer nuclear plants in the large size units required by American utilities has been an important step toward achievement of nuclear competitiveness.

A second major factor in the reduction of generating station costs has been technological improvements in the design and manufacture of equipment and also in methods of plant construction. Such developments have been more important in nuclear than in conventional plants where technology is more mature. These developments in nuclear technology are being discussed in other sessions.

Other factors which have played a significant part in reductions of power plant capital costs are the relative absence of inflationary effects in this sector of the American economy since 1958, thus permitting the benefits of technical advances to be reflected in price decreases, and the competition of manufacturers for the electric utility market.

In addition to the capital cost reductions, there have also been reductions in the operating costs of both nuclear and conventional steam-electric plants. Improvements in nuclear plant performance and in their fuel cycle costs are being discussed in other sessions and will not be considered here except for the prices of enriched uranium and plutonium.

The US schedule of charges for enriched uranium for both domestic and foreign users was first published in 1956. It remained unchanged until 1961, when the natural uranium feed component of the schedule was reduced. In 1962 the separative work component of the schedule was also reduced as a result of improvements and economies in the diffusion plant operations. Although the exact amount of the reduction depends upon the degree of enrichment, for 3 per cent enriched material, the two reductions combined amounted to about 32 per cent.

Domestic power reactor operators are paid by the Atomic Energy Commission for the plutonium they deliver. Current policies call for payment to be made on the basis of the estimated value of the material when used as a fuel in thermal reactors. Although the estimated fuel value depends somewhat on the specific reactor considered, the Commission feels that $10 per gram of plutonium isotopes 239 and 241 in nitrate form is a reasonable approximation to what a free market price might be in the near-term future. The fuel value of plutonium will almost certainly become higher, at least relative to enriched uranium, when fast reactors become commercial.

Improvements in electricity generation from fossil fuels

There have been improvements in the generation of electricity in large new fossil fuel plants as well as in nuclear plants. The over-all efficiencies of fossil fuel plants have increased about 5 per cent since 1958, labour requirements have been reduced, other operating efficiencies achieved, central controls and automation introduced, and reductions in fuel and particularly coal costs obtained.

Electrical utilities consume about half the coal produced in the United States, and coal is the fuel used for about two-thirds of the nation's steam-electric plants. In terms of national averages, delivered prices for coal have decreased by about 10 per cent since 1958. Moreover, coal companies have been aggressively competing for new large plants. Actual and expected decreases in the delivered price of coal for large plants are the result of reductions not only in the price of coal at the mine but also in the cost of transportation. Under the pressure of economic competition from nuclear power, from the location of generating plants at the mine mouth, and from the possibility of the movements of coal by pipelines, railroads have improved coal transportation service and have reduced rates through the use of special trains for large scale movements of utility coal.

ENERGY SITUATION AND FUTURE PROSPECTS

The dynamic changes in the energy field enumerated above have led to energy requirements and resources being studied intensively by various branches of the Federal Government, individual companies, trade associations, and various non-profit research groups. As a result, the energy situation and future prospects are perhaps better understood than ever before although substantial areas of uncertainty still remain. These studies differ greatly in their areas of primary interest, comprehensiveness and sophistication.

One of the earliest postwar studies of energy requirements and the role of nuclear power was a Commission-sponsored study published in 1953 [2]. In subsequent years other studies were made for the Commission [3] and the Joint Committee on Atomic Energy [4], [5]. In 1962, the Commission, at the request of the President, undertook to study the role of nuclear power. The report [1] resulting from this study discussed the general energy situation and outlined a research and development program for nuclear power. The President subsequently requested an Interdepartmental Energy Study [6] for use in planning an integrated energy research and development program for all the major energy systems. This Interdepartmental Study does not, however, make new forecasts of energy requirements.

Energy studies which project requirements through the year 2000 are of greatest interest in the analysis of the role of nuclear power since it is in this period that nuclear power is expected to achieve maturity. Of course, the benefits of nuclear power are not limited to this period but are expected to increase with time as energy demands grow and the lower cost fossil fuel resources are gradually depleted. Table 1 shows some of the more recent long term forecasts of energy requirements. For practical purposes, total energy requirements for the United States may be taken as about 80×10^{15} British thermal units in 1980 and about 135×10^{15} in the year 2000.

Examination of the forecasts of Table 1 in terms of population and *per capita* energy consumption, as shown in Table 2, reveals that variations in the population forecasts are as much a source of variation in the total energy forecasts as differences in estimates of *per capita* energy consumption.

Factors affecting nuclear power prospects

The role which nuclear power fills in supplying energy needs will depend in part upon the relative availability and price of nuclear and fossil fuels. The magnitude of the nation's energy resources has been considered by most of the energy studies already cited as well as some other important studies such as that by the National Fuels and Energy Study Group (1962) [9]; the report, *Energy Resources*, to the Committee on Natural Resources

Table 1. Recent long-term energy consumption forecasts for the United States

(Total energy in 10^{15}Btu)

	1963 (actual)	1980	2000
Philip Sporn [a] (1959)		78 [e]	105
AEC-TID-8209 [b] (1960)		86	170
Atomic Energy Commission [c] (1962)		82	135
Resources for the Future [d] (1963)		79	135
Arithmetic mean	50	81	136

[a] Reference [7], p. 77.
[b] Reference [3], p. 3.
[c] Reference [1], appendices, p. 48.
[d] Reference [8], p. 31.
[e] Estimated from 1975 and 2000 figures given by Sporn.

Table 2. Population and *per capita* energy consumption inherent in recent long-term energy forecasts

	1963 (actual)		1980		2000	
	Population 10^6	Energy *per capita* 10^6Btu	Population 10^6	Energy *per capita* 10^6Btu	Population 10^6	Energy *per capita* 10^6Btu
Philip Sporn [a] (1959)			254 [e]	307 [e]	300	350
AEC-TID-8209 [b] (1960)			260	332	388	438
Atomic-Energy Commission [c] (1962)			246	333	320	422
Resources for the Future [d] (1963)			245	323	331	408
Arithmetic mean	189	262	251	324	335	404

[a] Reference [7], p. 77.
[b] Reference [3], p. 3.
[c] Reference [1], appendices, p. 48
[d] Reference [8], p. 31.
[e] Estimated from 1975 and 2000 figures given by Sporn.

of the National Academy of Sciences (1962) [10]; and the report on *Supplies, Costs and Uses of the Fossil Fuels* by the Energy Policy Staff of the Department of the Interior [11]. These studies differ by a factor of 5 in their estimation of the nation's total resources of coal, oil, natural gas and oil shales. The high estimates presume that future improvements in technology will make it possible to find and develop large undiscovered and marginal resources at reasonable costs.

In spite of disagreement as to resource magnitude, there is agreement that, at the minimum and taken without regard to type or cost, non-nuclear energy resources are adequate for well into the next century. When the individual fuels are considered, there is less agreement. In the case of the fluid fuels, some authorities believe that by 1980 peak levels of domestic production will have been passed. Other authorities expect that production levels of these fuels could still be increasing by the end of the century. The weight of authoritative opinion would seem to be that peak levels of domestic production will have been passed well before the year 2000.

Natural uranium, if used efficiently, is expected to be available at reasonable costs and is not expected to place any serious restrictions on the growth of nuclear power. Nuclear reserves and resources are being discussed by Faulkner and McVey of the U.S. Atomic Energy Commission.

As far as enriched uranium availability is concerned, there do not appear to be any practical limitations to the ability of the United States to enrich all the uranium needed for any foreseeable amounts of domestic power as well as for such markets as may exist in Europe and the rest of the Free World. At present the United States has determined that 150 000 kilograms of contained uranium-235 is available for use in reactors abroad. Future allocations of enriched uranium can be expected as justified by the growth of nuclear power. This material is made available through the International Atomic Energy Agency, Euratom and various bilateral agreements. Under this determination reactor owners can receive assurance of the long term availability of enriched uranium.

From the resource standpoint and without regard to prices, both coal, the main fuel for thermal power generation, and uranium are adequate for any demands that may be made upon them during the remainder of the century. While future prices are uncertain, the magnitude of resources is such that it is likely that both will be available at acceptable prices during the remainder of this century. Further in the future, nuclear power systems utilizing both converter and breeder reactors are the best prospect for providing the large amounts of power which the nation will need at reasonable cost. The development of breeder reactors is essential since they greatly increase the amount of energy obtainable from a given amount of uranium thereby conserving resources. Also they make the cost of power relatively insensitive to ore costs, thereby allowing our vast resources of known high cost ores to be used.

Level of electricity demand

Even though there is agreement between projections of total energy requirements, there is serious disagreement as to the level of electricity demand. Forecasts for the year 2000 show more uncertainty about total electricity requirements than about the percentage of those requirements which will be supplied by nuclear power. Table 3 shows a number of forecasts of electricity generation. The forecasts range between 2.2 and 3×10^{12} kilowatt-hours for the year 1980 and between 4.7 and 10 kilowatt-hours for the year 2000. The last two forecasts in the table are of particular importance because they furnish additional information concerning projected electricity requirements. The projection by Resources for the Future (RFF) provides detailed forecasts of electricity requirements by end-uses and by economic sectors. The forecast by the Federal Power Commission (FPC) gives electricity requirements by geographic area. Both are useful in estimating the potential growth of nuclear power. Extension of the

Table 3. Forecasts of annual electricity generation (consumption) in the United States

Forecast [a]	1980			2000		
	10^9 kWh	% total energy	kWh *per capita*	10^9 kWh	% total energy	kWh *per capita*
Sporn (1959)[b]	2 940	32.4	11 600	6 200	41.3	20 700
EEI (1960)	2 895	–	11 800	6-10 000	–	17 600-29 400
TETCo (1961)[b]	2 900	30.0	11 200	–	–	–
AEC-FPC (1962)[b]	2 994	31.4	12 200	9 300	48.2	29 100
Lasky (1962)	2 700	27.7	10 800	–	–	–
RFF (1963)	2 229	26.2	9 100	4 711	27.4	14 200
FPC (1963)[b]	2 820	–	10 600	–	–	–

NOTE. — Generation in 1963 was 1 008 times 10^9 kilowatt-hours. This was about 21% of total energy and amounted to 5 320 kWh *per capita.*

[a] See following references for meaning of names and initials: Sport [7]; EEI [12]; TETCo [13]; AEC-FPC [1]; Lasky [9]; REF [8]; FPC [14].

[b] About 5% added in 1980 and 3% in the year 2000 for generation by other than utility companies. Other forecasts already include such generation.

FPC estimate further into the future, on a basis consistent with the 1962 AEC-FPC forecast, gives an estimate of electricity generation in the year 2000 of about 8×10^{12} kilowatt-hours.

Table 4 shows the energy consumption of various sectors of the American economy in 1960 and projections by Resources for the Future. The amount of electricity consumed by each sector in 1960, measured in terms of input energy for the production of electricity, is also shown.

Electric utilities are aggressively seeking to capture large portions of the space heating and cooling market in new homes as well as in many commercial and industrial installations. Success in this effort would lead to substantially greater proportions of the residential market being supplied by electricity and some increase in the commercial and industrial sectors. The extent to which electricity can further penetrate the industrial sector depends largely on its ability to complete as a source of process heat. Another possibility for further use of electricity lies in its increased use for transportation. Some people believe that large portions of the railway system will be electrified in the next few decades. However, electricity would have to come into common use for automobiles before it could capture large portions of the transportation market. While it is not now doing so, possibilities such as the development of better fuel cells or batteries or means of transmitting electric power through highways to moving vehicles, all suggest this as a possibility under conditions that may exist 20 or 40 years from now.

GROWTH OF NUCLEAR POWER

Although there is a wide difference of opinion as to the growth of electricity generation in future years, there is good agreement that the relative growth of nuclear power will be quite rapid. Table 5 shows the percentage contribution of hydro, fossil fuel, and nuclear energy to electricity generation. In all years the percentage of nuclear power as predicted by the Commission in 1962 is the lowest. In the 1975-1980 period the actual number of kilowatt-hours of nuclear power predicted by Mr. Sporn [7] and by Resources for the Future [8] are about 40 per cent higher than those predicted by the Commission. All three estimates agree that by the turn of the century nuclear power will be supplying about half the electricity generated in the United States; however, when expressed in terms of actual electrical energy produced by nuclear plants, the Commission's forecast substantially exceeds the others since it is based on a higher prediction for total electricity generation from all sources, nuclear and non-nuclear.

The progress of nuclear power in recent years provides substantial justification for the belief that

Table 4. Projections[a] of energy consumption by economic sectors

Economic sector	Year 1960 (actual)			Year 1980		Year 2000	
	Energy 10^{15} Btu	% of total	% of energy used to make electricity	Energy 10^{15} Btu	% of total	Energy 10^{15} Btu	% of total
Residential	9.01	19.9	26.4	14.5	18.4	18.5	13.7
Commercial	3.84	8.5	36.5	6.5	8.2	9.0	6.7
Industrial	15.95	35.2	27.4	29.0	36.7	55.5	41.1
Transportation	9.19	20.2	-0-	18.5	23.4	37.0	27.4
All others	7.36	16.2	15.4	10.5	13.3	15.0	11.1
Total	45.35	100.0	20.5	79.0	100.0	135.0	100.0

[a] By Resources for the Future [8].

Table 5. Estimates of the production of electricity from hydro, nuclear and fossil fuel sources[a]

(In percentages)

	1963 (actual)	1975		1980		2000		
		Sporn	AEC	RFF	AEC	Sporn	RFF	AEC
Hydro	18.1	12.5	12.8	13.6	10.1	5.8	8.1	3.7
Nuclear	0.4	7.5	5.3	19.2	9.8	53.4	53.7	50.0
Fossil	81.5	80.0	81.9	67.2	80.1	40.8	38.2	46.3

Note. — The references are the same as for Tables 1 and 2.

[a] Percentages are for utility generation only; they exclude generation by non-utility industrial concerns. Such generation was about 10% of utility generation in 1963 and is estimated at about 5% in 1980 and 3% in the year 2000. This generation is mainly from fossil fuels.

nuclear power may indeed supply half the nation's electricity by the year 2000. At the time of the 1958 Geneva Conference, the United States had only one central station, civilian nuclear power plant on line, namely, the 60 megawatt Shippingport reactor. In 1964, the total capacity on utility lines reached nearly 1 000 megawatts. Rather specific utility plans for additional light water cooled and moderated reactors call for about 4 500 megawatts of nuclear capacity installed by the end of 1968. This figure includes the 800 MW reactor at Hanford.

Beyond 1968 plans are less specific, although many utilities have general plans for building nuclear plants in this period. On the basis of the rapid growth expected through 1968 and the favorable economic conditions now existing, at least 6 000 megawatts of installed capacity seems likely in 1970. Given continued progress toward the solution of site and public acceptance problems, installed nuclear capacity in the United States in 1980 is now expected to be in the range of 60 000 to 90 000 megawatts as compared with 40 000 previously forecast. The FPC has recently predicted about 70 000 megawatts; some nuclear manufacturers are predicting 80 000 to 100 000 megawatts.

Estimates of the portion of total energy, as opposed to the portion of electrical energy, which will be supplied by nuclear power, are shown in Table 6. In 1980, the forecasts cited expect nuclear power to supply from 3 to 5 per cent of total energy. On the basis of some of the higher levels of nuclear capacity now being predicted for 1980, the percentage of nuclear power might be from 5 to 7 per cent. For the year 2000, the nuclear power predictions vary between 14 and 23 per cent of total energy. At present there does not appear to be any reason to increase nuclear power's predicted share of total energy in the year 2000. The developments which have led to probable increases in 1980 forecasts have tended to move forward the time at which predicted developments would occur, but they have not been technological break-throughs which would tend to increase the long range competitive value of nuclear power.

Economic benefits

The direct economic benefits which will accrue to the United States economy from using nuclear power are expected to be substantial. The Atomic Energy Commission in its 1962 report estimated that nuclear power would save the nation about $30 000 million during the remainder of this century. The estimated savings were based on the Commission's projection of nuclear power, on the assumption that average fossil fuel costs would remain constant over the remainder of the century, and on rather conservative estimates of nuclear power economics. The fossil fuel costs which would exist in the absence of nuclear power are, of course, almost impossible to forecast with confidence. The assumption of constant fossil fuel costs did not preclude short-term reductions in fossil fuel prices or decreases in some fuels and increases in others.

FUTURE PROGRAMME

Most of the capacity installed during the next two decades will be light water reactors. However,

Table 6. Estimates of total energy requirements supplied by hydro, nuclear and fossil fuel sources

(In percentages)

	1963 (actual)	1975		1980		2000		
		Sporn	AEC	RFF	AEC	Sporn	RFF	AEC
Hydro	3.8	2.9	3.4	3.3	3.0	2.3	2.1	1.7
Nuclear	0.1	1.8	1.4	4.7	3.0	21.3	14.0	23.3
Fossil	96.1	95.3	95.2	92.0	94.0	76.4	83.9	75.0

Note. — The references are the same as for Tables 1 and 2.

starting in the early 1970s advanced converters are likely to represent an increasing percentage of new capacity. Beyond 1985 breeder reactors will come into commercial use in increasing numbers and light water reactors, advanced converters and breeders will all be in service. The proportion of each type installed beyond 1985 will depend in a complex way upon their relative economics, the rate of growth of nuclear power, the breeding gain of fast breeders, and the price of uranium.

The United States Government believes that the broad purposes of its nuclear power development effort will be best served by industry operating as much as possible within the framework of our traditional American system. The Government therefore has encouraged private, public and co-operatively owned utility companies to build and operate their own nuclear power plants, and has helped a private corporation to enter into a venture for chemical processing of irradiated fuel elements and extraction of the remaining fissionable material. Indemnity insurance coverage is being provided to those liable, for nuclear safety, where it is not available from non-government sources. The Commission is also requesting legislation that will permit private ownership of all reactor fuel materials. The Government will continue to be responsible for the regulation of nuclear power plants in order to assure public health and safety.

The Commission's 1962 report called for a growing emphasis in research and development activities on advanced converter and breeder reactors. As part of its implementation of this program, the Commission early this year announced its interest in co-operative arrangements for the construction of four advanced converter reactor types: heavy-water moderated, high temperature gas-cooled, seed and blanket, and sodium graphite. The merits of advanced converters have been the subject of much discussion. The technical objective of our advanced converter program is effectively to extend the availability of low cost uranium beyond that which would result from use of conventional boiling or pressurized light water reactors. The advanced systems will (1) permit a more efficient conversion of fission heat to electrical energy (high temperature systems), (2) permit greater use of the fertile uranium, U^{238}, in the mined uranium (high conversion ratio uranium fuelled reactors), and (3) permit efficient utilization of fertile thorium in high conversion ratio systems using thorium–U^{233} fuel. This latter point is a very important factor in the advanced converter program since thorium reserves, although not as well defined and cataloged as uranium reserves, appear to be available in significant quantities at reasonable costs. The advantages of converters in extending resources may be of considerable importance if natural uranium and thorium turn out to be more costly than expected or if competitive uranium–plutonium breeders are more difficult to develop than anticipated. The extent to which advanced converters come into use will depend primarily upon their achieving favorable economics as compared with present reactor types. Converters will undoubtedly be used to supply plutonium inventories for breeders for many years after breeders become economic. Moreover, some of the advanced converters may also prove particularly advantageous because of the ease with which large ones can be built, achieving economies of scale in providing large power sources for applications such as the desalting of large amounts of water.

The Commission is moving towards realizing the goal of the liquid metal cooled breeder program — namely, the development of competitive, safe, reliable breeder reactors for use in commercial, central station, power plants by the later 1980s. In the early 1970s a 200-300 MW(e) prototype should be constructed to demonstrate technical and economic feasibility and by the early 1980s 400-800 megawatt plants should be operating to demonstrate the competitiveness of the system. By the late 1980s, breeder reactors should be ready for use by utilities in full-scale 1 000-1 500 MW(e) units. The expected rapid growth of nuclear power in the next two decades makes it important that research and development efforts on breeders continue on schedule, so that the relative number of breeders and converters built are such that the lowest cost power generation will be realized.

Neither the total energy estimates discussed here nor the nuclear estimates make allowance for any such large scale uses of process heat as, for instance, the heat energy for desalting water. Requirements of large amounts of energy for desalting water, to the extent that other uses of energy for procuring water are not displaced, would probably increase both nuclear and total energy requirements. The application of nuclear reactors to water desalting are being discussed by Commissioner Ramey in another session of this Conference [15].

CONCLUSIONS

The projection of energy requirements and the role of nuclear power bear out the historical pattern of constant augmentation and replacement of one energy source by another as mentioned at the beginning of this paper. Nuclear power will not become the major source of all the nation's energy during this century even if it captures over one-half of the electricity market. However, in the next century nuclear power could well — as fuel wood, coal and fluid hydrocarbons have all done in their turn — furnish over one-half of the nation's energy. Whether additional energy sources such as fusion will eventually enter the market and compete with fission remains for the future to determine.

In the past, this progression of new and better energy sources has contributed immeasurably to material progress and through continued diligent research and development should continue to do so in the future. Certainly the availability of large amounts of very low cost nuclear energy can go far towards solving the world's pressing problems of adequate food, water, raw materials, and living space.

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ABSTRACT - RÉSUMÉ - АННОТАЦИЯ - RESUMEN

A/192 Etats-Unis d'Amérique

Besoins futurs en énergie et rôle de l'énergie nucléaire

par G. F. Tape *et al.*

Les six années qui ont suivi la dernière Conférence de Genève ont été très actives dans le domaine de l'énergie. La consommation d'énergie a fortement augmenté, un pourcentage de plus en plus important étant utilisé sous forme d'électricité. On a vu se renverser ou se modifier fortement les tendances traditionnelles de la production et des prix dans les industries des combustibles fossiles, et l'énergie nucléaire est devenue un facteur important de la compétition sur le marché de l'électricité.

Les dépenses d'investissement qu'exigent les centrales nucléaires et traditionnelles ont considérablement diminué grâce au progrès technique et à l'augmentation rapide de la taille des génératrices. Le prix du charbon, combustible principal pour la production d'électricité, a diminué, et il sera possible de réduire encore le coût de production des centrales classiques en utilisant de nouvelles techniques de transport du charbon et de l'électricité. Pour les centrales nucléaires, le coût du cycle du combustible a diminué tant en raison des améliorations techniques que de la réduction du prix de l'uranium enrichi consentie à deux reprises par la Commission de l'énergie atomique. La concurrence entre le charbon et l'énergie nucléaire est très vive dans les régions où le prix des combustibles est élevé.

Les besoins et ressources en énergie, ainsi que le rôle de l'énergie nucléaire, ont fait l'objet d'études intensives au cours des dernières années. De ce fait, la situation de l'énergie et les perspectives futures sont probablement mieux comprises qu'auparavant, bien que certains domaines d'incertitude demeurent. Au cours des trois dernières années, cinq études principales sur l'énergie furent effectuées par le Gouvernement fédéral ou à sa demande, notamment le

rapport de la Commission à l'énergie atomique au Président sur "l'énergétique nucléaire dans le secteur civil". De nombreuses autres études importantes ont été effectuées avec ou sans le concours des pouvoirs publics.

On s'accorde d'ordinaire à prévoir que la consommation totale d'énergie en l'an 2000 sera le triple de la consommation en 1960, et l'on estime que les ressources en charbon permettront de dépasser nettement le début du siècle prochain, mais les opinions divergent quant à la capacité de la technique à fournir ce charbon au prix actuel ou au-dessous. Les ressources américaines en pétrole brut et en gaz naturel seront probablement épuisées bien avant le charbon, bien qu'il doive être possible d'améliorer sensiblement l'approvisionnement du pays en recourant aux importations, à l'huile de schiste, à la conversion du charbon, ou peut-être à la production d'autres combustibles de synthèse, grâce à l'énergie d'origine nucléaire.

Même là où l'on s'accorde quant aux besoins totaux en énergie, il existe des désaccords marqués quant au niveau de la demande d'électricité. Les prévisions des experts varient du simple au double lorsqu'il s'agit des besoins en électricité en l'an 2000. Les opinions diffèrent aussi beaucoup en ce qui concerne la rapidité avec laquelle l'énergie d'origine nucléaire s'implantera sur le marché de l'électricité dans les quelques dizaines d'années à venir; toutefois, les prévisions se rejoignent sur le fait qu'en l'an 2000 l'électricité nucléaire dominera dans les centrales nouvelles et fournira la moitié de l'énergie produite.

En 1962, la Commission à l'énergie atomique a établi des prévisions concernant la puissance nucléaire à installer d'ici à l'an 2000. L'évolution depuis 1962 indique que la progression de l'électricité d'origine nucléaire sera probablement plus rapide qu'on ne le prévoyait alors. La réalisation des prévisions dans ce domaine dépend des progrès ultérieurs de la technologie des réacteurs à eau et du développement d'une technologie avancée des réacteurs convertisseurs et surgénérateurs. Les avantages économiques directs réalisés grâce à l'installation de centrales nucléaires se compteront en milliards de dollars d'ici à l'an 2000. La recherche de prix de revient plus bas du fait de la concurrence des autres combustibles, la réduction de la pollution de l'atmosphère, le développement des ressources et les mesures propres à favoriser les échanges internationaux procureront d'autres avantages substantiels.

La plupart des centrales nucléaires qui seront installées aux Etats-Unis pendant les deux prochaines décennies seront équipées de réacteurs à eau légère. Cependant, des programmes relatifs à des types perfectionnés de réacteurs convertisseurs et des réacteurs surgénérateurs refroidis à l'aide de métaux liquides sont en cours d'exécution, et ces deux types de réacteurs devraient être mis en service dans une proportion croissante après 1985.

A/192 США

Будущие потребности в энергии и роль атомной энергетики

Дж. Ф. Тэйп *et al.*

За минувшие шесть лет после последней Женевской конференции наблюдается быстрое развитие энергетической промышленности. Значительно возросло потребление энергии, причем большая часть ее используется в форме электрической. Некоторые традиционные производственные и стоимостные показатели, связанные с обычной топливной промышленностью, коренным образом изменились, и атомная энергия стала важным конкурентом на рынке электроэнергии.

Благодаря технологическому прогрессу и быстрому росту мощности энергетических установок резко понизились капитальные затраты для атомных и обычных электростанций. Цены на уголь, являющийся основным топливом для электростанций, непрерывно понижаются, а новые формы транспортировки угля и передачи энергии еще больше снизят стоимость энергии, вырабатываемой обычными электростанциями. Стоимость топливного цикла для атомных станций тоже уменьшилась как благодаря техническим усовершенствованиям, так и в результате двух снижений цен на обогащенный уран, проведенных Комиссией по атомной энергии США. В тех районах страны, где топливо сравнительно дорого, наблюдается острая конкуренция между углем и атомной энергией.

В последние несколько лет тщательно изучались потребности в энергии и энергетические запасы, а также роль атомной энергетики. В результате этого мы имеем теперь лучшее представление, чем когда-либо, как о теперешнем положении в области энергетики, так и о перспективах ее развития в будущем, хотя все еще остаются большие неясности в этой области. За последние три года правительством США или по его поручению было произведено пять больших исследований по энергетике, включая представленный президенту США отчет Комиссии по атомной энергии о «гражданском применении атомной энергии». Правительственными и другими организациями было осуществлено также много других важных исследований. Перспективные исследования показывают, что к 2000 году потребление энергии будет в три раза больше по сравнению с 1960 годом. Существует общее мнение, что запасы угля будут достаточными в течение значительной части следующего столетия. Однако по вопросу о том, позволит ли технология будущего поставлять уголь из этих запасов по существующим или по более низким ценам, мнения расходятся. Запасы нефти и природного газа в США почти наверняка будут исчерпаны гораздо раньше запасов угля, хотя их недостаток на местном рынке будет в значительной степени восполнен за счет импорта топлива, использования нефтеносных сланцев, переработки угля и, возможно, путем производства новых синтетических видов топлива при помощи ядерной энергии.

Хотя и достигнуто вполне определенное общее мнение относительно энергетических потребностей будущего, однако имеются существенные разногласия в отношении уровня будущих потребностей в электроэнергии. Авторитетные прогнозы потребностей в электроэнергии на 2000 год содержат цифры, отличающиеся почти вдвое. В значительной степени расходятся также мнения о скорости проникновения атомной энергии на электроэнергетический рынок в ближайшие десятилетия; однако все эти прогнозы сходятся на том, что к 2000 году в строительстве новых электростанций будут преобладать атомные станции, которые будут производить половину всей вырабатываемой энергии.

В 1962 году Комиссия по атомной энергии США предсказывала уровень общей мощности атомных станций, которые предполагается построить до 2000 года включительно. Однако работы, проведенные с тех пор, показывают, что развитие атомной энергетики, вероятно, пойдет быстрее, чем предполагалось.

Достижение предсказанных уровней атомной энергетики зависит от будущего развития технологии водных реакторов и усовершенствования технологии реакторов-конвертеров и реакторов-размножителей. Непосредственные экономические выгоды от атомных электростанций будут выражаться к 2000 году во многих миллиардах долларов. Помимо этого, будут также значительные дополнительные выгоды: снижение цен на конкурирующие виды топлива, уменьшение загрязнения воздуха, сохранение топливных запасов и дальнейшее развитие международной торговли.

Большая часть установленной мощности, которая будет введена в строй в США в течение следующих двух десятилетий, будет обеспечиваться за счет реакторов на обычной воде. Однако работы по усовершенствованным реакторам-конвертерам будут проводиться и после 1985 года, когда реакторы обоих типов будут вступать в строй во все большем масштабе.

A/192 Estados Unidos de América

Necesidades futuras de energía y el papel que en ellas representa la energía nuclear

por G. F. Tape *et al.*

Los seis años que han transcurrido desde la última Conferencia de Ginebra han sido años dinámicos para las industrias de la energía. El consumo de energía ha crecido en forma apreciable, y una parte cada vez mayor de esta energía se usa en forma de electricidad. Algunas de las tendencias históricas de la producción y los precios de la industria de los combustibles fósiles se han invertido o han cambiado mucho y la energía nuclear se ha convertido en un competidor importante en la producción de electricidad para uso público.

El capital necesario para sufragar una planta de energía, sea nuclear o convencional, ha disminuido enormemente debido a los adelantos técnicos y al rápido aumento de tamaño de las unidades generadoras de energía. El costo del carbón, el combustible más importante para la producción de electricidad, ha venido disminuyendo continuamente, y nuevos métodos de transporte del carbón y de transmisión de energía reducirán aún más el costo de la energía producida por una planta convencional. El costo del ciclo de combustible de una planta nuclear ha decrecido como resultado de los adelantos técnicos y de dos reducciones en la lista de precios del uranio enriquecido de la Comisión de Energía Atómica. La competencia entre el carbón y la energía nuclear es intensa en lugares donde el precio del combustible es elevado.

Las necesidades y reservas de energía, así como el papel que representa la energía nuclear, han sido estudiados de una manera intensa en los últimos años. Como resultado de estos estudios, la situación de la industria de la producción de energía y sus posibilidades futuras nunca se han conocido tan bien, aunque todavía quedan campos importantes por conocer. En los últimos tres años se han hecho cinco grandes estudios sobre la energía, bien por el Gobierno Federal o bien bajo sus auspicios. Estos estudios incluyen un informe sometido al Presidente por la Comisión de Energía Atómica sobre "Los usos civiles de la energía nuclear". Muchos otros estudios importantes han sido llevados a cabo por el Gobierno y por entidades privadas.

Las predicciones unánimes son que el consumo total de energía en el año 2000 triplicará el consumo del año 1960. La opinión general es que las reservas de carbón serán suficientes al menos durante la mayor parte del próximo siglo, pero hay diversidad de opiniones en lo que respecta a la capacidad de los adelantos técnicos para proveer estas reservas de carbón al costo actual o a más bajo costo. Es casi seguro que las reservas de petróleo crudo y de gas natural de los Estados Unidos escasearán antes que las reservas de carbón, aunque el abastecimiento doméstico mejorará notablemente con las importaciones, las pizarras bituminosas, la conversión de carbón, o tal vez con la producción de otros combustibles sintéticos con la ayuda de la energía nuclear.

Aun en los casos en que hay unidad de opinión en lo que respecta a las necesidades totales de energía, hay graves divergencias en lo tocante a la demanda de electricidad. Las predicciones serias difieren hasta en un factor dos respecto a las necesidades eléctricas en el año 2000. También están en desacuerdo las opiniones en lo tocante a la velocidad con que la energía nuclear se introducirá en la industria de la producción de electricidad en los próximos decenios; sin embargo, las predicciones están de acuerdo en que para el año 2000 la energía nuclear dominará la producción de energía en las nuevas instalaciones y producirá la mitad de la energía total.

En 1962 la Comisión de Energía Atómica predijo la cantidad de plantas nucleares que se instalarían durante el año 2000. Los adelantos producidos desde 1962 indican que el crecimiento del uso de la energía nuclear probablemente será más rápido que el que se predijo en 1962. La realización de las predicciones tocantes al aumento del uso de la energía nuclear dependen de los adelantos que se hagan en la técnica de los reactores de agua y del desarrollo en la técnica avanzada de los reactores convertidores y de los reactores reproductores. Los beneficios económicos derivados de la instalación de la energía nuclear serán de muchos miles de millones de dólares para el año 2000. Grandes beneficios adicionales resultarán de la producción de combustibles que compitan con la energía nuclear para reducir los costos de producción, de la reducción de la contaminación de la atmósfera, del aumento de recursos y del incremento del comercio internacional.

La mayor parte de la potencia que se instale en los Estados Unidos en las dos próximas décadas lo será en forma de reactores de agua natural. No obstante, se sigue trabajando en los programas concernientes a los reactores convertidores avanzados y a los reproductores refrigerados por metales líquidos, y a partir de 1985 cada vez entrarán en servicio más reactores de ambos tipos.

Пути развития ядерной энергетики в СССР

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ВВЕДЕНИЕ

27 июня 1954 г. в Советском Союзе была пущена в эксплуатацию Первая атомная электростанция мощностью 5000 *квт* (эл.).

Истекшее десятилетие во многих странах было периодом зарождения и первых практических шагов новой отрасли техники — мирной ядерной энергетики, призванной использовать на благо человечества высвобождающуюся энергию деления ядер урана и плутония.

Период, прошедший после Второй Женевской конференции по использованию атомной энергии в мирных целях, характеризуется интенсивными научными и инженерными исследованиями и многими практическими достижениями в СССР и ряде других стран.

Накопленные знания и опыт к настоящему времени позволяют более правильно оценить решенные и главным образом нерешенные проблемы и наметить более эффективные пути дальнейшего развития ядерной энергетики с учетом конкретных условий каждой страны.

ПРОГРЕСС ЭНЕРГЕТИКИ В СССР И ЕГО ОСОБЕННОСТИ

Создание материальной и технической основы коммунистического общества в Советском Союзе, развитие промышленности и сельского хозяйства, рост потребления энергии населением требуют дальнейшего широкого строительства электростанций и высоких темпов роста выработки электрической энергии. Производство электроэнергии и установленная электрическая мощность в СССР должны соответственно составить:

в 1970 г.—900—1000 млрд. *квт·ч*, 180—200 млн. *квт*,
в 1980 г.—2700—3000 млрд. *квт·ч*, 540—600 млн. *квт*.

Напомним, что производство электроэнергии в СССР в 1963 г. составило 412 млрд. *квт·ч*, тогда как в 1960 г. оно равнялось 292 млрд. *квт·ч*, в 1950 г.—91 млрд. *квт·ч*, а в 1940 г.—48 млрд. *квт·ч*. За последние несколько лет ежегодный прирост производства электроэнергии в СССР составляет 11—12%. В 1963 г. ввод новых мощностей на электростанциях составил 10 млн. *квт*.

Строятся крупные конденсационные тепловые электростанции мощностью до 2400 *Мвт*, теплоэлектроцентрали мощностью 400 *Мвт* и больше, крупные гидроэлектростанции на 4000—5000 *Мвт*, среди которых крупнейшие в мире на Ангаре и Енисее в Сибири. К началу 1964 г. в СССР действовало 5 тепловых электростанций мощностью свыше 1000 *Мвт* каждая; к концу 1965 г. будет уже 11 таких крупных электростанций, мощность одной из них превысит 2000 *Мвт*. Создана единая энергетическая система Европейской части СССР, общая мощность которой в 1965 г. превысит 50 млн. *квт* [1].

Строительство по типовым проектам крупных тепловых электростанций с единичными мощностями блоков 200—300—500—800 *Мвт* (эл.) и повышенными параметрами пара (130—240 *ат* и 560—580° С), широкое использование сборного железобетона при сооружении зданий, налаженное в стране крупносерийное производство энергетического стандартного оборудования, успешное строительство дальних линий электропередач на напряжение 500 *кв* пропускной способностью до 1 млн. *квт* — все это непрерывно улучшает показатели обычной энергетики, снижает удельные капитальные затраты и стоимость вырабатываемой электроэнергии.

Этот продолжающийся технический прогресс современной крупной теплоэнергетики обязательно должен учитываться в требованиях, предъявляемых к экономичности и конкурентоспособности атомных электростанций (АЭС) в Советском Союзе.

Изучение энергетического и топливного баланса страны с учетом новых месторождений показывает, что энергетические потребности в целом по СССР могут быть обеспечены за счет запасов органического топлива и гидроресурсов на весьма длительный срок. Однако неравномерность размещения запасов органического топлива по стране вызывает существенное удорожание производства электроэнергии в ряде районов страны, например в Европейской части СССР.

Существует несколько способов удовлетворить растущие энергетические потребности в Европейской части СССР. К ним относятся: 1) строительство тепловых электростанций, работающих на дорогих углях, добываемых в донецком бассейне, или на дешевых углях, доставляемых по железной дороге из Сибири; 2) строительство сверхдальних мощных линий передачи энергии из Сибири в Европу; 3) строительство АЭС в достаточно широких масштабах, определяемых их конкурентоспособностью. При сочетании в разных пропорциях всех указанных способов может быть решена задача дальнейшего развития энергоснабжения районов Европейской части СССР в ближайшие 10—20 лет.

Таким образом, вопрос о развитии ядерной энергетики в Советском Союзе в настоящее время — это прежде всего вопрос о выборе экономически наиболее выгодного для страны пути удовлетворения энергетических потребностей в районах, неблагоприятных по условиям снабжения органическим топливом и энергией.

Указанные обстоятельства побуждают, пока не достигнут необходимый уровень конкурентоспособности АЭС, продолжать накопление инженерного опыта и всестороннее изучение перспектив развития ядерной энергетики с проведением необходимых исследовательских, конструкторских, проектных и экспериментальных работ.

При высоких темпах и огромных масштабах развития энергетики в СССР ощутимый экономический эффект от применения атомных электростанций может быть получен при значительной доле их в общем балансе наращивания новых энергетических мощностей.

В связи с этим необходимо тщательно подготовить, оценить и выбрать наиболее эффективный путь развития крупной ядерной энергетики и на его основе построить долгосрочную программу развития ядерной энергетики в стране.

РАЗВИТИЕ ЯДЕРНОЙ ЭНЕРГЕТИКИ В СССР

Мощности атомных электростанций в 1964 г. в Советском Союзе превысят 900 тыс. *квт* (эл.). К 1970 г. в СССР предполагается ввести в эксплуатацию АЭС общей электрической мощностью в несколько миллионов киловатт, рассматривая период до 1970 г. как период отработки и сооружения крупномасштабных прототипов для последующего перехода к нарастающему серийному строительству мощных АЭС в 1970—1980 гг.

В настоящее время пущена и находится в стадии освоения первая очередь Белоярской АЭС им. И. В. Курчатова электрической мощностью 100 *Мвт* с ядерным перегревом пара. Осуществляется пуск первой очереди Нововоронежской АЭС электрической мощностью 210 *Мвт*[2,3]. Сибирская атомная электростанция, запроектированная на 600 *Мвт* (эл.), превысила свою проектную мощность. Сооружение и пуск этих станций позволили получить большой опыт проектирования, монтажа и производства реакторного оборудования и материалов для крупных водо-водяных и уран-графитовых энергетических реакторов, в том числе с ядерным перегревом пара. Ведется сооружение второго блока Белоярской АЭС на 200 *Мвт* (эл.). Начато строительство второго блока Нововоронежской АЭС на 365 *Мвт* (эл.).

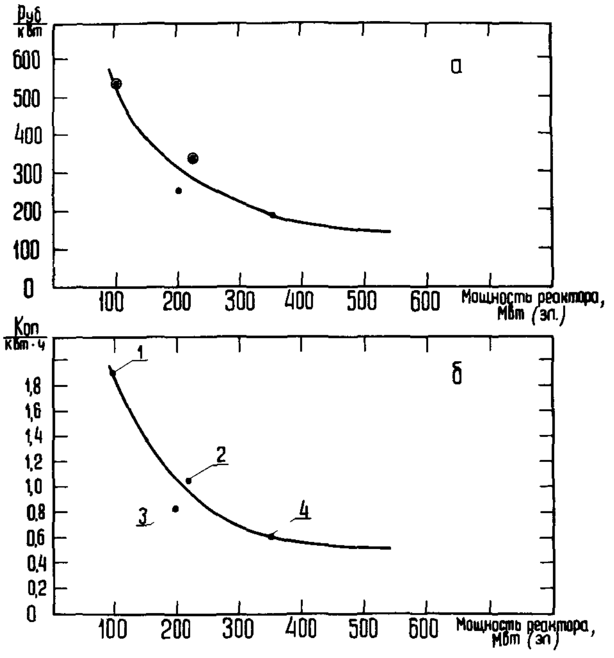

Рис. 1. Экономические показатели по Белоярской и Нововоронежской АЭС:

а — капитальные затраты на 1 *квт* электрической мощности:

● — расчет;

⊙ — фактические затраты;

б — себестоимость электроэнергии:

1 — первый блок Белоярской АЭС; 2 — первый блок Нововоронежской АЭС; 3 — второй блок Белоярской АЭС; 4 — второй блок Нововоронежской АЭС

Дальнейшая разработка и совершенствование реакторов этих типов с целью повышения экономичности ведется в направлении увеличения единичных мощностей при одновременном увеличении средней глубины выгорания ядерного топлива до 15 000—20 000 *Мвт·сутки/т* и с применением других усовершенствований[4,5]. Динамика ожидаемого изменения экономических показателей для Нововоронежской и Белоярской атомных электростанций приведена на рис. 1. Высокие удельные капитальные затраты на сооружение первых блоков в значительной степени обусловливаются относительно малыми единичными мощностями блоков, затратами на освоение площадки под АЭС в целом и высокой стоимостью экспериментальных и опытных образцов оборудования.

Десятилетний опыт эксплуатации Первой атомной электростанции и шестилетняя безаварийная работа реактора на быстрых нейтронах БР-5 мощностью 5000 *квт* с натриевым охлаждением в Обнинске показали возможность достижения при достаточно представительных массовых реакторных испытаниях «энергетических» глубин выгорания ядерного горючего до 60 000 *Мвт·сутки/т* двуокиси урана и плутония, то есть значений, достаточных для получения конкурентоспособной энергии от АЭС большой мощности с реакторами как на тепловых, так и на быстрых нейтронах.

В ближайшие месяцы будет пущена атомная электростанция с кипящим водяным реактором в Мелекессе мощностью 50—75 *Мвт* (эл.)[6].

В эксплуатации находятся экспериментальные образцы малых транспортабельных блочных АЭС: ТЭС-3 с водо-водяным реактором мощностью 1,5 *Мвт* (эл.) в Обнинске и АРБУС с органо-органическим реактором мощностью 750 *квт* (эл.) в Мелекессе,—предназначенные для использования в отдаленных районах страны, доставка топлива в которые затруднена и неэкономична[7].

Успешно проводит свою пятую навигацию первое в мире гражданское атомное судно — ледокол «Ленин», снабженное тремя реакторами водо-водяного типа тепловой мощностью 90 *Мвт* каждый. В прошлом году после трехлетней работы без перегрузки была успешно проведена замена активных зон всех его реакторов. Установленные новые активные зоны обладают еще большим ресурсом. Работа энергетических установок ледокола «Ленин» в течение пяти лет надежно подтвердила безопасность работы его атомных реакторных установок во всех эксплуатационных режимах[8].

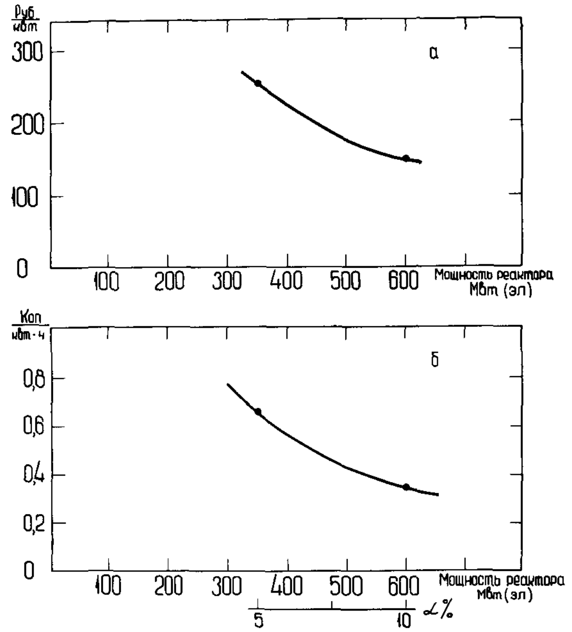

Рис. 2. Экономические показатели реакторов на быстрых нейтронах с натриевым теплоносителем (расчет):

а — капитальные затраты на 1 *квт* электрической мощности;

б — себестоимость электроэнергии. α — накопление продуктов деления в % ат.

РЕАКТОРЫ НА БЫСТРЫХ НЕЙТРОНАХ

Экспериментальные и проектно-конструкторские работы, проведенные в области физики и разработки тепловыделяющих элементов, освоение технологии натриевого теплоносителя, а также успешная разработка, изготовление и испытание опытных образцов оборудования для натриевых контуров позволили отказаться от ранее намеченного строительства реактора на быстрых нейтронах мощностью 50 *Мвт* (эл.). В настоящее время принято решение о сооружении реактора на быстрых нейтронах БН-350 электрической мощностью 300—350 *Мвт*[9].

Коэффициент воспроизводства в этом реакторе при работе его в начальный период на U^{235} составит 1,1 и постепенно будет доведен примерно до 1,5 после перехода его полностью в режим работы размножителя на плутонии. Предполагается, что глубина выгорания топлива в начальный период эксплуатации будет равна 5—6% ат. и доведена со временем за счет применения тепловыделяющих элементов с направленным удалением продуктов деления до 8—10% ат.

Интенсификация теплосъема в активной зоне реактора, увеличение температуры натрия на выходе из реактора до 600—630° С и увеличение подогрева теплоносителя в реакторе, а также глубины выгорания топлива позволяют рассчитывать в дальнейшем создать на базе БН-350 реактор мощностью 500—600 *Мвт* (эл.), обеспечивающий получение экономичной электроэнергии. Такой реактор предполагается построить в качестве дальнейшего шага в использовании реакторов-размножителей, рассматриваемых нами как главный путь развития ядерной энергетики в СССР. Расчетные данные по экономическим показателям реакторов на быстрых нейтронах и ориентировочная динамика их изменения приведены на рис. 2.

АЭС ЭЛЕКТРИЧЕСКОЙ МОЩНОСТЬЮ 1000 *Мвт*

Работы в области дальнейшего совершенствования реакторов для ядерной энергетики ведутся в СССР также в направлении выявления возможностей значительного увеличения единичных мощностей реакторов до 1000 *Мвт* (эл.) и разработки оптимальных реакторов-конвертеров, обеспечивающих наиболее быстрое вовлечение в топливный цикл U^{238}.

Выполненные в СССР проектные проработки на базе имеющихся экспериментальных данных подтверждают техническую возможность создания уран-графитовых реакторов единичной мощностью порядка 1000 *Мвт* (эл.), охлаждаемых обычной водой при сверхкритических параметрах или углекислым газом, а также реакторов на быстрых нейтронах, охлаждаемых натрием с коэффициентом воспроизводства 1,7 при воспроизводстве в активной зоне, близком к единице. При этом параметры пара на атомных электростанциях с указанными типами реакторов будут близки к параметрам, достигнутым современной энергетикой. Достижение указанных единичных мощностей обеспечивает снижение удельных капитальных затрат и эксплуатационных расходов и получение конкурентоспособной энергии.

Единичная мощность 1000 *Мвт* (эл.) и выше может быть также достигнута на уран-графитовых реакторах, охлаждаемых водой под давлением при более низких параметрах с возможным одновременным использованием отводимого тепла для целей опреснения воды или теплофикации.

РЕАКТОРЫ-КОНВЕРТЕРЫ

Наиболее эффективными реакторами-конвертерами, как и следовало ожидать, являются реакторы на природном уране с тяжеловодным замедлителем, охлаждаемые или углекислым газом (типа строящегося в Чехословацкой Социалистической Республике), или органическим теплоносителем. Очень эффективным конвертером является реактор на быстрых нейтронах с натриевым или газовым теплоносителем, в особенности при времени пребывания горючего вне реактора 1,5—2,0 года и меньше.

Проектные и экспериментальные работы по проработке реактора на природном уране с тяжеловодным замедлителем и органическим теплоносителем мощностью до 400—500 *Мвт* (эл.) показали, что для достижения хороших экономических показателей такого реактора существуют определенные технические трудности, связанные с обеспечением термической и радиационной стабильности органического теплоносителя, невозможностью достичь высоких параметров пара, усложненностью технологической схемы из-за обилия контуров.

Как показывают опыт проектирования, расчеты и исследования по газо-графитовому реактору мощностью 350—400 *Мвт* (эл.), многие трудности, свойственные тяжеловодно-органическому реактору, в этом случае отсутствуют. Однако перспективы достижения больших глубин выгорания, необходимых для достижения конкурентоспособности, затруднены из-за худших свойств графита как замедлителя, а применение с этой целью окисного горючего заставляет перейти на слабообогащенный уран и работать при сниженном коэффициенте воспроизводства. Достижение необходимых по экономическим соображениям глубин выгорания до 7000—10000 *Мвт·сутки/т* на металлическом уране и его сплавах при рабочих температурах представляет собой серьезную проблему.

Весьма перспективным с этой точки зрения может явиться использование тепловыделяющих элементов малого диаметраируткового типа на основе слаболегированного урана, подвергнутого специальной термической обработке с целью получения удовлетворительной размерной стабильности под облучением.

Сооружаемый Чехословацкой Социалистической Республикой при участии Советского Союза тяжеловодный реактор с газовым охлаждением мощностью 150 *Мвт* (эл.) рассчитан на использование тепловыделяющих элементов данного типа. Проектирование, строительство и эксплуатация этого реактора наряду с накоплением инженерного опыта по созданию и работе оборудования, систем и приборов для тяжеловодных и газовых контуров АЭС позволят также получить сведения по достижимым глубинам выгорания на прутковых тепловыделяющих элементах в промышленных масштабах.

Более полно удовлетворяет требованиям повышения единичной мощности до 800—1000 *Мвт* (эл.) и получения пара высоких параметров (давление свыше 90 *ат* и температура более 500° С) при одновременном наиболее эффективном использовании ядерного горючего и интенсивном вовлечении в топливный цикл урана-238 и тория реактор-конвертер на быстрых нейтронах, постепенно переходящий в режим работы реактора-размножителя. Такой реактор-конвертер-размножитель может быть выполнен в едином конструктивном исполнении для работы в режиме как конвертера, так и размножителя и рассчитан на использование в качестве ядерного сырья, как урана, так и тория. Характеристики конвертера-размножителя для урана и тория оказываются весьма удовлетворительными во всех режимах работы (табл. 1)[10].

Таблица 1. Характеристики реактора-конвертера-размножителя на быстрых нейтронах

Характеристики	Активная зона уран-235, уран-238 Экран природный или обедненный уран	Активная зона плутоний-239, уран-238 Экран природный или обедненный уран	Активная зона уран-235, уран-238 Экран торий	Активная зона уран-235, плутоний-239, уран-238 Экран торий
Электрическая мощность реактора, *Мвт*	500	500	500	500
Коэффициент полезного действия, %	42	42	42	42
Давление пара, *ат*	130	130	130	130
Температура пара, °С	565	565	565	565
Коэффициент воспроизводства	1,20	1,50	1,15	1,35
Загрузка делящихся изотопов, *кг*	1290	1140	1300	1010

НЕДОСТАТОЧНОСТЬ РАССМОТРЕНИЯ ЭКОНОМИКИ ТОЛЬКО ОТДЕЛЬНЫХ АЭС

Высказанные выше соображения относятся к техническим возможностям и экономическим показателям отдельных реакторов и атомных электростанций. Однако, как показывает опыт и изучение публикуемых материалов, экономические показатели отдельных АЭС не дают достаточно правильного представления об экономичности использования их в народном хозяйстве и не позволяют судить о наиболее выгодном пути развития ядерной энергетики в общегосударственном масштабе. Экономические показатели отдельных АЭС в значительной, иногда определяющей степени зависят от субъективных факторов, таких, как цены на аренду ядерного горючего, кредит на плутоний и т. п.

Необходим научный подход с выявлением на базе анализа технических, экономических и сырьевых предпосылок, объективных пропорций и взаимозависимостей между отдельными видами производств, входящих в систему ядерной энергетики. Такая система производств, входящих в ядерную энергетику и обслуживающих ее, должна быть сопоставлена с альтернативными способами удовлетворения энергетических потребностей страны или ее отдельных районов с целью выбора наиболее эффективного, то есть технически и экономически обоснованного для данного района и данного периода времени пути развития энергетики.

Производства, входящие в систему ядерной энергетики, а именно: добыча и обогащение урана, химическая переработка облученных тепловыделяющих элементов, дообогащение регенерата ядерного горючего, изготовление тепловыделяющих элементов из свежего и отработавшего горючего, должны рассматриваться как «собственные нужды» ядерной энергетики. Отработавшее горючее и произведенный плутоний также следует рассматривать как подлежащие использованию в ядерной энергетике в соответствии с их ценностью как горючего и как источников нейтронов.

ЭКОНОМИКА ЯДЕРНОЙ ЭНЕРГЕТИКИ КАК ОТРАСЛИ ПРОМЫШЛЕННОСТИ

В 1961-1963 гг. в Советском Союзе на основании накопленного опыта проектирования, строительства и эксплуатации атомных установок и предприятий топливного цикла был проведен технико-экономический анализ перспектив развития атомной энергетики СССР.

Рассматривалась возможность и необходимые условия достижения экономически конкурентоспособных показателей для всей системы производств, входящих в атомную энергетику, включая атомные электростанции и обслуживающие их производства. Изучение проводилось в сравнении с развитием обычной энергетики, также включая необходимое расширение топливной базы и транспортных средств.

Было рассмотрено много вариантов развития ядерной энергетики, различаемых по типу или комбинации типов используемых реакторов, по степени технического прогресса их основных характеристик, по темпам и масштабам развития ядерной энергетики в период до 1980 г. и по условиям работы предприятий топливного цикла. В настоящем докладе не представляется возможным изложить все результаты исследований, однако некоторые из них, наиболее общие, рассмотрены ниже. В табл. 2 приведены данные по возможному техническому прогрессу основных характеристик реакторов различных типов. Эти данные явились исходными при проведении одной из серий расчетов и исследований. Результаты анализа позволяют сделать определенные выводы о возможном развитии ядерной энергетики в условиях Советского Союза.

1. Ядерная энергетика как новая, только начинающая развиваться отрасль энергетики на первом этапе своего развития будет в состоянии конкурировать с обычной энергетикой в районах с относительно высокой стоимостью производства электроэнергии. По мере технического совершенствования АЭС и улучшения их экономических показателей число районов, где АЭС окажутся конкурентоспособными, будет постепенно возрастать.

Таблица 2. Ожидаемый технический прогресс в характеристиках реакторов при увеличении единичных электрических мощностей реакторов от 300 до 800 *Мвт*

Характеристики	Газо-графитовые реакторы на природном уране	Тяжеловодно-органические реакторы на природном уране	Водо-графитовые реакторы на слабообогащенном уране с перегревом пара в активной зоне	Водо-водяные реакторы на слабообогащенном уране	Реакторы на быстрых нейтронах с натриевым теплоносителем	
					Урановый переработчик	Плутониевый размножитель
Коэффициент полезного действия (брутто), %	35—37	30—33	40—45	30—33	40—42	40—42
Начальная концентрация делящихся изотопов, *кг/т*	7,14	7,14	30—50	30—50	190	150
Накопление продуктов деления, *кг/т*	3,6—5,2	3,6—7,7	30—40	30—40	50—100	50—100
Коэффициент воспроизводства	0,5—0,6	0,7—0,8	<0,4	<0,4	1,1—1,2	1,5—1,6

В районах Европейской части СССР при использовании донецкого угля в качестве топлива ожидаемые суммарные удельные капиталовложения на строительство тепловых электростанций, угольных шахт и транспорт для перевозки угля в период 1970—1980 гг. оказываются довольно высокими. При этом большая часть капиталовложений (50—60%) должна быть израсходована на развитие угольной базы и транспорта и только 40—50% — на строительство собственно электростанций.

Для того чтобы развитие атомной энергетики в указанных районах было экономически оправдано в сравнении с другими источниками энергоснабжения, необходимо, чтобы в ядерной энергетике были достигнуты примерно следующие экономические показатели.

	Суммарные удельные капиталовложения в АЭС и смежные производства, *руб/квт*	Себестоимость производства электроэнергии на АЭС, *коп/квт·ч*
	150—160	0,40—0,45
или	170—180	0,37—0,42
или	190—200	0,33—0,38

Указанный уровень экономичности АЭС может быть достигнут при увеличении единичной мощности реакторов до 500—1000 *Мвт* (эл.), коэффициента полезного действия до 35—40%, повышения глубины выгорания до 30 000—40 000 *Мвт·сутки/т* и до 60 000—100 000 *Мвт·сутки/т* в реакторах на тепловых и быстрых нейтронах соответственно. Получение таких глубин выгорания при высоких температурах в тепловыделяющих элементах с использованием металлического урана или его сплавов, по-видимому, трудно осуществимо, но безусловно достижимо при использовании керамического (окисного или карбидного) горючего. Кроме того, должно быть обеспечено серийное производство всех элементов оборудования и материалов для атомных электростанций и рациональная организация высокомеханизированного и автоматизированного на принципах массового производства изготовления тепловыделяющих элементов и переработки отработавшего ядерного горючего с временем внешнего цикла до 1,5—2 лет.

2. Экономически более выгодным (табл. 3 и 4) и в то же время позволяющим наиболее эффективно использовать ядерное горючее является развитие ядерной энергетики с преимущественным использованием реакторов на быстрых нейтронах единичной мощностью 500—1000 *Мвт* (эл.) с организацией смешанного уран-плутоние-

Таблица 3. Ориентировочная структура средневзвешенных удельных капиталовложений в развивающуюся ядерную энергетику при использовании реакторов различных типов

Наименование	Газо-графитовые реакторы на природном уране	Тяжеловодно-органические реакторы на природном уране	Водо-графитовые реакторы на слабообогащенном уране с перегревом пара в активной зоне	Водо-водяные реакторы на слабообогащенном уране	Реакторы на быстрых нейтронах с натриевым теплоносителем
Доля капиталовложений в атомные электростанции, % . . .	75	80	66	66	79
Доля капиталовложений в предприятия топливного цикла, % . .	25	20	34	34	21
Средневзвешенные удельные капиталовложения в ядерную энергетику, включая топливный цикл, *руб/квт*	239	231	173	205	161

Таблица 4. Ориентировочная структура средневзвешенной себестоимости электроэнергии при развитии энергетики с использованием реакторов различных типов

Наименование	Газо-графитовые реакторы на природном уране	Тяжеловодно-органические реакторы на природном уране	Водо-графитовые реакторы на слабообогащенном уране с перегревом пара в активной зоне	Водо-водяные реакторы на слабообогащенном уране	Реакторы на быстрых нейтронах с натриевым теплоносителем
Амортизация с текущим ремонтом, %	77	79	45	49	65
Топливо, %	11	10	48	45	25
Зарплата и прочие расходы, %	12	11	7	6	10
Средневзвешенная себестоимость электроэнергии, *коп/квт·ч*	0,40	0,42	0,43	0,48	0,33

Таблица 5. Характеристики топливного цикла для реакторов различных типов на 1 млн. *квт* (эл.)

Тип реактора	Рабочая концентрация делящегося изотопа, *кг/т*	Необходимые производительности по изготовлению и химической переработке тепловыделяющих элементов, *т/год*	Пусковая потребность в уране на период 3 года до начала возврата регенерата и плутония, *т*	Ежегодная потребность в уране после начала возврата регенерата и плутония, *т/год*
Реакторы на природном уране				
Газо-графитовые и тяжеловодно-органические	до 7	130—170	800—1000	40—100
Реакторы на слабообогащенном уране				
Водо-водяные и водо-графитовые с ядерным перегревом пара	до 50	20—25	80—100	16—20
Реакторы на быстрых нейтронах (активные зоны)	до 200	6 —8	18—25	Отсутствует; производится избыточный плутоний
Реакторы на быстрых нейтронах (экраны)	до 7	20—25	80—100	Менее 1,0

вого топливного цикла и с увеличением по мере накопления плутония доли реакторов-размножителей на быстрых нейтронах, работающих на плутонии.

Развитие ядерной энергетики с использованием реакторов на быстрых нейтронах требует незначительных по масштабам производств по изготовлению и химической переработке тепловыделяющих элементов активной зоны, умеренных мощностей по изготовлению и переработке экранных элементов и при дообогащении уранового регенерата активной зоны плутонием, вырабатываемым в реакторе, то есть требует обогащенного горючего только для обеспечения первоначальной загрузки каждого вновь вводимого реактора и одной-двух его перегрузок.

В этом случае развитие энергетики не требует непрерывного наращивания промышленности по добыче и обогащению урана и практически не зависит от них, так как наличие двух-трех комплектов активных зон оказывается достаточным «пусковым импульсом» для дальнейшей работы реакторов на быстрых нейтронах в режиме самообеспечения с одновременным накоплением избытка плутония на ввод новых мощностей с темпами порядка 8—10% в год. Этот темп может быть существенно повышен за счет добавления в энергетику делящихся веществ, ранее предназначавшихся для военных целей. Заявление Советского правительства от 21 апреля 1964 г. открывает такие возможности.

Величина «пускового импульса» увеличивается практически пропорционально вводимой мощности и составляет на 1 млн. *квт* вводимой электрической мощности для экономически конкурентоспособного реактора около 18,0—25,0 *т* урана с обогащением до 20%.

При этом на каждый миллион киловатт введенных электрических мощностей необходимо иметь предприятия топливного цикла по химической переработке и изготовлению смешанных уран-плутониевых твэлов в объемах до 6—8 *т/год* для горючего активной зоны и в объемах до 20—25 *т/год* для урана или тория из экрана.

В табл. 5 приведены сравнительные производительности предприятий топливного цикла, соответствующие 1 млн. *квт* (эл.) для реакторов различных типов.

3. Анализ структуры производств в системе ядерной энергетики показал, что доля капиталовложений в топливный цикл не превышает 20—30% при небольших мощностях ядерной энергетики в начальный период развития и по мере наращивания мощностей АЭС может быть снижена до 10—15%.

В этом заключается одно из основных экономических преимуществ ядерной энергетики при широком ее развитии, вытекающее из чрезвычайно высокой теплотворной способности ядерного горючего.

Этим обстоятельством обусловливается полученный в предварительных оценках результат, что эксплуатация атомных электростанций и обеспечивающих их предприятий топливного цикла при больших масштабах развития ядерной энергетики требует меньших трудозатрат по сравнению с эксплуатацией таких же мощностей угольных электростанций и необходимых для их работы предприятий по добыче и транспортировке угля, что в конечном счете характеризует более высокий уровень производительности труда, присущий ядерной энергетике.

ЗАКЛЮЧЕНИЕ

Наиболее правильным направлением развития ядерной энергетики в широких масштабах следует считать развитие с преимущественным использованием реакторов на быстрых нейтронах, работающих в первый период в конвертерном режиме и переходящих постепенно в режим размножения с коротким (~ 5 лет) временем удвоения ядерного топлива.

Строительство нескольких АЭС с реакторами на тепловых нейтронах, по которым в настоящее время накоплен большой инженерный опыт, представляется целесообразным в районах, где это в ближайшие годы является экономически оправданным.

Весьма важным наряду со строительством надежных и экономичных АЭС является разработка простых и дешевых методов переработки облученного топлива и удаления отходов в промышленных масштабах. До создания такой технологии может оказаться экономически оправданным длительное хранение отработавших тепловыделяющих элементов с невысоким содержанием ценных изотопов.

Развитие ядерной энергетики откроет большие возможности перед развитыми и развивающимися странами. Оно в значительной мере позволит повысить производительность труда в энергетике, существенно сократить объемы перевозок топлива, уменьшить зависимость общегосударственной энергетики от топливной базы и транспорта, в особенности для стран с ограниченными ресурсами органического топлива, существенно удешевить производство электроэнергии в районах с дорогим топливом и создать предпосылки для более широкого развития промышленности и освоения природных богатств в этих районах, использовать энергию излучения продуктов деления для создания принципиально новых технологических процессов в химии и других отраслях народного хозяйства.

По-видимому, в районах с дорогим топливом в СССР атомная энергетика после 1980 г. будет одним из основных направлений развития энергетики. В период до 1980 г. масштабы строительства АЭС в Советском Союзе предположительно могут измеряться несколькими десятками миллионов киловатт (эл.).

Есть все основания считать, что ближайшие 10—15 лет станут периодом широкого развития экономичной ядерной энергетики.

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ABSTRACT - RÉSUMÉ - АННОТАЦИЯ - RESUMEN

A/294 USSR

Trends in atomic power development in the USSR

By N. M. Sinev *et al.*

Atomic power generation has passed the research and development stage and is now a practical possibility. It will play an important role in the power industry of several countries in the near future.

Wide-scale development of atomic power generation must be based on advance planning that has been thoroughly and scientifically substantiated.

Selection of the most effective version of atomic power development to make the best use of material and labour resources is a problem of paramount importance to the national economy. This necessitates the comprehensive comparative analysis of economic efficiency, with due consideration of the possible lines along which atomic power may develop in the years to come.

The planned nature of the socialist economy is such that an analysis need not be confined to separate atomic power stations but can be a comprehensive analysis within the framework of national or state economic plans, taking into account the required timescale for nuclear power development and the need to set up specialized industries.

The paper discusses the basic principles of this analysis and evaluates in a comparative way different versions of nuclear power development with reactors of various types.

The results of these analyses lead to a number of important conclusions as to future trends in nuclear power generation.

A/294 URSS

Tendances du développement de l'énergétique nucléaire en URSS

par N. M. Sinev *et al.*

La production d'énergie d'origine nucléaire, qui vient de passer du stade des tâtonnements à celui des applications pratiques, est destinée à jouer prochainement un rôle capital dans bon nombre de pays.

Il faut que ce vaste développement de l'énergie d'origine nucléaire repose sur des programmes minutieusement mis au point selon des méthodes scientifiques.

Ce qui importe pour l'économie nationale, c'est le choix de la variante la plus efficace de l'énergie d'origine nucléaire, qui permette d'utiliser d'une façon rationnelle les ressources matérielles et les réserves de main-d'œuvre.

De ce fait, il y a lieu d'analyser le rendement économique relatif sous ses aspects les plus divers, en tenant compte des tendances qui pourraient se manifester à longue échéance dans le développement de l'énergie d'origine nucléaire.

La planification étant à la base de l'économie socialiste, cette analyse, au lieu de se faire séparément pour chaque centrale atomique, peut s'effectuer d'une façon globale dans le cadre des plans d'économie nationale ou des plans d'Etat, compte tenu du rythme nécessaire pour assurer le développement de l'énergie nucléaire et tout en permettant l'implantation de productions spécialisées.

Le mémoire étudie les principes essentiels de cette analyse et indique les résultats comparatifs de l'évaluation à laquelle on doit procéder pour chaque variante possible de la production d'énergie d'origine nucléaire à l'aide des divers types de réacteurs.

Les résultats de ces études permettent d'aboutir à un certain nombre de conclusions importantes sur les tendances du développement ultérieur de l'énergie d'origine nucléaire.

A/294 URSS

Tendencias del desarrollo de la energética nuclear en la URSS

por N. M. Sinev *et al.*

El desarrollo de la energía atómica está pasando de la etapa experimental y de investigación a la vía de su aplicación práctica, y en un futuro próximo ocupará en muchos países un puesto relevante en el campo de la obtención de energía.

Todo desarrollo en gran escala de la energía nuclear debe basarse en una cuidadosa planificación científica.

La elección de la variante más eficaz del desarrollo de la energía nuclear, con vistas a facilitar una utilización racional de los recursos materiales y de trabajo personal, es de máxima importancia para la economía nacional.

En relación con ello, surge la necesidad de un análisis comparativo de los rendimientos económicos desde los diferentes puntos de vista, teniendo en cuenta la proyección en el futuro de las posibles directrices del desarrollo de la energía nuclear.

El carácter planificado de las economías socialistas permite llevar a cabo este análisis, no aisladamente para diferentes centros de energía atómica, sino encuadrándolo dentro de los planes económicos conjuntos nacionales y estatales, teniendo en cuenta los ritmos necesarios del desarrollo de la producción de energía nuclear y de la creación de las industrias especializadas.

En el informe se discuten los principios básicos de este análisis y se dan los resultados de las estimaciones comparativas del desarrollo de la energía nuclear según los diferentes tipos de reactores utilizados.

Los resultados de estos análisis permiten obtener una serie de importantes conclusiones sobre las vías del ulterior desarrollo de la energía nuclear.

Nuclear power in the United Kingdom

By Sir William Penney*

When we last came together here under the auspices of the United Nations, for the Second Conference on the Peaceful Uses of Atomic Energy, the application of atomic energy for the generation of electricity was at a very early stage. In the six years since then, a nuclear industry has developed in many countries. In 1958 we still showed the exuberance and over-optimism of a very young industry. Subsequently we had growing pains and we went through a period of doubt and uncertainty. That phase too has passed. We now have a good many years' work on the commercial application of nuclear power behind us. This has given us greater knowledge of the economic uncertainties still ahead and has also given us solid confidence in the future of nuclear power, based on a balanced and realistic estimate of prospects. Even on a cautious basis, we can confidently expect that nuclear power will become competitive within a few years in several countries; and thereafter it will be able to compete over wider and wider fields. In the more distant future nuclear power will make a major economic contribution to satisfying expanding energy needs.

I suggest, therefore, that confidence based on experience and realism is the appropriate background for this Third Conference.

PROGRESS WITH THE FIRST UK NUCLEAR POWER PROGRAMME

The UK embarked on the first Nuclear Power Programme in 1955. At the time of our last conference it was planned to install 5 000 MW or more of nuclear capacity in the United Kingdom by 1966. However, supply prospects for coal and oil improved and prices fell; there were advances in conventional plant design and costs were reduced; in 1960, the programme was stretched out, and completion is now expected in 1969.

For this programme, the pioneering work of reactor development, the supporting basic research, the acquisition of uranium and the manufacture [1] and reprocessing [2, 3] of fuel are the tasks of the Atomic Energy Authority, who have created extensive facilities to support the programme. The design and construction of nuclear power stations and the development of improved designs are mainly the task of industrial consortia who have built up skilled design teams and research facilities. The stations themselves are ordered, owned and operated in England and Wales by the Central Electricity Generating Board (CEGB), who have set up supporting laboratories, and in Scotland by the South of Scotland Electricity Board (SSEB). Thus, as a result of carrying out the programme, a fully equipped, skilled and experienced national nuclear industry has been created.

Orders have now been placed for all the stations in the present programme. The first three, at Berkeley (CEGB), Bradwell (CEGB) and Hunterston (SSEB), are supplying power to the grid. Together with the Atomic Energy Authority stations at Calder Hall and Chapelcross, these stations are designed to have an output capacity of 1 250 MW; they should this year supply some 5% of the total power produced for the UK Electricity Boards. By this September, some 18 000 million kW hours of nuclear electricity should have been generated in the UK. Six more stations, with a total designed output capacity of 3 900 MW, are under construction for the CEGB at Hinkley Point, Trawsfynydd, Dungeness, Sizewell, Oldbury and Wylfa; they will come on power progressively in the next five years. By 1969 nuclear power should be supplying about 12% of total electricity production in the UK [4, 5].

The programme has been based entirely on the Magnox type of reactor. The consortia are incorporating improvements in successive stations [6-8]. The guaranteed output of individual reactors is rising from 138 MW(e) at Berkeley to 590 MW(e) at Wylfa. The mean fuel rating is rising from about 2.3 MW(th)/t U to 3.2 MW(th)/t U. An increase in the thickness of steel pressure vessels is leading to higher gas pressures; and in the stations being built at Oldbury and Wylfa, concrete pressure vessels are being used [9, 10], permitting still higher gas pressures. Thermal efficiencies are rising from 24% to over 33%; and the fuel rating (electrical) from under 0.6 MW(e)t U to over 1 MW(e)/t U. These advances, combined with improvements in station layout and management of work, are leading to an appreciable fall in capital costs per kilowatt and to reductions in fuel costs [1, 11]. The main data are given in Table 1 below.

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* Chairman, UKAEA.

Table 1. Capital costs and performance data for UK commercial nuclear power stations

Station	Date first reactor on power	Guaranteed output MW(e)	Thermal efficiency %	Fuel rating (electrical) MW(e)/t U	Capital [a] cost £/kW
Berkeley	1962	275	24.4	0.59	186
Bradwell	1962	300	28.2	0.63	176
Hunterston	1964	300	28.3	0.60	[b]
Hinkley	1964	500	26.4	0.72	150
Trawsfynydd	1964	500	29.4	0.85	137
Dungeness	1965	550	32.9	0.92	114
Sizewell	1965	580	30.5	0.91	107
Oldbury	1966	600	33.6	1.02	108
Wylfa	1968	1 180	31.5	1.00	100

[a] I.e., total station cost including tender price, site costs, and Generating Board engineering charges.
[b] Under negotiation.

THE UK DEVELOPMENT PROGRAMME

While industry has been mainly concerned with improving the Magnox system, the Atomic Energy Authority have been developing more advanced systems. The broad objectives of development have been arrived at after consultation with the Generating Boards and the industrial consortia.

The Authority sought first to exploit further the potential of the gas-cooled graphite-moderated system, building on experience from developing the Magnox system. This led to development of the advanced gas-cooled reactor (AGR), which was under way at the time of the last Geneva Conference. The prototype at Windscale went on full power early in 1963. This prototype has the highest coolant outlet temperature of any power reactor at present operating. During the first fifteen months of full power operation it has worked well. It has given a high availability and the fuel has behaved excellently [12].

The Authority's immediate task is to demonstrate on the actual reactor that the technical problems of the AGR system have been solved. This work is expected to be completed within a year or so, and over the next few years the amount of effort devoted to the AGR system by the Atomic Energy Authority will fall. The effort will be concentrated on realising the development potential of the system. One aspect of this is developing improved fuel elements [13] with objectives such as raising fuel temperatures, improving neutron economy and reducing fuel fabrication costs. There will also be work on the problems of designing very large reactors (of 1 000 MW or so).

The Authority's longer term development of the AGR system includes work on unclad, dispersed ceramic fuels [14]. As the AGR system is further developed in this way, its operating conditions should approach those of the High Temperature Gas-Cooled system. The Authority are taking part in the ENEA project at Winfrith in Dorset to investigate an HTGC system [15, 16]; the 20 MW(th) DRAGON reactor is expected to go critical this year. Supporting work is being carried out by the Authority and by the other nations collaborating in the project. The high temperature gas-cooled reactor is an advanced concept and poses major problems. One of the most important is to develop fuels able to retain fission products effectively at the very high temperatures involved and much work is being devoted to this. Studies are also being made on a variety of fuel cycles using plutonium and thorium-232 as well as uranium-235 and uranium-238. It is likely to take many years to develop the system to the stage of commercial application.

The Atomic Energy Authority have carried out work on water moderated systems for many years and have studied a number of reactor designs. The Authority have recently embarked on development of the steam-generating heavy water reactor (SGHW) system. A 100 MW(e) prototype is under construction at Winfrith, Dorset, which should be on power in 1968 [17, 18]. The Authority will use the development of this prototype as the basis for work on the long term development potential of this type of reactor and those related to it [19, 20]. The advantages of the SGHW will differ from those of the gas-cooled graphite moderated systems. For example, SGHW reactors may enable a wider range of sizes to be covered economically. Our work on this system should ensure therefore that we are in a position to exploit both of the main lines along which advanced types of thermal reactor are likely to be developed.

The largest single part of the Authority's development effort is now devoted to work on fast reactors. The programme has the aim of producing power at low cost using the plutonium from thermal reactors; and in the very long term this system should permit much higher utilisation of natural uranium. The Dounreay Fast Reactor, which was completed in 1960, has now operated successfully at its design rating of 60 MW(th) for long periods since June 1963 and has been supplying power to the grid [21]. This is the first fast reactor to have produced electricity for public use and to have operated at such high power levels. The reactor has been easy to control over the full power range and is proving a valuable fuel test facility [22, 23].

The immediate task now is to choose the most suitable fast reactor fuel for future development. Priority is being given to plutonium/uranium oxide fuels [24, 25], although carbides and cermets are being considered as well [26, 27]. Studies are being made of the behaviour of alternative fuel cladding materials under the temperature and irradiation conditions of a fast reactor core. Manufacturing and reprocessing techniques are being developed [25]. The first objective of fuel development is to achieve burn-up of 5% of all heavy atoms, but it is hoped to achieve much higher burn-up in the long run.

In parallel with this, the Authority are studying major design problems of a large fast reactor installation and are developing the associated engineering techniques. The ZEBRA zero-energy facility is being used to provide reactor physics information and to correlate this with the results of computer studies [28].

When a satisfactory fuel has been developed and the main reactor design features have been decided, Government approval will be sought to build a prototype fast reactor. This will have to be large enough to demonstrate the operating characteristics for the core and fuel of a 1 000 MW(e) commercial fast reactor. If the programme goes as now planned the prototype should be on power soon after 1970; the first commercial station could then be on power towards the end of the 1970s.

The Authority expect that fast reactors will provide the most economic use of plutonium in the long run. But large plutonium stocks will begin to accumulate in the UK several years before fast reactors are in commercial use on a sufficient scale to absorb them. It may be desirable to use plutonium stocks in thermal reactors during these years. Some development effort is therefore being devoted to the use of plutonium instead of uranium-235 as enrichment in advanced gas-cooled and SGHW reactors [29, 30].

A broad programme of general research will also continue. There will be substantial effort on research into problems common to a number of reactor systems, basic studies on the properties of materials, the effects of radiation, the structure of solids, nuclear physics, instrumentation and health and safety problems, and work in other fields including direct conversion and disposal of wastes [31-36]. A proportion of Authority effort will continue to be devoted to pure research. A significant contribution to general research is made by the Universities and private industry [37-39].

The Atomic Energy Authority's expenditure on all types of civilian research and development rose steadily until by 1962 it reached about £50 million per annum. This level of spending is likely to continue for some years; much of it will be on work in support of the nuclear power programme. In addition, the GEGB and private industry will continue to devote research effort to problems arising from design, construction and operation of the commercial stations [40-43].

In the long term, this large research and development effort by the United Kingdom should be repaid many times over through bringing down the total cost of power to the nation. This will come partly through the reductions we hope to achieve in the cost of nuclear electricity; and partly through the general increase in available fuel resources. These are the issues dealt with in the remainder of this paper.

ECONOMIC ASSESSMENT OF NUCLEAR POWER

That the trend of nuclear power costs will be downwards is beyond doubt. But if we ask ourselves, with any system, "What will be the cost of power?", there can be no simple answer. Estimates of nuclear costs mean little without definition of the underlying assumptions and an appreciation that these must be subject to wide variation.

The generating costs of nuclear electricity are sensitive to the assumptions made on the rate of interest and station life (which together determine the rate of annual capital charges) and on the lifetime load factor achieved (which determines the number of units over which the capital charges are spread). Taxes also have their effect. Differences of approach on these issues have their greatest impact on comparisons between nuclear and conventional power. But they can also be decisive in comparing nuclear types if the balance between capital and fuel costs is different.

The rate of interest and taxes assumed varies from country to country depending upon national policy, on the availability of capital and on the financial and tax structure. In the United Kingdom, we now expect the long-term cost of borrowing to be around 5.5%. But to ensure that the rate on new investment is consistent with the level of earnings agreed between the electricity industry and the Government, the rate used for economic assessment by our CEGB is 7.5%. This has not always been so. When we embarked on the UK power programme in 1955 before the need for a sufficient level of earnings came to the fore, the rate in use was 4%, which was then the expected long-term borrowing rate. Such large changes in interest rate can significantly alter the economic picture. With the station at Wylfa, for example, if 75% load factor and 20-year life are assumed the generating costs with interest at 7.5% are estimated at 0.6 pence/kWh, but a fall in interest rate to 4% reduces this to 0.56 pence/kWh.

While the rate of interest and taxes are essentially financial matters, the assumptions used on useful life, load factor and fuel burn-up must follow mainly from technical judgements. At this stage in the development of nuclear power there is room for wide differences of opinion on each of these assumptions. The effect of such differences is again large. This is illustrated in Table 2 where the generating costs of the CEGB stations in the present UK nuclear programme are shown on two sets of assumptions (with 7.5% interest and no credit for irradiated fuel assumed in each case).

Apart from the costing assumptions used, estimated costs are also much dependent on the size of programme of a particular reactor type. This determines how much advantage can be taken of the great economies of scale possible through building large reactors and placing several reactors on one site. It determines the ability to reduce costs by placing repeat orders, and it affects the cost of fuel, which is also reduced by manufacturing on a large scale. To get the maximum advantages of nuclear power, it is necessary to have a strong construction programme, large stations, large reactors and some standardization.

The characteristics of a national nuclear industry also affect costs. Its skill and experience are obviously important. So too is the size of the industry in relation to demand, which affects the level of overheads. The commercial policy of the manufacturers, their competitiveness and their willingness to take risks can have a big effect on prices. The costs of a nuclear programme are also influenced by the degree of boldness or caution adopted by utilities in their specifications, and by the extent to which they encourage standardization of designs. These organisational considerations may themselves be big enough to have a decisive effect on comparisons between different nuclear systems and on their competitiveness with conventional power.

Other assumptions having an important bearing on nuclear costs, and with scope for wide differences of view, are those relating to the cost of the natural or enriched uranium used and the credit for irradiated fuel [44,45].

The area of uncertainty widens further still when comparison of nuclear costs with those of alternative conventional plants is made. The major uncertainty is the level of conventional fuel and fuel transport costs for many years ahead. Demand for conventional fuel is rising rapidly, while new sources of supply are constantly being opened up. A broad judgement must therefore be made of the likely balance of the two factors. Allowance must also be made for the fact that a large nuclear programme will produce strong competition for conventional fuel supplies and will help to keep prices down.

With such a formidable combination of uncertainties it is tempting to throw up one's hands in despair of making a valid assessment of relative economics. But for decision-making we must establish the areas of greatest probability. We can best do this by assessing costs on alternative sets of ground rules which give extreme ends of the range within which the truth is most likely to be found.

In each generating system, the ranges of costs for nuclear and conventional power will overlap and finally cross as nuclear technical development proceeds and nuclear stations are increased in size. Once the two begin to overlap, nuclear power will have gained an economic place in the generating system. But the period of overlap will last for many years: initially this will reflect geographical differences in conventional fuel costs; in the longer term it will be the result mainly of system limitations on the load factor at which nuclear stations can work. In an integrated system, the conventional stations which would have been built in the absence of a small nuclear programme would be in areas of high fuel cost and would operate at relatively low load factor. As nuclear stations come to be considered for a larger share of new capacity, they will have to justify themselves against conventional stations

Table 2. *CEGB nuclear stations: Generating costs on varying assumptions*

(Pence/kWh sent out)

	20-year life, 75% load factor, 3 000 MWd/t burn-up			25-year life, 85% load factor, 4 000 MWd/t burn-up		
Station	Capital charge [a]	Running cost [b]	Generating cost	Capital charge [a]	Running cost [b]	Generating cost
Berkeley	0.83	0.38	1.21	0.68	0.30	0.98
Bradwell	0.77	0.30	1.07	0.62	0.24	0.86
Hinkley	0.69	0.35	1.04	0.56	0.27	0.83
Trawsfynydd	0.63	0.33	0.96	0.50	0.27	0.77
Dungeness	0.50	0.24	0.74	0.40	0.20	0.60
Sizewell	0.47	0.26	0.73	0.38	0.21	0.59
Oldbury	0.47	0.23	0.70	0.38	0.19	0.57
Wylfa	0.44	0.23	0.67	0.35	0.19	0.54

[a] Capital charges cover interest and amortisation on station cost, interest during construction and initial fuel.

[b] Running costs cover fuel replacement, fuel hold up, fuel handling, other works costs, insurance, indirect costs and royalties Apart from fuel replacement the pence/kWh costs for these items can vary with load factor.

built in progressively less-expensive fuel areas, which would operate at a somewhat higher load factor. The nuclear stations would work at the highest possible load factor. We must therefore make detailed economic comparisons on the basis of the effect each station has on total system costs, and not just compare the cost of power from the individual stations being considered.

Techniques for making comparisons of system costs have been established by the electricity authorities in the United Kingdom [5]. Nuclear capital and fuel costs can now be estimated on the basis of the experience gained by the industry over several years. The essential problem that remains is to set the range of assumptions. In doing this we have to strike a balance between, on the one hand, the caution needed in face of the capital investment required for nuclear power and the technical uncertainties where new types are concerned, and, on the other, the boldness needed if the economies of scale in nuclear power are to be realized.

PROSPECTS IN THE UNITED KINGDOM

In the United Kingdom we recently made a detailed economic study of the part which nuclear power could play in our electricity generating system, with stations to be commissioned between 1970 and 1975. The Government's decision announced in a White Paper [46] in April this year was that the CEGB would plan to commission 5 000 MW of nuclear power in England and Wales in this period; this would be regularly reviewed and the possibility of another station in Scotland would also be examined.

The study showed that even on conservative assumptions nuclear power could command a place in the generating system on economic grounds in the period 1970-1975. In my own view, a programme of 5 000 MW over six years is rather on the small side if we are to get nuclear costs decisively attractive. However, the Government had also to take into account the considerable extra capital required. In the words of the White Paper, because of this and "the many calls on the country's scarce capital resources, it is necessary to steer a course between committing the country to an excessive immediate burden of capital costs and failing to take advantage of the prospective low total costs of nuclear power. It is also necessary to ensure that the programme is large enough to provide adequate experience and to sustain facilities for rapid expansion in later years".

Looking beyond 1975, a considerable expansion of the UK programme seems likely. There is every reason to expect that, if development proceeds as planned, nuclear power in these later years will prove significantly cheaper than conventional power for an increasingly large proportion of the new plant required by the UK Electricity Boards.

On the choice of reactor type, each of the more advanced types has its advocates; each appears capable of showing an advantage over its competitors under certain economic conditions. Our own studies showed that the AGR was one of the most promising systems for the continuance of the British nuclear power programme, but we also want to look further at some water-moderated reactors before a final choice is made. We are, therefore, trying to find out more about the costs of all these systems on the basis of firm tenders from British industry. The problem then will be to judge the tenders on a comparable basis, both in respect of capital and running costs. This is not going to be easy because it will be necessary to extrapolate from the tenders for possible first UK stations in order to get figures for a run of stations; and doing this involves many of the difficulties of making proper comparisons which I have already described.

For the moment, therefore, the choice for the next stage of the UK programme is still open. In about a year's time, the information on which a good decision can be based should be available. If the AGR work goes as well as we expect, the AGR will be a very strong competitor.

With economic power possible from a number of reactor types, the same wide choice is now possible for many countries. As a result, nuclear power, with one system or another, has the chance of being competitive in widely differing circumstances. This view is borne out by estimates made both in the USA and Europe. There seems every reason, therefore, to expect a big growth of nuclear power in several countries in the next few years.

CONTRIBUTION TO ENERGY SUPPLIES

As nuclear power becomes more and more attractive, it will provide a growing economic contribution to fuel supplies. And it is clear that a large long-term growth in the energy provided by nuclear power as well as conventional sources will be necessary. The UK Government has set the target of a steady and continuous growth rate of 4% a year in real terms for our gross national product. The relationship between growth rate and fuel demand cannot be forecast precisely. But if we do achieve a growth rate of 4% or near to it, our present-day use of 275 million tons coal equivalent a year will rise to between 400 and 450 million tons by 1980 and to between 600 and 800 million tons by the end of the century.

Coal will remain a major source of energy in the UK. The discovery of oil or natural gas under the North Sea might provide us with an important new source. But it is likely that much of our growing demand for energy will have to be met by imported oil or nuclear energy.

A great expansion of demand for oil is foreseen for Western Europe, North America and the developing countries. There should be no difficulty about meeting world demand for oil for the next 10 or 20 years. Beyond that, new reserves will have to be found to meet even bigger increases in demand. With the oil industry's long and successful record of finding the reserves needed, there is no reason to think that these will not be found. However, the discovery and development of these reserves will require a big and costly effort by the oil industry. A large contribution to energy supplies by nuclear power would help to keep down the general level of energy costs.

Another factor of importance in the case of the UK is that the import cost of generating an equivalent amount of electricity from oil is much higher than the import cost of generating it from uranium, especially if we rely on our own diffusion plant for enrichment.

I conclude therefore that we must be prepared to meet economically a UK demand for nuclear power to supply perhaps 100 million tons coal equivalent a year by the mid-1980s, and perhaps 250 million tons by the end of the century. We could certainly satisfy this demand. We have a strong nuclear industrial base already in existence. There are reactor systems already available which can compete with present conventional power costs; and systems under development should lead to much lower costs.

It seems likely, however, that a really major expansion of low cost nuclear power will depend on the successful development of fast reactors. Initially, the main benefit from the introduction of economic fast reactors should be the raising of plutonium values due to the more efficient use of plutonium possible in fast reactors than in thermal reactors; this should lead to a general lowering of nuclear power costs compared with those possible with only thermal reactors. Looking further ahead, the main contribution of the fast reactor will be in ensuring efficient utilisation of uranium. We may well be faced with appreciable rises in the price of uranium in the long term, as the cheaper reserves are exhausted [47].

It would perhaps be thirty or forty years before, in the absence of fast reactors, the need to conserve uranium resources would become acute. But there is much to be done. The development of fast reactors will take many years and, around the world, commercial stations are unlikely to be on power in any numbers until the 1990s. Large programmes of breeder stations will need enormous stockpiles of plutonium for their initial fuelling, which will have to be drawn either from thermal reactors or, much later, from earlier breeders. The doubling times with which breeders are likely to increase their original fissile inventories will be long, so that the first breeder reactors must be brought into operation some years before any large expansion of nuclear fuel utilization is required.

The UK is therefore moving ahead with fast reactor development. With this and work in other countries now well under way, we can, I think, be confident that economic fast reactors will be available when they are needed.

Rapid expansion of nuclear power will also require solution to the problems of waste management and siting. The waste management problem is largely solved: liquid storage should be adequate for many years [35]; and the work on fixation of high activity wastes in glass has progressed far enough [36] to show that this is a practicable and economic alternative. We can expect siting limitations on nuclear stations to become progressively less onerous as experience demonstrates the safety of nuclear power [48-50]. One siting advantage which nuclear stations will enjoy over the coal or oil fired stations is their freedom from the problem of atmospheric pollution.

CONCLUSION

In this paper I have looked forward to the end of this century and beyond. This requires no apology. It is essential to an understanding of the role of nuclear power. For there are two cardinal elements affecting world energy prospects: the growth of population, which may double by the beginning of the next century; and the deep desire of all nations to offer their people a better life.

A better life for a growing world population means a rapid economic expansion of the new stations and a sustained growth in the already developed countries. This will require large extra supplies of cheap energy. By the end of this century, we can expect world energy demand to have multiplied several times.

At our first two conferences, we saw grounds for hope that nuclear power would make a large contribution to satisfying this growing demand. The achievements since then have confirmed these hopes. Economic nuclear power will be produced in quantity in several countries by stations now building or soon to be ordered; and during the 1970s and 1980s, nuclear energy should become the cheapest source of power over a steadily widening field. Moreover, the development of fast reactors should ensure that nuclear power will be able to expand rapidly without running into long term difficulties over the supply of fuel.

The Conference can therefore look forward to an ever-growing need for nuclear power, confident that the nuclear industry will be able to satisfy that need and to satisfy it cheaply.

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ABSTRACT - RÉSUMÉ - АННОТАЦИЯ - RESUMEN

A/559 Royaume-Uni

L'énergétique nucléaire au Royaume-Uni

par sir William Penney

Le mémoire traite de la réalisation du programme d'énergétique nucléaire du Royaume-Uni et des plans provisoires pour son extension après 1970.

A l'époque de la seconde Conférence de Genève, en 1958, l'utilisation de l'énergie d'origine nucléaire était à ses débuts dans la plupart des pays. Le Royaume-Uni possède maintenant plusieurs centrales nucléaires en fonctionnement et, à la fin de la décennie, il disposera d'environ 5 000 MW(e) de puissance installée nucléaire.

Depuis le fonctionnement couronné de succès de Calder Hall en 1957, les progrès en matière de réacteurs au Royaume-Uni se sont poursuivis en passant par le programme des centrales du type "Magnox", jusqu'à la mise en service du prototype de réacteur avancé à refroidissement par gaz de Windscale. La mise au point, grâce à une coopération internationale, du type de réacteur à haute température à refroidissement par gaz dans le projet DRAGON de l'OCDE est à mentionner à cet égard. Le programme du Royaume-Uni est basé sur des recherches générales menées sur un vaste front, et les études ont été élargies pour comprendre un projet important à modération à l'eau (réacteur à eau bouillante modéré à l'eau lourde). Des progrès notables ont été enregistrés pour le réacteur à neutrons rapides maintenant en cours d'étude et dont le but est de produire de l'électricité à un coût rentable et d'obtenir une utilisation élevée de l'uranium naturel. Des recherches sont également en cours sur l'enrichissement en plutonium dans les réacteurs à neutrons thermiques.

Le mémoire discute des problèmes que posent des estimations économiques. Etant donné que l'énergie d'origine nucléaire est caractérisée par de faibles frais de fonctionnement et par des frais d'investissement élevés, les estimations dépendent des conditions économiques et des caractéristiques du réseau de production d'énergie dans le pays en cause, ainsi que du degré de prudence dont on fait preuve. L'ensemble de ces facteurs détermine le taux des charges financières et les règles de base à prendre en considération. Les perspectives économiques pour l'énergie d'origine nucléaire ou pour des systèmes particuliers varieront donc d'un pays à l'autre.

Le mémoire traite de la situation au Royaume-Uni, où l'électricité d'origine nucléaire devrait, après 1970, concurrencer, sur le plan économique, l'énergie classique.

La troisième Conférence de Genève arrive en temps opportun pour montrer que les avantages à long terme du recours aux combustibles nucléaires deviendront de plus en plus apparents à mesure que la demande mondiale d'électricité augmentera et que les programmes nucléaires actuels porteront leurs fruits.

A/559 Соединенное Королевство

Развитие атомной энергетики в Великобритании

Сэр У. Пенни

В докладе обсуждается осуществление программы по атомной энергетике Великобритании и предварительные планы по ее расширению на период 70-х годов.

К моменту Второй Женевской конференции 1958 года применение атомной энергии в

большинстве стран находилось еще на сравнительно ранней стадии. В настоящее время в Великобритании эксплуатируется уже несколько атомных электростанций, а к концу текущего десятилетия общая мощность атомных станций страны составит около 5000 *Мвт* (эл.).

Реакторостроение началось в Великобритании после успешного введения в строй реактора в Колдер-Холле в 1957 году и развивается в результате осуществления программы сооружения атомных электростанций с магноксовыми реакторами и введения в строй усовершенствованного прототипа реактора с газовым охлаждением в Виндскейле. Эта программа включает проведение совместно с Организацией экономического сотрудничества и развития разработки высокотемпературной реакторной системы с газовым охлаждением по проекту DRAGON. Программа Великобритании осуществляется путем выполнения в широком масштабе различных исследований общего характера; помимо этого, в нее была включена разработка крупного проекта реактора с водяным замедлителем SGHW (тяжеловодный реактор с генерацией пара в активной зоне). Большие успехи достигнуты в работах по реактору на быстрых нейтронах, который разрабатывается в целях экономичного производства электроэнергии и высокой степени использования природного урана. Ведутся также исследования по обогащению плутония в реакторах на тепловых нейтронах.

В докладе рассматриваются вопросы, ответы на которые необходимы для оценки реакторов с экономической точки зрения. Поскольку для атомной электростанции характерны низкие эксплуатационные расходы и относительно высокие капитальные затраты, оценки зависят от экономических условий, характеристик энергосистемы в данной стране и от соответствующей предусмотрительности. Эти факторы определяют как размеры капитальных затрат, так и принимаемые за основу правила оценки. Поэтому определение экономических перспектив атомной энергетики в целом или отдельных энергосистем будет изменяться в каждой отдельно взятой стране.

В докладе обсуждается развитие энергетики в Великобритании, где атомная электроэнергия должна стать экономически конкурентоспособной с обычной электроэнергией в 70-х годах.

Созыв Третьей Женевской конференции является вполне своевременным для того, чтобы показать, что в дальнейшем выгоды от использования ядерного топлива будут становиться все более и более очевидными по мере роста мирового спроса на электроэнергию и по мере того, как осуществляемые в настоящее время программы по разработке реакторов начнут приносить свои плоды.

A/559 Reino Unido

La energía nuclear en el Reino Unido

por Sir William Penney

El presente informe describe los progresos realizados de acuerdo con el programa nuclear del Reino Unido y los planes provisionales para extenderlo a los años setenta.

Durante la celebración de la segunda Conferencia de Ginebra en 1958, la aplicación de la energía nuclear se encontraba en un estadio relativamente inicial en la mayor parte de los países. En el Reino Unido hay actualmente en funcionamiento varias centrales de energía nuclear y para fines de la presente década habrá unos 5 000 MW(e) de origen nuclear.

El desarrollo de los reactores en el Reino Unido después de la operación con pleno éxito de Calder Hall en 1957, ha evolucionado del programa de las centrales magnox a la operación del prototipo de reactor refrigerado por gas, mejorado, en Windscale. Incluye el desarrollo, en cooperación con la OECD, del proyecto DRAGON, un reactor de alta temperatura refrigerado por gas. El amplio campo de investigación general y de desarrollo, base del programa del Reino Unido, se ha extendido recientemente con el fin de incluir un proyecto de reactor moderado por agua (reactor de agua pesada generador de vapor). Se ha progresado bastante en el proyecto del reactor rápido que se está desarrollando con el propósito de conseguir energía económica y una elevada utilización del uranio natural. También se investiga la utilización del plutonio enriquecido en reactores térmicos.

Este informe discute cuestiones a las que se podrá responder después de hacer valoraciones económicas. Dadas las características de la energía nuclear: bajo costo de operación apareado con unos costos de capital relativamente altos, las valoraciones dependen de las circunstancias económicas y de las características del sistema productor de energía en el país en cuestión y del grado de seguridad que se aplique. Todo ello determina los intereses del capital y las normas básicas que hay que suponer. Las perspectivas económicas previstas para la energía nuclear o para los sistemas individuales variarán de un país a otro, por consiguiente.

Este informe discute la situación en el Reino Unido, donde la energía nuclear podrá competir económicamente con la ordinaria en la década que empieza en el año 1970.

La tercera Conferencia de Ginebra ha sido convocada oportunamente para mostrar que los beneficios a largo plazo de la explotación de los combustibles nucleares se incrementará conforme aumente la demanda mundial de electricidad y los programas que actualmente se están desarrollando den sus frutos.

Needs of nuclear power generation and the related programme in Japan

Japan Atomic Energy Commission

In the last ten years Japan has achieved a high rate of economic growth in spite of the shortage of domestic energy resources and having, therefore, to depend substantially on imports to meet her energy requirements. This economic growth will continue for many years to come. She must, therefore, secure low-cost energy supplies as well as achieve technical know-how and improve her industrial structure.

This is the reason why Japan has a keen interest in the peaceful uses of atomic energy, and is making every effort to promote related research and development though she has only ten years' experience in this field.

In 1961, the Japan Atomic Energy Commission established the Long-Range Nuclear Development Programme clarifying its policy and its targets for developing the use of atomic energy.

LONG-TERM PROSPECTS OF SUPPLY AND DEMAND OF ENERGY

The Long-Range Nuclear Development Programme is based on the National Income Doubling Plan, established by the Government in 1960 in which the gross national productivity is required to increase at the rate of 7.8% per year in order to double the level of national economy by 1970 with a steady stabilized growth.

According to the Plan the total energy demand will rise in 1970 to 303 million tons coal equivalent (7 000 kcal/kg) and in 1980 to 514 million tons, i.e., increasing to 2.3 and 3.9 times, respectively, the demand in 1959. Of this total demand, that for electricity is expected to increase to 235×10^6 MWh and 430×10^6 MWh in 1970 and 1980 respectively (2.8 and 5.1 times that in 1959). Whereas for other types of energy over the same period, the estimated increase is 2 and 3.2 times the 1959 figure. The proportion of electricity in the total energy demand rises from 38% in 1959 to 47% and 50% in 1970 and 1980 (Table 1).

As regards the primary energy supply, the Plan estimates an increase to 283 million tons in 1970 and 455 million tons in 1980 (increases of 2.1 and 3.4 times the 1959 figure).

A sharp rise in oil demand is expected to reach 98 kl (1970) and 199 kl (1980) (increases by factors of 3.5 and 7.2 over the 1959 value), while a moderate increase (by factors of 1.5 and 1.7) to 91.9×10^6 MWh in 1970 and to 105.9×10^6 MWh is expected for hydroelectric power. The proportion of each of the total energy supply at the same three dates is shown in Table 2; for both hydroelectric power and coal, the percentage steadily decreases, whereas for oil the reverse applies.

The sharp increase in energy supply has to be met by imports, for which the percentage of the total energy supply increases from 33.6% in 1959 to 58.8% and 72.5% in 1970 and 1980 respectively.

Electricity supplies in 1970 are estimated as 91.9×10^6 MWh from hydropower and 169.7×10^6 WMh from thermal power; the percentage of the latter increases sharply from 36% in 1959 to 65% in 1970. As regards generating capacity, including reserve capacity, it is estimated that 21 500 MW is required for hydraulic hydropower in 1970 and 31 400 MW thermal power (Table 2).

LONG-RANGE ENERGY POLICY AND ROLE OF NUCLEAR POWER

The National Income Doubling Plan requires, as the fundamental policy of long-range supply, the establishment of an economic structure for energy supply, reduction of the amount of foreign currency spent on the import of energy and stabilization of energy supply. On the basis of the economic prospect of the Plan, the Japan Atomic Energy Commission set out the Long-Range Nuclear Development Programme in 1961. The philosophy of this Programme on nuclear power generation can be summarized as follows:

(1) A generation capacity of 36 220 MW from new installations is required by 1970 and 48 190 MW in the following ten years.

(2) For the newly installed capacity, the possibility of utilizing hydropower is limited so that the emphasis will be on thermal power.

(3) For thermal power most energy sources will have to be imported.

(4) Development of cheaper energy sources and diversification of those available is required.

These considerations lead to the adoption of nuclear power generation. The Atomic Energy Commission has decided in the Programme that 1 000

Table 1. Forecast of energy demand

(Unit, 1 000 tons of coal at 7 000 kcal/kg)

Energy	Year			Rate of increase (%)		
	1959 (actual)	1970	1980	1959 (actual) 1950	1970 1959	1980 1959
Total energy	131 815	302 760	513 614	(8.7) 207	(7.8) 230	(6.7) 390
Electricity[a]	(84.5)[b] 50 691	(235.0)[b] 141 000	(430.0)[b] 258 000	(10.6) 246	(9.7) 278	(8.1) 509
Other energy	81 124	161 700	255 614	(7.7) 194	(6.5) 199	(5.6) 315

[a] Unit of electricity is 10^6 MWh.

[b] Average rate of increase per year.

MW(e) of nuclear power generation will be achieved by 1970 and 6 000 to 8 500 MW(e) during the next ten years (1971–1980).

Although it was estimated in the Plan that the Japanese economy would grow steadily at an average increase per year of 7.8% of the gross national productivity, actual records show the higher growth rate of 15.3% from 1959 to 1962. Also energy demand is showing an average growth rate of about 13% per year. This indicates that the growth of energy demand will be greater than estimated in the Plan, in particular a sharp rise in electricity demand is expected requiring the installation of large-scale thermal power stations. Thus nuclear power will gain in importance because it satisfies the principles, of "the lowest possible cost" and "stabilized supply" of energy. Recently the National Energy Policy Committee of the Ministry of International Trade and Industry's Council of Industrial Structures reviewed future policy and made public its report in which the same conclusion is reached as outlined above.

In view of this development situation, it is important that the targets set for the construction of nuclear power stations in the Long-Range Nuclear Development Programme should not only be realized but must also be stepped up in due course.

NUCLEAR POWER PROGRAMME AND ITS PROBLEMS

Prospect of nuclear power becoming competitive

It is generally expected that power stations burning crude oil will be the most popular thermal power stations constructed in the future to meet the increasing electricity demand. Power costs from these stations will fall due to the reduction in unit capital cost because of the larger scale, the increase of thermal efficiency and the downward trend in the price of oil, etc., and is expected to reach 6.7 to 8.4 mill per kWh by 1970.

On the other hand, the estimate based on available data on power reactor development and operating experience obtained in other countries and which takes account also of the high interest rate prevailing in Japan and the need for earthquake-proof designing, gives the cost of nuclear power as being competitive with that of oil-burning thermal stations by 1970. The nuclear power cost is expected to be further reduced if the present rate of technical progress continues.

Table 2. Forecast of primary energy supply

(Unit, 1 000 tons of coal at 7 000 kcal/kg)

Energy	Year			Percentage of total energy		
	1959 (actual)	1970	1980	1959 (actual)	1970	1980
Total energy	133 729	283 226	454 689	100	100	100
Hydropower (at end of transmission line)	(61.6)[a] 36 950	(91.9) 55 140	(105.9) 63 540	27.6	19.5	14.0
Coal	50 636	81 278	100 858	37.8	28.7	22.2
Oil	39 356	140 618	284 537	29.5	49.6	62.6
Others	6 787	6 190	5 754	5.1	2.2	1.2
Per cent of imported energy	33.6	58.5	72.5			

[a] Unit of electricity is 10^6 MWh.

Nuclear power generation programme

The Commission's Programme as mentioned above states that a total nuclear power generation capacity of 1 000 MW(e) will be developed by 1970 (preparatory period), and 6 000 to 8 500 MW(e) during the period from 1971 to 1980 (the period for industrial development).

Foreign reactors of proven type will have to be imported during the sixties, since Japan lagged behind other advanced countries in launching research and development on peaceful uses of atomic energy. In this respect, either light water-cooled or graphite-moderated gas-cooled reactors will be constructed. These two types of reactors will be constructed gradually by our own technology. In addition, the Programme expects that several reactors of the new types which may be developed will probably be constructed to some extent by Japan.

Regarding the demand for nuclear fuel, it is only possible to say at present that several hundred tons of natural uranium will be required by 1970 and several thousand tons by 1980.

Speaking of uranium resources in Japan, prospecting and experimental extraction of ores are being performed primarily by the Atomic Fuel Cooperation. Confirmed deposits around Ningyotoge and other areas amount to about 2 000 tons of U_3O_8—thus the fuel supply will have to rely on imports. There seems to be no problem in importing foreign natural uranium for the time being and for enriched uranium Japan expects to obtain supplies from the United States and IAEA.

In the field of spent fuel reprocessing, the construction of a plant capable of handling about 200 tons per year of natural uranium and slightly enriched uranium fuels is planned for completion in 1970.

Construction of nuclear power plants

JPDR, an experimental power reactor with an output of 12.5 MW(e) which the Japan Atomic Energy Research Institute imported from the General Electric Company of the United States, was completed in October 1963, and various experimental research studies are in progress to provide the data needed for future nuclear power technology.

An installation programme of the utility companies leading to the 1 000 MW(e) nuclear power target referred to earlier can be summarized as follows:

(a) Japan Atomic Power Company *

A 166 MW(e) graphite-moderated gas-cooled power reactor imported from the General Electric Company of the United Kingdom is now under construction by this Company at Tokai-mura. It is to be completed in March 1965. The JAEC has also decided to build a 250-300 MW(e) power station at a site in Tsuruga city, Fukui prefecture. For this station a light water-moderated reactor is to be adopted. Construction will start in 1964 and will be completed in 1968.

(b) Other utility companies

Three utility companies, Kansai, Tokyo and Chubu each have their own programme to construct nuclear power stations of about 300 MW(e) with completion dates in 1969 and 1970. In order to implement these programmes, they are attempting to secure sites and are investigating the conditions around likely areas.

The purpose of the Japan Atomic Power Company's present programme is to prepare the ground for a smooth promotion of programmes, and to follow by clarifying unknown factors associated with the foreign reactors of proven types. On the other hand, the purpose of the programme of these three companies is to accumulate an over-all experience of power reactors in the research and development stage, during the initial preparatory period, thus making practicable the introduction of nuclear power generation after 1970. Private industries will bear a major role in this development; the economics of nuclear power is of great importance to them.

The unit cost of the Japan Atomic Power Company's first commercial scale reactor is considered greater than originally estimated. The unit power cost of a light water-cooled reactor is estimated to be about 8.4 mill per kWh and is a little higher than that of an oil-burning power station.

In order to promote nuclear power generation during the research and development stage, the Government has to extend assistance to private utility companies. For this, financial help at a low interest rate, the establishment of a reprocessing service for spent fuels and a buy-back policy for spent fuels are now under consideration by the Atomic Energy Commission.

RESEARCH AND DEVELOPMENT OF POWER REACTORS

In the research and development field for future power reactors, a conceptual design of the prototype heavy water-moderated reactor is being prepared primarily by the Japan Atomic Energy Research Institute. Research and development of this type of reactor has been promoted by the Atomic Energy Commission as the Home-Made Reactor Project since 1963 with the expectation that the type will be proven for practical use after 1975.

Also, to use plutonium fuel efficiently, efforts are being made towards research and development of fast breeder reactors, and construction of a fast critical assembly has been under way since 1963.

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* Japan Atomic Power Company was established in November 1957 by private utility companies, the Electricity Resources Development Corporation, and electric and mechanical manufacturers, to construct and operate practical scale nuclear power stations in order to industrialize nuclear power generation in the preparatory period.

The future policy in relation to fast breeder reactors is now under careful consideration by the Commission.

NUCLEAR SHIP DEVELOPMENT

One of the important applications of nuclear power is its utilization for marine propulsion and it is expected that nuclear ships will be economically competitive with conventional ships in the future. Japan, as a shipping and shipbuilding country, considers it necessary to build up a technology associated with construction and operation of nuclear ships. The Japan Nuclear Ship Development Agency was set up in 1963 to have the primary responsibility for construction of an oceanographic survey ship of about 6 700 gross tons in which will be installed a 35 MW light water-moderated reactor.

The first nuclear ship in Japan is scheduled for completion in 1968. After 2 years (1969–1970) of experimental navigation, it is scheduled for oceanographic survey duties.

ABSTRACT - RÉSUMÉ - АННОТАЦИЯ - RESUMEN

A/577 Japon

Besoins d'énergie d'origine nucléaire et programme japonais correspondant

Commission de l'énergie atomique du Japon

Suivant les lignes du Plan de doublement du revenu national décidé en 1960 par le Gouvernement, la Commission de l'énergie atomique a établi en février 1961 le Programme de développement et d'utilisation à long terme de l'énergie atomique, portant sur la période de 20 ans, 1961–1980. Selon ce plan, et compte tenu de la croissance économique, la demande d'énergie électrique en 1970 et en 1980 sera respectivement de 2,8 et 5 fois environ plus élevée qu'en 1959, ce qui exige un développement important de la production d'énergie.

La possibilité de recourir à l'énergie hydroélectrique pour obtenir la puissance installée supplémentaire voulue est limitée, et l'effort devra porter sur l'accroissement de puissance installée thermique. En conséquence, le pourcentage des sources énergétiques importées passera à 59 p. cent du total en 1970 et à 73 p. cent en 1980, principalement en raison de l'importation de pétrole brut pour la production d'électricité.

Ainsi, non seulement pour préserver l'équilibre de sa balance des paiements mais aussi pour assurer un approvisionnement stable en ressources énergétiques, le Japon doit développer des sources d'énergie moins coûteuses et diversifier son approvisionnement énergétique. Le Programme de la Commission et le récent rapport du Comité de la politique énergétique nationale du Ministère du commerce extérieur et le Conseil de la structure industrielle indiquent que l'énergie d'origine nucléaire doit devenir l'une des principales sources d'énergie du pays.

Le Programme fixe l'ordre de grandeur de la production future d'énergie d'origine nucléaire: environ 1 000 MW(e) pour les premiers dix ans (stade de développement) et 6 000 à 8 500 MW(e) pour les dix ans suivants (stade d'exploitation industrielle). Il est prévu que les centrales seront construites et exploitées par des entreprises privées. L'expérience des trois dernières années a démontré que la demande d'énergie électrique dépassera les prévisions du Plan.

La construction de centrales, la recherche et les études dans un large domaine, la création d'organismes et d'une législation, etc., se font de manière suivie. Quant à l'équipement nucléaire, un réacteur de puissance expérimental est en fonctionnement et la première centrale doit être mise en service en 1965.

Quatre autres centrales nucléaires sont prévues vers 1970. En conséquence, la production énergétique nucléaire dépassera en 1970 les objectifs du Programme. Les réacteurs sont importés, mais la technologie de l'industrie nationale est activement développée. De plus, une usine de traitement des combustibles irradiés pouvant traiter environ 200 tonnes par an doit être achevée pour 1970.

Des études et recherches sur la propulsion nucléaire de navires ont été conduites conformément au Programme. En 1963 le projet du premier bateau à propulsion nucléaire a été établi, et un organisme spécial a été créé à cet effet.

A/577 Япония

Необходимость использования атомной энергии и программа развития атомной энергетики в Японии

Комиссия по атомной энергии Японии

Согласно плану Японии об удвоении национального дохода, который был принят правительством к 1960 году, Комиссия по атомной энергии Японии в феврале 1961 года разработала долгосрочную программу развития и использования атомной энергии, рассчитанную на 20 лет, то есть на период с 1961 по 1980 год. В соответствии с этим планом и в связи с ростом экономики потребности в электроэнергии в

1970 и 1980 годах увеличатся соответственно почти в 2,8 раза и в 5 раз по сравнению с 1959 годом. Поэтому потребуется значительное расширение производства электроэнергии. Возможность постройки дополнительных гидроэлектростанций большой мощности ограниченная, поэтому основное внимание, естественно, будет уделено сооружению тепловых электростанций. Вследствие этого доля импортируемых источников энергии по отношению ко всем источникам энергии возрастет до 59% в 1970 году и до 73% в 1980 году в основном за счет ввоза сырой нефти для производства электроэнергии.

Таким образом, не только с точки зрения разумной политики расходования валютного фонда, но также и в целях обеспечения устойчивого положения с энергетическими ресурсами Япония должна разработать дешевые источники энергии, а также разнообразить виды снабжения энергией. В программе Комиссии по атомной энергии и в недавнем докладе Национального комитета министерства внешней торговли и промышленности по общей энергетической политике указывается, что ядерная энергетика должна превратиться в один из основных источников снабжения страны энергией.

Программа устанавливает масштабы развития атомной энергетики: общая мощность атомных электростанций должна составить почти 1000 *Мвт* (эл.) в первые десять лет (начальная стадия развития) и 6000 — 8500 *Мвт* (эл.) во втором десятилетии (стадия промышленного прогресса). Предполагается, что эти станции будут строиться и эксплуатироваться частными фирмами коммунального энергоснабжения. Последние три года показали, что потребности в электроэнергии возрастут еще больше, чем это было определено в плане.

Постепенно осуществляется строительство энергетических установок, проводятся широкие научно-исследовательские и опытно-конструкторские работы, создаются организации и разрабатывается соответствующее законодательство и т. д. Что касается атомных электростанций, то демонстрационный энергетический реактор уже действует, а строительство первой промышленной энергетической установки будет завершено в 1965 году. Кроме этого, четыре атомных электростанции, как ожидается, будут завершены строительством к 1970 году. В связи с этим масштабы производства атомной электроэнергии к 1970 году превысят плановые цифры программы. В настоящее время реакторы импортируются, однако активно разрабатывается технология их производства внутри страны. Кроме того, к 1970 году предполагается закончить сооружение установки по переработке облученного топлива производительностью около 200 *т* в год.

В соответствии с программой проводятся научно-исследовательские и опытно-конструкторские работы по строительству судов с ядерным двигателем. В 1963 году разработан план строительства первого атомного судна и с этой целью создано специальное агентство.

A/577 Japón

Necesidad de generar energía nuclear en Japón y programa consiguiente

Comisión de Energía Atómica de Japón

De acuerdo con las directrices del Plan de Duplicación de la Renta Nacional, aprobado en 1960 por el Gobierno, la Comisión de Energía Atómica de Japón estableció, en febrero de 1961, el Programa a largo plazo sobre el Desarrollo y la Utilización de la Energía Atómica, que cubría 20 años; de 1961 a 1980. De acuerdo con el Plan y con el desarrollo de la economía, la demanda de energía eléctrica alcanzará, en los años 1970 y 1980, aproximadamente un valor 2,8 y 5 veces mayor, respectivamente, que en 1959. Esto hará necesario un desarrollo en gran escala de la capacidad de generación de energía. El agotamiento gradual de emplazamientos adecuados para nuevas centrales hidroeléctricas de gran tamaño, tendrá como consecuencia lógica el desarrollo de la energía eléctrica de origen térmico. Por consiguiente, la proporción de los recursos energéticos importados, frente a la totalidad de los recursos energéticos, aumentará hasta el 59% en 1970 y el 73% en 1980, aumento debido, principalmente, a la importación de crudos de petróleo para la generación de energía.

Por consiguiente, tanto desde el punto de vista de una sana política de divisas como del de asegurar un suministro estable de los recursos energéticos, Japón debe desarrollar los recursos más baratos y diversificar las fuentes de suministro de energía. El Programa de la Comisión y el informe reciente del Comité de Política Nacional sobre la Energía, del Consejo de Estructura Industrial del Ministerio de Comercio Internacional e Industria indican que la generación de energía de origen nuclear deberá convertirse en una de las principales fuentes de suministro de energía del país.

El Programa establece el ritmo que debe adoptarse: unos 1 000 MW(e) instalados en los diez primeros años (fase preparatoria) y de 6 000 a 8 500 MW(e) en los diez años siguientes (fase de desarrollo industrial). Estas centrales se espera que sean construidas y explotadas por compañías eléctricas privadas.

Los tres últimos años han demostrado que la demanda de energía eléctrica rebasará ampliamente las previsiones del Plan.

Se ha llevado a cabo de manera regular la construcción de centrales, la investigación y desarrollo de amplio alcance, el establecimiento de organizaciones y de legislación, etc. En lo referente a centrales nucleares, se encuentra actualmente en explotación un reactor de potencia experimental y la primera central comercial se espera entre en servicio en 1965. Además, se prevé, que hacia 1970 estarán en explotación cuatro centrales nucleares. Por consiguiente, la capacidad de producción de energía de origen nuclear en 1970 superará los objetivos del Programa. Los reactores son importados, pero se está desarrollando activamente una tecnología para fabricarlos en el país. Además, se ha previsto la puesta en marcha en 1970 de una fábrica de tratamiento de combustibles irradiados, capaz de tratar unas 200 t al año.

Se han llevado a cabo trabajos de investigación y desarrollo en relación con la propulsión naval nuclear de acuerdo con lo previsto en el Programa. En 1963 se estableció el plan para la construcción de un primer barco de propulsión nuclear, para lo cual se constituyó un organismo especial.

La contribución de la energía nuclear a la solución del problema energético argentino

por J. L. Alegría, B. J. Csik, E. V. Nasjleti, C. C. Papadópulos y O. A. Quihillalt*

Siete años atrás la República Argentina recibió una propuesta formal para la construcción de una central nuclear. Tal proyecto no se llevó a cabo debido a que, examinado a la luz de los estudios realizados por la Comisión Nacional de Energía Atómica hasta esa época, no reunía las garantías y ventajas exigibles en relación con los costos de instalación y generación, con la experiencia de operación y con la participación de la técnica y la industria nacionales. Desde aquella época se han producido cambios que alteraron profundamente la situación. En numerosos países se han instalado centrales nucleares y la experiencia mundial crece rápidamente. Si bien el costo de instalación continúa siendo mayor que el de las plantas térmicas convencionales, la diferencia se ha reducido considerablemente. En cuanto al costo de generación de energía nucleoeléctrica, éste ha llegado a ser competitivo para grandes unidades operando como centrales de base en zonas de alto costo de energía.

En el país el costo de energía es elevado. La insuficiencia de la electrificación, característica común en la mayoría de los países en desarrollo, sigue siendo uno de los graves problemas que afectan a la evolución normal. La instalación de nuevas centrales eléctricas es una urgente necesidad, constituyendo los problemas de financiación la dificultad principal para la solución del problema energético.

La industria nacional ha progresado y en particular se ha creado una pequeña industria nuclear que le permitirá disponer del combustible y aun de elementos combustibles para abastecer las usinas nucleares a instalar. El país posee actualmente un equipo técnico-nuclear de relativa importancia, base para una ampliación futura.

Un factor de confianza es la existencia de un elevado espíritu de cooperación internacional y en particular la del Organismo Internacional de Energía Atómica que puede prestar una ayuda importante.

La consideración de estos factores, que hace siete años hicieron estimar como prematuro e inadecuado aquel proyecto de central nuclear, nos lleva a adquirir el convencimiento de que el momento de encarar un plan de potencia nuclear ha llegado. Así culminan los estudios preliminares realizados durante estos años, cuya síntesis es el presente trabajo.

Al efectuar este análisis, se han tomado en cuenta exclusivamente los factores económicos, sin utilizar los que derivan de considerar la necesidad nacional de conservar los recursos naturales para su utilización óptima. Es evidente que, de haberlos incluido en el estudio previo, aquellos argumentos reforzarían la posición de las centrales nucleares. Los trabajos preliminares ya han dado su primer fruto. La Comisión Nacional de Coordinación de Grandes Obras Eléctricas acaba de aprobar en la reunión del 10 de abril de 1964, la realización del estudio de factibilidad de una central nuclear, estudio que demandará un año de tiempo y para el cual se cuenta con la valiosa ayuda del OIEA.

REPÚBLICA ARGENTINA–CARACTERÍSTICAS

Datos generales

Situada en la extremidad meridional de América del Sur, la Argentina continental cubre una superficie de 2 790 000 km^2, y tiene una población de 22 millones de habitantes. La mayor parte de su territorio es de clima templado y templado-frío, encontrándose zonas de clima subtropical en el norte del país. Está caracterizada por una desigual distribución demográfica. La mayor concentración de la población se presenta en la región de las pampas húmedas, con un 75% del total. La ciudad de Buenos Aires, que se encuentra en esta región, constituye con sus alrededores (Gran Buenos Aires) el conglomerado metropolitano mayor del Hemisferio Sur con 7 000 000 de habitantes. La zona que incluye la ciudad de Buenos Aires y las principales ciudades que se encuentran sobre el curso inferior del río Paraná y costa argentina del Río de la Plata se denomina zona del Gran Buenos Aires–Litoral, expresión que luego emplearemos al referirnos a la misma en el presente trabajo. Esta zona está caracterizada por ser la de mayor desarrollo industrial y centro de convergencia de los principales sistemas de comunicación del país.

El índice de crecimiento demográfico del país es de 1,9% y el de alfabetismo superior a 92%. El 68% de la población reside en zonas urbanas. La red caminera tiene 175 000 km, de los cuales un

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* Comisión Nacional de Energía Atómica, Buenos Aires.

15% son pavimentados; existen 44 000 km de líneas férreas y una flota mercante con un registro bruto de 1 300 000 toneladas.

Aspectos económicos

El suelo argentino y su clima ofrecen condiciones excepcionales para la agricultura y la ganadería, actividades que tienen un papel fundamental en la economía del país. Representan el 34% del producto bruto y el 85% de las exportaciones. El total de estas últimas alcanza anualmente un valor aproximado de 1 300 millones de dólares. La industrialización se ha incrementado sensiblemente en las últimas décadas. En la actualidad, sobre un producto bruto anual equivalente a 10 000 millones de dólares, el 19,3% corresponde a la industria. La producción anual de los principales rubros industriales es: acero, 450 000 toneladas; ácido sulfúrico, 220 000 toneladas; cemento portland, 3 millones de toneladas, y automotores, 185 000 unidades. La producción de combustibles en orden de importancia es: petróleo y gas natural, 14 millones de toneladas equivalentes de petróleo (t.e.p.), combustibles vegetales, 1,9 millones t.e.p., y carbón, 125 000 t.e.p. La importación de materia prima semielaborada y de maquinarias es aún muy importante y gravita fuertemente en la balanza del comercio exterior.

La economía argentina, en conjunto, presenta todas las características de un país en proceso de desarrollo: renta individual débil, moneda vulnerable y balanza del comercio exterior fluctuante. Sin embargo, posee un conjunto de factores favorables como son: una superficie útil apreciable, recursos energéticos, materias primas abundantes y un núcleo de población importante, que inducen a predecir un rápido proceso de desarrollo.

Recursos energéticos

Las reservas energéticas de la República Argentina son relativamente abundantes, ocupando el primer lugar el petróleo y el gas natural. Se encuentran ubicadas en general en zonas separadas de la región Gran Buenos Aires - Litoral por distancias superiores a los 1 000 km.

Petróleo y gas natural. Las zonas productoras principales se encuentran en la región patagónica, en la región noroeste y en la zona andina central. Las reservas comprobadas de petróleo y gas natural son 800 millones de m^3 equivalentes de petróleo (fig. 1).

Carbón. La República Argentina dispone de una reserva de 460 millones de toneladas de carbón. Se encuentra en su casi totalidad en el yacimiento de Río Turbio, en el extremo sur del país. Para su transporte a Buenos Aires debe cubrir un trayecto de 250 km por ferrocarril y 2 000 km por vía marítima. Es un carbón apto para ser empleado en centrales eléctricas (fig. 1).

Uranio. En la actualidad el potencial uranífero argentino se estima en 25 000 toneladas de U_3O_8. De éstas, 4 000 toneladas han sido ya evidenciadas. La capacidad anual de producción de U_3O_8 de pureza nuclear es de 100 toneladas. Existen dos plantas de tratamiento y una de extracción de preconcentrados (fig. 2).

Potencial hidráulico. El potencial hidráulico económicamente aprovechable es del orden de los 11 000 MW. Su distribución geográfica se muestra en la figura 3. Se estima que 6 000 MW son los aprovechables en una primera etapa de desarrollo.

ACTIVIDADES NUCLEARES

El organismo oficial encargado de promover y coordinar el esfuerzo nuclear argentino es la Comisión Nacional de Energía Atómica (CNEA). Sus principales actividades han sido hasta el presente: la formación de personal, la prospección, producción y tratamiento de minerales nucleares y la investigación básica y tecnológica. En el cumplimiento de su misión, la CNEA ha invertido hasta el presente un total equivalente a 80 millones de dólares. En la actualidad tiene un presupuesto equivalente a 10 millones de dólares anuales y cuenta con un personal de 1 500 agentes, de los cuales cerca de 600 son graduados universitarios.

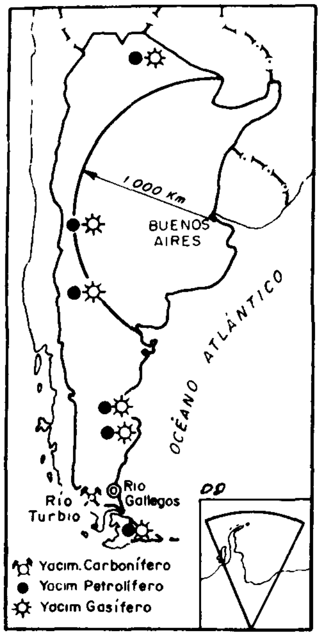
La CNEA ha construido y operado desde 1958 un reactor de investigación de 30 kW (RA-1, versión modificada del Argonaut) y una instalación crítica. En la actualidad está por ser completado, en las afueras de Buenos Aires, un segundo reactor de investigación (RAEP), tipo tanque, de una potencia térmica de 5 MW. Este reactor ha sido diseñado por personal de la Comisión y su construcción se realiza con la participación activa de la industria local. Los elementos combustibles se fabrican en los laboratorios y talleres de la Comisión. Esta tarea ha dejado una experiencia que permitirá en un futuro encarar la producción de elementos combustibles para reactores de potencia.

La posible participación de la energía nuclear para la generación de electricidad en la Argentina es objeto de permanentes estudios, cuya finalidad es evaluar diferentes tipos de reactores, estimar sus aspectos económicos y su proyección futura.

ELECTRIFICACIÓN Y DEMANDA

Potencia instalada

La potencia eléctrica instalada en la República Argentina es de 5 000 MW aproximadamente, produciéndose 15 GWh/año. El 93% de la capacidad de generación corresponde a centrales térmicas y el 7% a centrales hidráulicas. La baja proporción de la participación hidráulica es principalmente consecuencia de las grandes distancias que separan la región densamente poblada del país, de las zonas donde existen reservas hidráulicas.



AÑOS	CARBON (En miles de t)				PETROLEO (en millones de m^3)			GAS
	Producción Nacional	Rio Turbio	Importacion	Consumo	Producción Nacional	Importacion	Total	Producción en m^3
1950	72,9	26,4	1467,3	1540,3	3,730	3,559	7,289	764 605
1955	143,9	135,9	1272,0	1415,9				1064 610
1960	279,8	265,4	1446,2	1726,0	10,152	3,684	13,836	3 550 343
1962	212,8	210,9	758,4	971,2	15,607	1,215	16,822	6 173 016
* 1973					27,000			12 300 000

* Producción estimada

Figura 1.
Combustibles convencionales.
Yacimientos y consumo

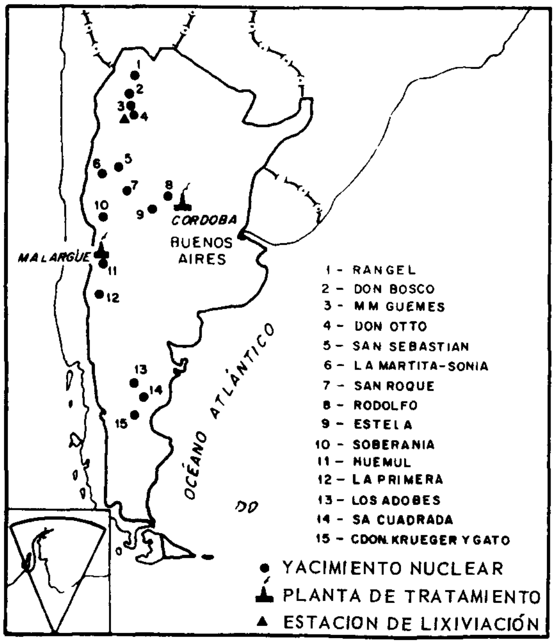


Figura 2. Principales yacimientos nucleares

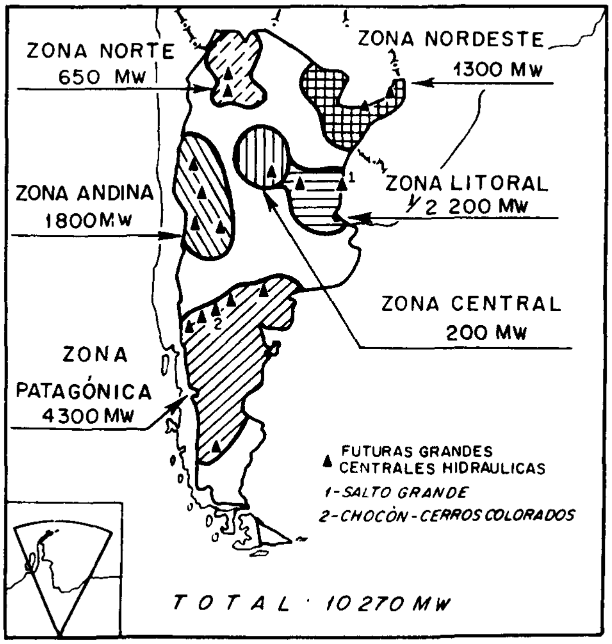


Figura 3. Reservas hidráulicas. Potencia instalable en MW

El 30% de la capacidad de generación instalada corresponde a grupos de autogeneración. Este alto porcentaje se debe a que la expansión de la capacidad de generación de servicio público ha sido inferior al crecimiento de la demanda en las últimas décadas. El 68% de la potencia total instalada, o sea 3 400 MW, se encuentra en la zona del Gran Buenos Aires - Litoral. De esta potencia, 2 400 MW se encuentran instalados en el Gran Buenos Aires propiamente dicho. Las zonas que le siguen en orden de importancia son las de Córdoba y Mendoza con 310 y 200 MW respectivamente.

Existen en la República Argentina seis sistemas eléctricos independientes (fig. 4). Unicamente el del Gran Buenos Aires - Litoral es de una magnitud tal como para ser considerado de interés al estudiar la posibilidad de la instalación de centrales nucleares en un futuro inmediato. La potencia efectiva interconectada del mismo es en la actualidad de 2 100 MW.

Consumo de combustible

El consumo de combustible para la generación de electricidad en la República Argentina alcanza los 5 millones de toneladas equivalentes de petróleo por año. De este total, el 75% corresponde a fuel-oil, el 10% a Diesel-oil, el 10% a gas natural y el 5% a carbón. El consumo específico es relativamente alto (3 700 cal/kWh en promedio, en 1962), debido a la existencia de muchas centrales antiguas de bajo rendimiento y un elevado número de unidades de pequeña potencia.

Demanda

La producción de energía eléctrica en la República Argentina creció en promedio con una tasa de 7% anual acumulativo durante los últimos 40 años. En las últimas décadas la demanda lo hizo a un ritmo más acelerado, originándose una situación energética deficitaria cuyos efectos fueron especialmente sensibles en las zonas del Gran Buenos Aires - Litoral. Se estima que la demanda en los próximos decenios aumentará, duplicándose cada nueve años en promedio, lo que equivale a una tasa de crecimiento de 8% anual acumulativo. Esta evolución energética significa la necesidad de instalar 4 300 MW adicionales hasta 1972 y de 7 700 MW más, antes de 1980, o sea un total de 12 000 MW para el período 1964 - 80 (fig. 5).

Sistema Gran Buenos Aires–Litoral

El crecimiento de la demanda en el sistema Gran Buenos Aires - Litoral será en los próximos decenios el factor de mayor significación en el desarrollo de la electrificación de la República Argentina. El grado de interconexión de este sistema es elevado y aumentará en los próximos años. En la actualidad se dispone de 2 100 MW en la red de servicio público y se estima que hacia fines de 1972 la capacidad efectiva requerida será del orden de los 4 100 MW, lo que significa una expansión de 2 000 MW. En el año 1980 se necesitarán 7 100 MW lo que representará una expansión adicional de 3 000 MW en el período 1972 - 80 (fig. 6).

La situación de la región que abarca el sistema Gran Buenos Aires - Litoral, en cuanto se refiere a los recursos energéticos, es la siguiente: para la generación térmica dependerá del abastecimiento de combustibles producidos en otras zonas del país o importados, mientras que la contribución de la energía hidroeléctrica deberá llegar mediante extensas líneas de transmisión.

Dos grandes proyectos hidroeléctricos son contemplados para alimentar este sistema en un futuro inmediato. Uno de ellos (Salto Grande) está situado a 420 km de distancia de Buenos Aires, y el otro (Chocón - Cerros Colorados) se encuentra a 1 100 km (fig. 3). Sus aportes recién se materializarán para fines del año 1972, con una potencia inicial de 420 MW, hasta alcanzar en 1975 una potencia de 1 500 MW. A partir del año 1978 es de estimar que se producirán nuevos aportes hidráulicos.

La expansión de la capacidad de generación térmica del sistema Gran Buenos Aires - Litoral, que deberá realizarse hasta el año 1972, es de 1 500 MW. Antes del año 1980 se requerirán otros 1 500 MW térmicos adicionales. Para la satisfacción de las necesidades de combustibles, el país dispone de petróleo, gas natural, carbón y combustibles nucleares. Las reservas de petróleo y gas natural pueden proporcionar una parte importante de la energía térmica necesaria para atender la expansión de la capacidad de generación en los períodos considerados. En la actualidad, el empleo de carbón en las centrales eléctricas es muy reducido, no esperándose en un futuro inmediato que aumente el mismo en forma significativa.

Costo de la energía en el sistema Gran Buenos Aires - Litoral

El costo actual de la energía térmica en la zona considerada está comprendido entre 2 y 2,4 dólares por millón de calorías (equivalentes a 50 - 60 centésimas de dólar por millón de Btu). El costo de la energía hidroeléctrica que abastecerá esta región se estima que estará comprendido entre 9 y 11 mills/kWh. Estos valores caracterizan la región del Gran Buenos Aires - Litoral como zona de alto costo de energía.

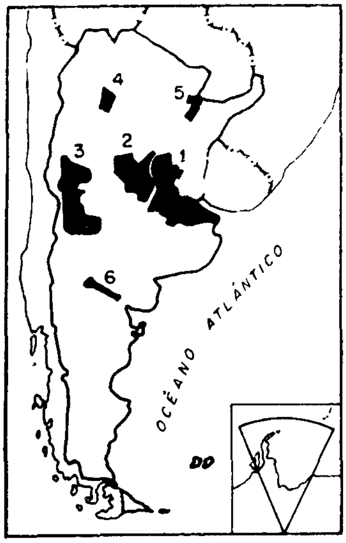
POSIBILIDADES DE LA ENERGÍA NUCLEAR

Los costos de la energía en general y de la energía térmica convencional en especial, en esta zona, permiten afirmar que existen válidas razones económicas para contemplar el empleo de la energía nuclear en la futura expansión del sistema Gran Buenos Aires - Litoral. Siendo la capacidad requerida de este sistema para fines de 1972 de 4 100 MW, es factible instalar una central nuclear de 350 MW para operar con alto factor de carga. Resultaría por tanto que la expansión térmica requerida hasta el año 1972 podría ser compuesta de 350 MW nucleares y 1 150 MW térmicos convencionales. Para el período 1972 - 80 se estima que se requerirá una ampliación de la potencia térmica en unos 1 500 MW, de los cuales 850 MW podrían ser nucleares.

Después del año 1980, o quizás ya antes, la participación de la energía nuclear será posible en otros sistemas eléctricos del país, por cuanto habrá aumentado considerablemente el grado de interconexión de las distintas zonas además del crecimiento propio de la demanda en cada una de ellas.

Selección del tipo de central nuclear

Se ha realizado, con la finalidad de seleccionar el tipo de central nuclear, una serie de estudios preliminares de evaluación de reactores a base de la experiencia mundial existente. Aun siendo cierto que la instalación de un reactor de potencia no significa que todos los reactores futuros sean del mismo tipo, resulta sin embargo conveniente poder aprovechar al máximo la experiencia adquirida, lo cual se logra manteniendo una misma línea. Para la selección del tipo del primer reactor a instalar en el sistema Gran Buenos Aires - Litoral, se consideraron únicamente reactores que cuentan con un



CAPACIDAD DISPONIBLE

1- Gran Buenos Aires-Litoral	2 100 MW
2- Córdoba	230 MW
3- Mendoza	130 MW
4- Tucumán	65 MW
5- Resistencia-Corrientes	35 MW
6- Alto Valle del Río Negro	28 MW

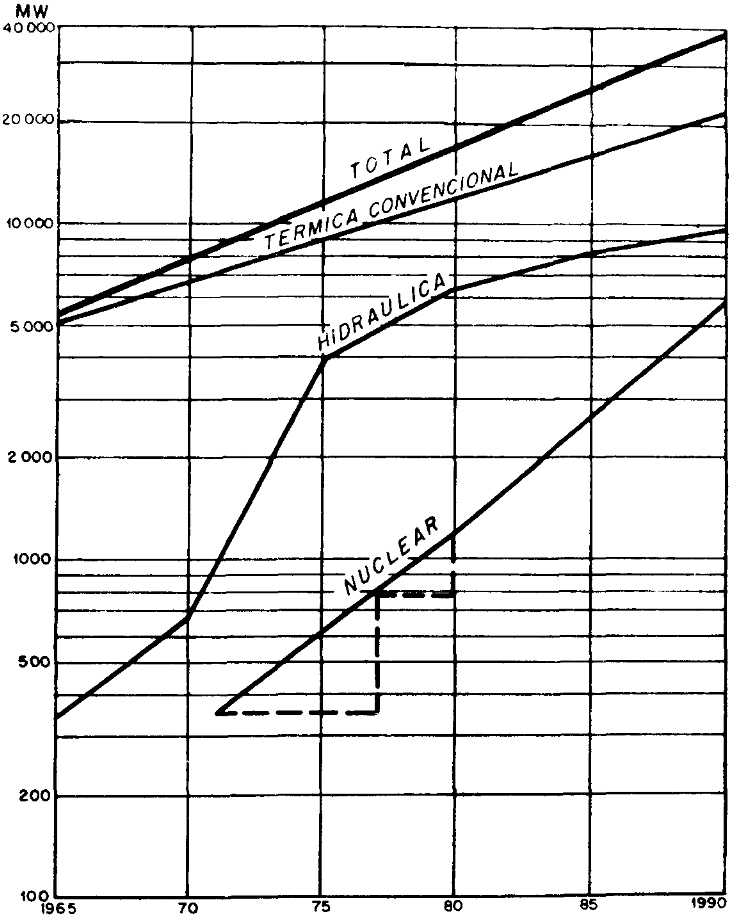


Figura 5. Evolución prevista de la potencia total instalada en la República Argentina

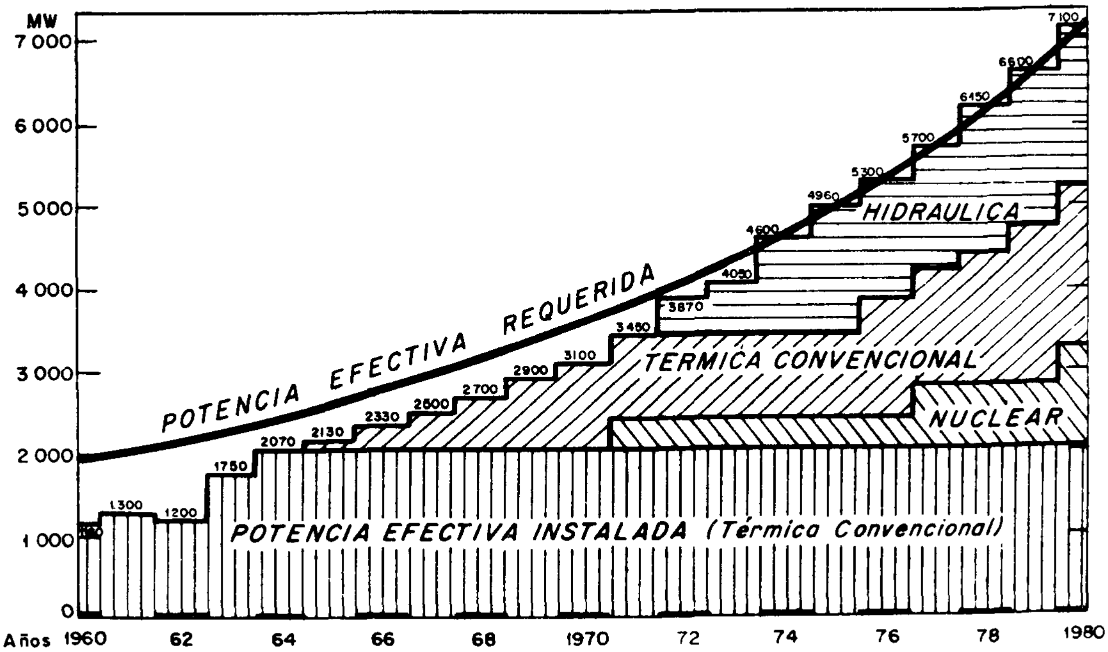


Figura 6. Evolución prevista del sistema Gran Buenos Aires-Litoral

prototipo funcionando satisfactoriamente en alguna parte del mundo.

Los principales factores de evaluación fueron: el costo de la energía eléctrica producida, el costo de instalación e inversiones complementarias y el grado de participación de la industria nacional. La posibilidad de autoabastecimiento en materia de combustibles nucleares, paralelamente con la evaluación de adicionales factores económicos y técnicos indican una preferencia, en principio, por los reactores a uranio natural.

Las condiciones de financiación pueden tener una considerable influencia en la selección final. Si algunos de los tipos de reactores considerados resultara favorecido de manera especial, desde este punto de vista, la decisión definitiva podrá ser diferente de la indicada antes como preferente.

FINANCIACIÓN DE LA CENTRAL NUCLEAR

La instalación de una central nuclear de una potencia del orden de 350 MW implica una inversión de magnitud, a ser realizada en un período de aproximadamente seis años. En consecuencia, los aspectos de financiación adquieren gran importancia, en especial tratándose de un país en desarrollo que no cuenta con abundantes recursos financieros propios.

Puede considerarse que en la Argentina existen, como recursos de financiación: los remanentes de explotación, el aporte estatal, el ahorro privado y el crédito exterior.

Remanentes de explotación. Generalmente, se espera que los remanentes de explotación, o recursos de autofinanciación, cubran cerca del 50% de las necesidades de expansión de la industria eléctrica, dejándose para el crédito exterior, el aporte estatal y el ahorro privado la tarea de absorber el saldo, en el orden de importancia relativa citado. Para el caso de una central nuclear, caracterizada por el mayor capital invertido, los remanentes de explotación probablemente alcancen a cubrir el 30% de la inversión inicial.

Aporte estatal. El aporte estatal en la Argentina está fuertemente condicionado a la actual situación del balance económico. Los presupuestos nacionales deficitarios y la competencia de otras necesidades características en el campo financiero, tales como transporte, vivienda y otras soluciones en el sector energético, tornan difícil confiar en que ese aporte pueda resultar significativo.

Aporte privado. El aporte privado no tiene peso en la solución del problema de financiación de una central nuclear en la República Argentina. Si bien el mercado de energía eléctrica en el país, por la naturaleza de la relación oferta-demanda y por los regímenes legales tarifarios vigentes, es ampliamente satisfactorio, la atención del capital privado es atraída hacia sectores más rápidamente retributivos que el de la producción y venta de la energía eléctrica. Sin embargo, es posible confiar en algún aporte privado, bajo la forma de créditos a corto y mediano plazo, negociados con las empresas argentinas que suministren obras o servicios durante la construcción de la central.

Crédito exterior. Se estima necesario que el crédito exterior cubra no menos del 60% de la inversión total bajo la forma de crédito industrial o de crédito bancario. El primero sería convenido a mediano plazo con los productores extranjeros de bienes de capital necesarios para la central, que no puedan ser producidos u obtenidos en el país. El segundo, a largo plazo, se emplearía para el suministro de bienes de capital local o foráneo que no tengan otro respaldo crediticio.

Será conveniente obtener un equilibrio adecuado entre las diversas fuentes de crédito. El crédito industrial exterior no debe convertirse en un elemento de competencia para la industria local, ahora en pleno desarrollo pero con pocas posibilidades de financiación. El crédito bancario exterior deberá negociarse de manera que admita la financiación indiscriminada de adquisiciones realizadas en el país y en el exterior. En caso contrario, este tipo de crédito también puede ofrecer inconvenientes en la adecuada utilización de la industria argentina, distorsionando la distribución relativa del aporte industrial local y foráneo.

Ante la presión de los otros requerimientos financieros de la Argentina, y dado el tope relacionado con el crédito integral del país, se estima necesario contar con créditos externos específicos para la realización en cuestión.

En cuanto al respaldo financiero, la República Argentina ha demostrado a lo largo de toda su historia crediticia ser un deudor rigurosamente responsable, circunstancia a la que se añade el panorama decididamente favorable de su mercado eléctrico.

CONCLUSIONES

El panorama del abastecimiento de energía eléctrica de la zona del Gran Buenos Aires – Litoral evidencia, para el futuro inmediato, la necesidad de una expansión en la capacidad efectiva requerida, que no podrá ser cubierta en su totalidad por los proyectos hidroeléctricos actualmente en estudio. Una situación similar se presenta para el futuro inmediato. Estas circunstancias llevan a la necesidad de instalar nuevas centrales térmicas convencionales o nucleares.

La estimación de costos unitarios de producción para centrales térmicas convencionales y nucleares en esta zona de alto costo de combustible fósil y el análisis de las características de las curvas de carga del sistema, permiten concluir que es plenamente factible considerar la instalación de una central nuclear de unos 350 MW de potencia.

El análisis del problema de financiación permite anticipar que la obtención de facilidades crediticias exteriores encaminadas específicamente a la instalación de una central nuclear, puede tener carácter determinante en la política energética de un país en desarrollo como la República Argentina.

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ABSTRACT - RÉSUMÉ - АННОТАЦИЯ - RESUMEN

A/715 Argentina

The contribution of nuclear energy to solving the Argentine energy problem

By J. L. Alegría *et al.*

This paper outlines the general characteristics of the Argentine Republic and the present energy situation. In particular, the energy resources, extent of electrification and demand for electric power, both present and as forecast, are specially discussed. A brief outline is presented of the country's development in the nuclear energy field.

Having stated the energy problem in Argentina, possible alternative solutions are discussed, and their respective advantages and disadvantages are considered. The possible contribution of nuclear energy is dealt with in further detail. Special attention is given to financial aspects, because of their fundamental importance to a developing country.

The paper ends with a discussion of all the factors and criteria used in selecting the type, size and location of the first nuclear power-station to be installed in Argentina.

A/715 Argentine

Contribution de l'énergie d'origine nucléaire à la solution du problème de l'énergie en Argentine

par J. L. Alegría *et al.*

Le présent mémoire donne un aperçu général des caractéristiques d'ensemble de la République Argentine et de sa situation actuelle dans le domaine de l'énergie. Il analyse notamment les ressources énergétiques, l'électrification et la demande actuelle en électricité ainsi que les prévisions pour l'avenir. Il rend brièvement compte du développement atteint en Argentine dans le domaine nucléaire.

Le problème de l'énergie ainsi posé, les auteurs examinent les diverses solutions possibles en considérant les avantages et les inconvénients de chacune d'entre elles. Ils examinent de façon plus détaillée le rôle que pourrait jouer l'énergie d'origine nucléaire. Une attention particulière est accordée aux problèmes de financement, étant donné leur importance capitale dans un pays en voie de développement.

Les auteurs examinent enfin les facteurs et critères dont on a tenu compte pour le choix du type, de la puissance et de l'emplacement de la première centrale nucléaire qui doit être installée dans la République Argentine.

А/715 Аргентина

Роль атомной энергетики в решении энергетических проблем Аргентины

Х. А. Алегриа *et al.*

В докладе дается общая характеристика Аргентины и рассматривается современное состояние энергетики страны. Подробно обсуждаются вопросы, связанные с энергетическими ресурсами, наличием энергии и потребностями в электроэнергии как в настоящее время, так и в будущем. Предлагается краткое описание позиции Аргентины в отношении атомной энергетики.

После изложения энергетической проблемы Аргентины обсуждаются возможные альтернативные решения этой проблемы с учетом их преимуществ и недостатков. Детально рассматривается возможный вклад ядерной энергетики. Дается специальный анализ финансовых аспектов в связи с их первостепенной важностью для развивающейся страны.

В конце доклада рассматриваются все факторы и критерии, которые учитывались при выборе типа, мощности и места расположения первой атомной электростанции, которая будет строиться в Аргентине.

Record of Session B

New economic data. Energy needs in coming years and the role of nuclear power in meeting these needs

Chairman: H. J. Bhabha (India)

Paper P/741 (presented by H. J. Bhabha)
Paper P/715 (presented by O. A. Quihillalt)
Paper P/559
Paper P/31 (presented by J. Cabanius)
Paper P/192 (presented by G. F. Tape)
Paper P/294 (presented by B. B. Batorov)
Paper P/1 (presented by W. B. Lewis)
Paper P/577 (presented by S. Komagata)

PANEL DISCUSSION

The role of nuclear power in meeting energy needs in other countries

J. P. BAXTER (Australia): In Australia there are no immediate plans for the production of nuclear power. I shall speak therefore of the role of nuclear power as we see it in the future. Australia is a large country with a small population; its area is approximately that of the United States of America and its population is just over 11 million but is growing rapidly. It is a highly industrialized country with a high *per capita* power consumption which is substantially exceeded only by the United States of America.

From some points of view Australia could be considered to be an under-developed country in that there are large resources still awaiting development. At present coal is the main source of power. There are some less extensive resources of hydroelectric power and a small amount of power is also obtained from oil. Coal resources are very extensive and are mainly situated on the eastern side of the country, and there is also some coal of not very good quality in the southern and western parts of the country.

At present in the larger industrial areas, where coal is both plentiful and cheap, new coal-fired stations can produce power at something below 4 mills per kWh and this sets a very difficult target for nuclear energy. The situation is made more difficult by the fact that in most of the States it would not be practicable today to incorporate very large nuclear power stations into the distribution system. In the not too distant future it may be possible for New South Wales and, a little later, Victoria to absorb stations with a capacity exceeding 500 MW, but in most of the other States the capacity would have to be limited to 200 MW. Under these circumstances, there seems little immediate prospect of the construction and operation of nuclear power stations. On the other hand it seems likely, partly because of the geographical distribution of coal and partly because of the rapidly growing population, that nuclear power will play an important role in the ultimate development of Australia. It may begin to do so within the next decade in South Australia, where there is at least a possibility that a 200 MW station will be operating in the middle of the 1970s. This may not be the case, however, if the current prospecting for oil and natural gas in that State should prove to be highly successful. The other State in which nuclear power may be used fairly soon is Tasmania, where hydroelectric power is used almost exclusively. This power source will soon be exploited to the maximum extent possible, so that the prospects of having a 200 MW station in Tasmania within the next decade are certainly worth considering.

Apart from the State generating systems, which are all operated by State power authorities and are not interconnected, except for a link through the Snowy Mountains between Victoria and New South Wales, there may be isolated power demands of some magnitude in one or two special cases. In the north and north-east very large deposits of bauxite have been found and the possibility of smelting that mineral in order to produce aluminium is being seriously considered. If this is done, nuclear power would have to be used and that might justify the construction of a full-scale plant with a prospect of considerable growth. In some other areas in the interior, such as the town of Mount Isa, where copper, silver, lead and zinc are mined and power consumption may increase to 100 MW, nuclear power may conceivably come into its own because of the long distance over which the alternative fuel, coal, has to be carried.

Australia's power programme, therefore, is a long-term one. We are keenly interested in the work being done in other parts of the world to reduce the cost of nuclear power and are very pleased with the efforts being made in Canada, the United States, Great Britain, and elsewhere to achieve this goal. The successful completion of this task would be extremely valuable from our point of view. Our own activities in this field are long-term, however, and our studies are concentrated on a very advanced and still somewhat speculative reactor system; we can in fact afford to take our time.

Although desalination is not an urgent requirement in our case, we are interested in it from the long-term point of view since Australia is one of the driest continents in the world.

We have a continuing interest in the production of uranium which we are still producing, and we are also continuing our exploration programme with a view to increasing our reserves. We believe that our country is a potential large-scale producer of cheap uranium, together with thorium, and in spite of the present slump in the market we are pressing on with our work in this connection.

J. Neumann (Czechoslovakia): I should like to outline briefly the basic economic characteristics of the energy situation in Czechoslovakia, which has led us to conclude that nuclear power stations are necessary, and also to define our basic technical policy with regard to the peaceful uses of atomic energy.

The Czechoslovak Socialist Republic is an industrially developed country. The rapid expansion of our national economy in the future, which will progressively raise the standard of living and promote cultural development, already necessitates and will continue to necessitate an abundant power supply to meet industrial and community requirements. The overall consumption of primary power resources is expected approximately to double within the next fifteen years. A characteristic feature of the development of the structure of power consumption is the more rapid growth of conventional types of energy, particularly electricity, production of which will amount to approximately 55 000 to 60 000 million kWh in 1970 and 110 000 to 115 000 million kWh by 1980.

Low-grade lignite, from which 90 per cent of the total national output of electric power is produced, is at present, and will still be in the near future, the basic source of power in Czechoslovakia. Deposits of coal suitable for power purposes are mainly concentrated in the north-western part of the country and most of the thermal power stations are consequently located there. In view of the deteriorating natural conditions in which coal is mined, the limited reserves and the irregularity of their distribution throughout the country, further development of electric power from domestic fossil fuels is meeting with considerable technical and economic difficulties. Particularly in view of the limited geological deposits available, the output of thermal power stations cannot be increased at the necessary rate within the next ten to fifteen years and can scarcely be increased at all after that time.

This situation is being met by a continual increase in imported energy, which will amount to nearly 20 per cent of all primary resources in 1965 and will also continue to increase after that. At the same time, a programme is being prepared for the widespread use of atomic energy in the industrial production of electricity.

This programme will be based on nuclear power reactors using natural uranium, with a heavy-water moderator and a carbon-dioxide heat conductor; an industrial prototype with an output of 150 MW(e) is being built at Bohunice. The technical parameters of this power station are well known and were described in a number of papers presented at the Second International Conference on the Peaceful Uses of Atomic Energy in 1958.* Some technical problems relating to the construction of a reactor of this kind will be described at the present Conference.** The basic scientific and technical problems relating to the project have now been solved and the power station should be commissioned by 1968.

We now consider that a programme of nuclear power station construction over the next ten to fifteen years can be based on reactors of the type mentioned. Experience acquired in solving the scientific and technical problems relating to the first nuclear power station and subsequent research and experimental work lead to the conclusion that power stations of this kind can produce electric power under satisfactory economic conditions. Thus, for instance, specific capital investments in the second power station of this kind, with two reactors with an output of 200 MW(e) each, will be 40-45 per cent, less than in the case of the prototype. The cost of electric power produced by such a station should be approximately equal to the average cost of electric power in the power stations network of the Central Council of Energy. Further increases in the unit power of reactors—we believe it will be possible to attain 400 MW(e)—should lead to a situation in which the cost of power produced by nuclear stations will be comparable with that of power produced by the best thermo-electric power stations by 1975. Accordingly, we now believe that, by using nuclear power stations of a selected type, it might be possible to meet an appreciable part of the estimated deficit in electric power by 1980, and that by then these stations may produce approximately 15 per cent of the electric power required in the country under favourable economic conditions.

Like most countries concerned with the problems concerning the utilization of atomic energy, we consider that in the more distant future it will be possible to produce electric power by using fast neutron reactors, which permit a fuller use of avail-

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* For example, P/2092, Vol. 8, pp. 322-328 and P/2094, Vol. 9, pp. 36-44.

** For example, papers P/522, Vol. 8 and P/523, Vol. 5, these Proceedings.

able supplies of nuclear fuel under favourable technical and economic conditions.

In preparing and carrying out our programme, we rely on international co-operation, particularly with the Soviet Union, which is giving us extensive assistance.

H. VON BÜLOW (Denmark): In Denmark the energy situation can be roughly summarized as follows. Firstly, Denmark has only insignificant indigenous conventional fuel reserves; secondly, Denmark's energy supplies are entirely contingent on world market conditions; and, thirdly, with regard to the use of atomic energy primarily for producing electricity, economic considerations are of paramount importance since only the peaceful applications of nuclear energy are envisaged.

We are very interested in the energy resources and requirements of the world as a whole and note, in particular, the following three factors: (*a*) the continued *per capita* increase in the consumption of energy, even in the more advanced countries; (*b*) the continued increase in world population; and (*c*) the increase in the energy requirements of the developing countries. In this connection, the following considerations should be borne in mind. First, nuclear energy can only play a significant part in meeting energy requirements if breeder reactors are used. Secondly, saturation effects must be taken into account in the long-term evaluation of the world's energy requirements, though it cannot be assumed that they will influence the increase in the total world energy consumption during the next few decades. Thirdly, there is a very large margin of error, at least of the order of 30 to 100 years, in estimates of the time it will take to exhaust the economically available conventional fuel resources. Fourthly, other important factors which should be taken into account are, for example, the time it will take to develop the technology of breeder reactors to the point at which they can be economically operated and the rate of breeding which can be economically achieved.

The specific considerations to which I have referred, which do not cover all the important factors involved, have led us to the conclusion that a country like Denmark should invest in nuclear energy as soon as it is economically sound, taking future developments into account. We also consider that all the more advanced countries should share the responsibility for furthering technological development with a view to making nuclear energy economically competitive, so that it can serve as a genuine alternative to fossil fuels. We believe, therefore, that Denmark should play its part, even if only on a modest scale, in achieving that aim.

I. H. USMANI (Pakistan): I think it will be generally agreed that nuclear power must henceforth be regarded as an alternative source of energy and that the future trends in the development of nuclear technology will probably be conducive to better performance and more satisfactory cost economics for power reactors. I note, however, that the industrially advanced countries attach great importance to the competitiveness of nuclear power and are talking all the while in terms of large reactors and the large blocks of power which nuclear energy can supply to their national grids. Such considerations are merely of academic interest in Pakistan, since the question of competitiveness does not arise at all and we must have power for our economic development regardless of the cost.

Pakistan has a population of about 98 million. It is a part of the Indo-Pakistan sub-continent and is divided into two major provinces, East Pakistan, with a population of 54 million, and West Pakistan, with a population of about 44 million. In East Pakistan the climatic and geographical conditions resemble those of South East Asia and in West Pakistan they roughly resemble those of the Middle East.

East Pakistan is humid, green and fertile, and is one of the most densely populated areas in the world. As in the case of Holland, there is practically no hydroelectric potential. There is a flat, delta area, extending from the foothills of the Himalayas in the north to the Bay of Bengal and the total fall is of the order of 58 feet. There is a small hydroelectric potential of about 120 MW in the Karnaphuli hills in the Chittagong Hill Tracts near the Burma border which has already been harnessed. So far no oil has been discovered, there is no coal and only a very small amount of natural gas which is used partly for generating power and partly for other purposes. Even if the entire proven gas reserves of East Pakistan, which are located in one half of the province, were used for producing power — which we urgently need since the annual *per capita* consumption in the province is only 15 kWh compared to 4 000 or 5 000 kWh in the United States and Canada — the total generating capacity which they could sustain for the lifetime of the plant would be about 700 MW. Furthermore these reserves cannot be used exclusively for power production since they are also needed for the production of fertilizers, petrochemicals, etc. Even if 50 per cent of the reserves were devoted to power production the resultant generating capacity would amount only to about 350 MW, which would merely meet the requirements of plants already approved or planned that would be operating in East Pakistan by 1970. Six years after the establishment of a 350 MW gas-fired station the entire gas reserves would be exhausted. The situation cannot be fundamentally remedied by increasing oil imports since the cost of producing power from imported oil is about 79 US cents per million Btu. So we have had to consider other means. We have found, in studies carried out with the help of the International Atomic Energy Agency and a large number of reputable firms of consultants, that in the western half of the province, which is completely devoid of all energy resources, a nuclear power station using either a boiling-water or pressurized-water reactor of a proven concept, even with a generating capacity of 70 MW, could produce power at a cost of 8 to 9 mills per kWh.

In West Pakistan the hydroelectric potential is quite large, but unfortunately is confined to the northern and north-western hilly regions which are virtually inaccessible. Even if we continued to build hydroelectric power stations with a total capacity of about 2 500 MW every decade, an extremely high figure, the total capacity by the end of the present century would not be more than about 10 000 MW. Taking into account all the coal, gas and very small oil deposits available, the generating capacity over a period of 35 to 40 years would be about 8 000 MW less than that required, assuming that the *per capita* consumption doubled once every six years between now and 1980. I may say that if, after that, it doubled once every ten years it would still amount only to approximately 900-1 000 kWh per annum by the end of the century, which is roughly the same as in present-day Japan.

We have accordingly decided to set up a 132 MW heavy-water power reactor at Karachi and a 70 MW light-water power reactor at Rooppur in East Pakistan. We are now evaluating the tenders submitted, and I hope that negotiations with a view to obtaining financial assistance from friendly countries will soon be successfully concluded so that my country, which has no other alternative open to it, can implement the very modest programme envisaged.

K. E. Effat (United Arab Republic): The United Arab Republic is now undertaking an intensive development programme designed to double the national income every ten years. For this purpose an extensive programme of industrialization and land reclamation has been planned with a view to meeting the requirements of the rapidly increasing population and in order to carry out this programme and meet the ever-increasing demand for power it is essential that all the available energy resources in the country be fully exploited.

The total installed capacity of hydroelectric power plants and conventional thermal stations, including an output of 2 100 MW (e) in the High Dam hydrogenerating station, will amount to 4 000 MW in 1970 as compared with 400 MW in 1952. This means that the energy generated will have increased from 1 000 million kWh in 1952 to 11 000 million kWh by 1970, corresponding to an increase in the generated energy *per capita* from 47 to 350 kWh during the same period. Detailed economic and feasibility studies which have been carried out indicate that the installed generating capacity, in spite of this increase, will only satisfy the needs of the country up to 1972, after which an average additional capacity of 150-200 MW(e) will be required each year.

It is expected that, at the present rate of progress in nuclear power technology, there will be a marked improvement in the economics of such plants, particularly in the case of large plants, by the 1970s. Thus it is expected that an expanding nuclear power programme will be carried out in my country during the next decade. We have therefore decided to establish the first nuclear power station, which will have a net output of 150 MW(e). This station will be integrated in the 220 kV grid system and commissioned by 1969. The generating station will be linked up with a fuel-element fabrication plant and a desalination plant designed to desalt 20 000 m^3 of water per day. In spite of the fact that under prevailing conditions and within the size-range envisaged, nuclear power stations cannot compete favourably with conventional thermal stations in the United Arab Republic, this project is being undertaken in order to introduce nuclear power technology, provide experience and train personnel in the various disciplines required to meet the future needs of an expanding programme of nuclear power in the 1980s. In addition, experimental work will be carried out on the economics of production and utilization of desalted water under desert conditions. More details on this topic will be given at the relevant special panel to be held towards the end of the Conference.

A coastal site for the nuclear power station has already been selected on the Mediterranean Sea some 30 km west of Alexandria. Preparation of the site area is now in progress and construction work will start shortly after tenders have been submitted in response to the invitation issued by the United Arab Republic Atomic Energy Establishment.

L. C. Prado (Brazil): I should like to draw attention to certain factors which have influenced power production in Brazil during recent years. These factors acquire special significance when considered in relation to the present plans for producing electric power and the possibility of using nuclear power in some areas of Brazil.

In order to form a complete picture of the electric power needs in Brazil, the following factors must be taken into account: (*a*) the great deficiency in power supply; (*b*) the increasing demand due to the growth in population and rapid industrialization of the country; (*c*) the poor quality and insufficient resources of coal; (*d*) the limited production of petroleum from known reserves; and (*e*) the existence of untapped hydraulic power resources.

On account of the last three factors the generating capacity is at present mostly hydraulic in character. Conventional thermal plants are used only to supplement hydroelectric power grid systems in the most highly industrialized areas or to meet local requirements. In the latter case they are generally small.

One striking event that took place in recent years has led the authorities to revise the optimistic views they had held regarding the hydraulic energy potential and to reconsider the possible value of thermal power resources. It was found that the water supply in the reservoir built to feed a large hydroelectric plant in one of the most industrialized areas of the country was almost exhausted. This reservoir, which is located near the city of São Paulo, consists of a system of interconnected artificial lakes which collect the rain-water that falls on the area and water coming from rivers at lower levels. The water is pumped up roughly 30 m. The reservoir is near the edge of a plateau 720 m high and at the base there is a power plant, built some 35 years ago, whose installed capacity progressively reached the present figure of 800 MW. The way in which the water is utilized is quite ingenious, but the operation of the plant depends primarily on rain-water. As the result of a serious drought during the last five years, however, the average level of the reservoir decreased steadily, so that in 1963 the water reserve was less than 5 per cent of its nominal capacity. Thus the average amount of energy supplied by the plant was severely reduced to less than 30 per cent of the normal figure with the result that a 400 MW(e) thermal power plant, located in Piratininga, which was originally built mainly to take care of the peak load has been operating since then as a base-load station (utilization factor up to 90 per cent). The situation became so critical for local industry that great efforts had to be made to expedite the completion of a distant hydroelectric plant (Furnas) and the associated transmission line in order to supplement substantially the power demand. Recourse was also had to load interchanges, within the area, but even so it was impossible to avoid a certain amount of rationing. The thermal plant mentioned is a conventional oil-fired one. Studies were undertaken to determine the feasibility of producing a further 500 MW(e) of thermal origin, half from a new conventional plant burning Brazilian coal and half from a nuclear power station.

A year and a half ago a Government committee was set up to coordinate studies of the energy needs of the whole central-southern region of Brazil, the most industrialized area in the country. This committee has already recommended ways and means of meeting the greater part of the peak-load demand up to 1970 (there remains a power deficit of about 500 MW, which could be covered by thermal plants). Within this general framework nuclear power stations might well have a part to play.

I should also like to point out that the most important grid systems in the central-southern region are progressively being interconnected with a view to having a very large interconnected grid. In the initial stage the grid will not be ring-shaped, which is possible in other regions or countries; the final grid will be composed of a number of ring-shaped systems, linked by suitable transmission lines. It should be noted that the full interconnection between the two most important load centres in Brazil, Rio de Janeiro and São Paulo, which are only 400 km from each other, has been delayed for a number of years on account of the existing difference in the frequencies used in each grid, i.e., 50 and 60 cycles per second respectively. On the recommendation of the Government committee already mentioned, a plan to change the frequency in Rio de Janeiro from 50 to 60 cycles per second has recently been approved. The people in the area concerned are being told what changes must be made in their domestic appliances.

While the vast interconnected grid is being brought to completion, the desirability of producing additional power, using thermal plants, is becoming increasingly obvious and, in this connection, the possibility of using nuclear energy should be considered.

I should also like to comment on the power supply problem in the north-eastern region of Brazil, where roughly 400 MW are produced by a large hydroelectric plant. This plant utilizes the large flow of water in the São Francisco River and the natural drop at the Paulo Afonso Falls. These falls are amongst the most impressive in Brazil, but they are located about 500 km from the geographical centre of the area to be fed. Losses in the transmission lines and the cost involved are factors which may lead to the early setting up of one or more nuclear power plants to supply energy to some very distant areas in the region in question. On the other hand, the increasing industrialization of some districts, like Fortaleza or Recife, would benefit from a power supply coming from independent plants. Here again, the prospects of using atomic energy are promising.

GENERAL DISCUSSION

M. A. El-Guebeily (United Arab Republic): In the paper (P/741) presented by Dr. Bhabha the conclusions reached with regard to India are particularly important from the point of view of the developing countries. As regards the conclusion that the CANDU 200 MW reactor can be competitive with conventional thermal plants in certain parts of India, I should like to point out, however, that it seems to be generally believed that a pressurized-water, boiling-water or gas-cooled reactor with a capacity of less than 500 MW (e) would not be competitive with conventional power.

H. J. Bhabha (India): In the industrialized countries atomic power generally becomes competitive when reactors with a minimum capacity of 500 MW(e) are used. In certain circumstances, however, reactors of smaller size may be competitive. 200 MW(e) reactors of the Tarapur or CANDU type are competitive in India in areas where coal for conventional power stations would have to be conveyed by rail or sea over distances of 500 miles or more. Moreover, the coal used in India for generating power has a calorific value of only 9 000 Btu/lb or less.

T. G. CHURCH (Canada): In economic studies of fast neutron reactors, what annual interest rate is charged in the Soviet Union against the large amounts of capital invested in the fuel inventory for this reactor system?

A. M. PETROSYANTS (USSR): The economics of fast neutron reactors is so complex a question, so technically difficult and broad in scope, that it would be impossible to give the lengthy technical explanations required in the time allowed for discussion at this session, and I think the problem should be discussed in detail at the session specially devoted to fast reactors (Technical Session 1.4). A number of scientists and experts have failed to reach agreement on the question; indeed, there can be no unanimity on the subject.

B. SAITCEVSKY (France): What part will advanced Magnox reactors play in the United Kingdom programme? If they are not to play any part in the programme, why are efforts being made to develop them, as reported in some papers from the United Kingdom?

Sir William PENNEY (United Kingdom): The Magnox reactors being built at present will be operated for at least 20 to 30 years. The United Kingdom does not intend to build any more after the present programme is completed, but much of the research and development work on the Magnox reactors will help in connection with the Advanced Gas-Cooled (AGR) and High Temperature Gas-Cooled (HTGC) reactors and hence will be of great value.

O. D. KAZACHKOVSKY (USSR): It seems to me that some of the papers presented at this session display undue caution with regard to fast neutron reactors. It has been said that the industrial development of these reactors will begin in ten, twenty or even in hundreds of years and that meanwhile thermal neutron converters will be used for plutonium production. This is undesirable. Fast neutron reactors are the best converters, provided, of course, that enriched uranium is available. It is noteworthy that the conversion coefficient in such reactors increases proportionally with burn-up, whereas it decreases in the case of thermal reactors. According to the available economic estimates, fast neutron reactors are no more expensive than thermal ones. The fundamental technological problems relating to fast reactors have been solved, and considerable work has been done in the Soviet Union, the United States and the United Kingdom on the use of sodium as a heat-transfer medium in fast reactors. Moreover, sodium is already being used successfully in thermal reactors, e.g. the Hallam reactor in the United States. The safety problem in the case of fast reactors differs little from that of thermal reactors, and is sometimes considerably exaggerated. All these considerations justify a more rapid development of fast neutron reactors than is provided for in certain programmes.

H. J. BHABHA (Chairman): If I may attempt to sum up this session, it seems clear that the energy demand is going to increase very rapidly in the world as a whole and that it will, by the turn of the century, be about eight to ten times greater than at present. It is generally believed that nuclear energy, which is already competitive in certain areas, will provide an increasing amount of electric power and that, in some countries, it may provide as much as 50 per cent of the power produced by the end of the century. This may indeed be the position in the world as a whole.

It has been stated that in many industrialized countries, where, incidentally, conventional power is relatively cheap, nuclear power stations whose capacity is greater than 500 MW would now be competitive. The paper I presented showed that in three quarters of India 200 MW nuclear power stations can, in present circumstances, be competitive. That is so, for example, on the west coast where we are constructing a power station with two 190 MW boiling-water reactors. It is also the case in Rajasthan, where we are constructing a power station with two CANDU 200 MW reactors, and in the Madras area on the south-east coast of India. It is also clear that there may be other situations where even smaller-sized power stations might be justified and competitive.

If I may say so, there is no form of power as expensive as *no power*, i.e., doing without power altogether. In a situation where industry is brought to a halt because there is not an adequate power supply, very expensive power is often justified. In such cases one has to consider whether one should construct conventional stations and import the fuel, or set up nuclear stations and import the fuel. This question gives rise to a very important economic consideration, especially in countries where there is a shortage of foreign exchange. Everyone knows that, in terms of cents per million Btu, energy produced from nuclear fuel is much cheaper than that produced from conventional fuel. It may, for example, be as low as 14 cents per million Btu, whereas energy produced from coal costing, let us say, $4 a ton, would cost about 21 cents per million Btu. Thus the fact that a smaller amount of foreign exchange would be required to pay for nuclear fuel than for conventional fuel may tell in favour of atomic energy.

Another point which seems to have emerged from the discussion is that when we consider the cost of power produced by a particular type of reactor, we ought really not only to consider the reactor in isolation but the whole fuel cycle. This is particularly true in the case of breeder reactors and is a point which needs very considerable study. Furthermore, in assessing the capital investment required for setting up new types of reactor, account should be taken of the capital investment in supporting facilities. This too is particularly important in the case of breeder reactors, since reprocessing plants can only handle a certain amount of fuel and thus, when the number of breeder reactors is increased, more reprocessing plants are required.

However, considerations of this kind apply not only to nuclear power. In a paper presented at the Geneva Conference in 1958,* my colleague, Dr. Prasad, and I discussed the cost of providing nuclear power and conventional power. In India, for example, the quality of coal, which is relatively inferior, must be improved and washeries are used for this purpose. Thus the *pro rata* capital investment in washeries must be taken into account. In the case of long-distance transport, account must also be taken of the *pro rata* capital investment in railway facilities.

The tremendous technological effort that has been made since 1955 has already borne fruit. We know now that atomic power has come to stay. Indeed it would have become more competitive than it is already but for the fact that it has forced down the cost of conventional power: and I don't think it is given sufficient credit for the service it has rendered to humanity by doing so. Apart from that, it is quite clear that the cost of nuclear power has gone down much faster than the cost of conventional power.

So much for the general picture. The technical aspects will be treated in greater detail at some of the technical sessions.

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* Bhabha, H. J., and Prasad, N. B., *A study of the contribution of atomic energy to a power programme in India,* Proceedings of the Second International Conference on the Peaceful Uses of Atomic Energy, P/1624, Vol. 1, p. 89, United Nations (1958).

Compte rendu de la séance B

Nouvelles données économiques. Besoins en énergie pendant les années à venir et mesure dans laquelle l'énergie d'origine nucléaire peut y répondre

Président: **H. J. Bhabha (Inde)**

Mémoire P/741 (présenté par H. J. Bhabha)
Mémoire P/715 (présenté par O. A. Quihillalt)
Mémoire P/559
Mémoire P/31 (présenté par J. Cabanius)
Mémoire P/192 (présenté par G. F. Tape)
Mémoire P/294 (présenté par B. B. Batorov)
Mémoire P/1 (présenté par W. B. Lewis)
Mémoire P/577 (présenté par S. Komagata)

DISCUSSION DE GROUPE

Le rôle de l'énergie d'origine nucléaire dans l'approvisionnement en énergie d'autres pays

J. P. BAXTER (Australie): En Australie, nous n'envisageons pas de produire immédiatement de l'énergie d'origine nucléaire; c'est pourquoi je me bornerai à parler du rôle futur de cette forme d'énergie, tel que nous l'envisageons. L'Australie est un pays très étendu dont la population est peu nombreuse; sa superficie est à peu près celle des Etats-Unis d'Amérique; sa population dépasse à peine 11 millions d'habitants, mais elle augmente rapidement. C'est un pays hautement industrialisé; la consommation d'énergie par habitant y est très élevée et seule celle des Etats-Unis d'Amérique lui est nettement supérieure.

A certains égards, on peut dire que l'Australie est un pays sous-développé; elle possède en effet de vastes ressources qui attendent d'être exploitées. Le charbon est actuellement la principale source d'énergie. L'Australie possède également des ressources hydroélectriques, quoique moins importantes, et produit une faible quantité d'énergie grâce à des centrales thermiques chauffées au mazout. Les ressources en charbon sont considérables et sont surtout situées dans la partie orientale du pays. On trouve également du charbon de qualité assez inférieure dans les régions méridionale et occidentale.

Dans les zones industrielles les plus importantes, où le charbon est abondant et peu coûteux, de nouvelles centrales thermiques utilisant ce combustible peuvent actuellement produire de l'énergie à un prix inférieur à 4 mills par kilowattheure, ce qui serait difficilement réalisable avec des centrales nucléaires. La situation se complique encore du fait qu'il serait aujourd'hui peu pratique, dans la plupart des Etats, d'incorporer de grosses centrales nucléaires dans le réseau de distribution. Il se pourrait que, dans un avenir relativement proche, on puisse intégrer dans le réseau de la Nouvelle-Galles du Sud, et un peu plus tard dans celui de l'Etat de Victoria, des centrales d'une puissance supérieure à 500 MW, mais dans la plupart des autres Etats il faudra limiter la puissance à 200 MW. Dans ces circonstances, il ne semble pas qu'il y ait un intérêt immédiat à construire et à exploiter des centrales nucléaires. En revanche, il est probable que l'énergie nucléaire sera appelée, en fin de compte, à jouer un rôle important dans le développement de l'Australie, à cause de la distribution géographique des mines de charbon et de la rapidité de l'expansion démographique. Il pourrait déjà en être ainsi dans la prochaine décennie en Australie méridionale, où il ne serait pas impossible qu'une centrale de 200 MW fonctionnât vers 1975. Evidemment, cela ne sera pas le cas si les travaux de prospection du pétrole et du gaz naturel donnent d'excellents résultats dans cet Etat. La Tasmanie, où l'on utilise presque exclusivement l'énergie hydroélectrique, est un autre Etat où l'on pourrait assez prochainement recourir à l'énergie d'origine nucléaire. On sera bientôt arrivé à la limite maximale d'exploitation de l'énergie hydroélectrique, de telle sorte que l'on peut fort bien envisager la possibilité de construire en Tasmanie une centrale nucléaire de 200 MW pendant la prochaine décennie.

Outre les réseaux publics de production d'énergie, qui sont tous exploités par les services compétents des divers Etats et ne sont pas interconnectés (à l'exception d'une ligne qui réunit l'Etat de Victoria et la Nouvelle-Galles du Sud à travers les Snowy Mountains), on enregistre, dans un ou deux cas particuliers, des demandes isolées d'énergie d'une certaine importance. Dans le nord et le nord-ouest du pays, on a découvert des gisements de bauxite très importants et l'on envisage sérieusement de construire des fabriques d'aluminium. Dans ce cas, il faudra recourir à l'énergie nucléaire, ce qui justifierait la construction d'une centrale importante ayant de grandes possibilités d'expansion. Dans d'autres régions de l'intérieur, la ville de Mount Isa par exemple, où l'on extrait le cuivre, l'argent, le plomb et le zinc, et où la demande de puissance pourrait atteindre 100 MW, il est fort possible que l'on doive recourir à l'énergie d'origine nucléaire à cause des grandes distances sur lesquelles l'autre combustible utilisé, le charbon, doit être transporté.

Ainsi, on peut dire que le programme australien de production d'énergie est un programme à long terme. Nous nous intéressons de très près aux travaux entrepris dans d'autres régions du monde en vue de réduire le prix de revient de l'énergie d'origine nucléaire et nous sommes très satisfaits des efforts déployés à cette fin au Canada, aux Etats-Unis, en Grande-Bretagne et ailleurs. De notre point de vue, il serait extrêmement utile que cette tâche soit menée à bien. Il n'en reste pas moins que, dans ce domaine, les activités que nous avons entreprises sont à longue échéance et que les études auxquelles nous procédons sont consacrées presque exclusivement à un système de réacteur très avancé, qui est encore à l'état de projet quelque peu hypothétique. Nous avons encore du temps devant nous.

Bien que dans notre cas le problème du dessalement de l'eau de mer ne se pose pas de façon urgente, nous serons à la longue amenés à nous y intéresser, car l'Australie est un des continents les plus arides du monde.

Nous continuons à nous intéresser à la production d'uranium et nous en produisons encore. Nous poursuivons également notre programme de prospection afin d'augmenter nos réserves. Nous sommes persuadés que notre pays est, en puissance, un gros producteur d'uranium à bon marché, ainsi que de thorium, et nous continuons de plus en plus vigoureusement nos travaux dans ce domaine malgré la baisse actuellement enregistrée sur le marché.

J. NEUMANN (Tchécoslovaquie): Je voudrais décrire rapidement les caractéristiques économiques essentielles de la situation de la production d'énergie en Tchécoslovaquie, qui nous a convaincus de la nécessité de construire des centrales nucléaires, et exposer notre attitude fondamentale en ce qui concerne les techniques de l'utilisation de l'énergie atomique à des fins pacifiques.

La République socialiste tchécoslovaque est un pays industrialisé. L'expansion de son économie se fait rapidement, ce qui permettra d'augmenter progressivement le niveau de vie et de favoriser le développement culturel. De ce fait, nous avons déjà besoin et nous continuerons d'avoir besoin d'abondantes ressources en énergie, afin de faire face aux besoins de l'industrie et de la collectivité. On s'attend que, dans les 15 prochaines années, la consommation globale d'énergie primaire double approximativement. Une des caractéristiques essentielles de l'évolution de la structure de la consommation est le développement plus rapide encore de la production d'énergie de sources classiques, d'électricité notamment, production qui atteindra 55 à 60 milliards de kilowattheures environ en 1970 et 110 à 115 milliards de kilowattheures en 1980.

Actuellement, et pour un certain temps encore, la principale source d'énergie en Tchécoslovaquie est le lignite de qualité inférieure, qui permet d'assurer 90% de la production globale d'électricité. Les gisements de charbon utilisable pour la production d'énergie sont concentrés surtout dans la région nord-ouest du pays, et c'est donc dans cette région que sont situées la plupart des centrales thermiques. Etant donné que l'extraction du charbon se fait dans des conditions naturelles de plus en plus mauvaises, que les réserves sont limitées et réparties irrégulièrement dans le pays, le développement de la production d'énergie électrique à partir des combustibles fossiles locaux se heurte à d'énormes difficultés techniques et économiques. Comme les gisements géologiques exploitables sont limités, la production des centrales thermiques ne pourra pas augmenter à un rythme suffisant pendant les 10 ou 15 prochaines années et cessera probablement d'augmenter à la fin de cette période.

Pour faire face à cette situation, nous augmentons continuellement nos importations d'énergie, qui représenteront en 1965 près de 20% de toutes les ressources primaires, et s'accroîtront encore par la suite. Parallèlement, nous préparons un programme d'utilisation généralisée de l'énergie atomique en vue de la production industrielle d'électricité.

Pour ce programme, on utilisera surtout des réacteurs nucléaires à uranium naturel, modérés à l'eau lourde et refroidis au gaz carbonique; on construit actuellement à Bohunice un prototype industriel d'une puissance de 150 MW(e). Les paramètres techniques de cette nouvelle centrale sont bien connus; ils ont été donnés dans plusieurs mémoires présentés à la deuxième Conférence internationale sur l'utilisation de l'énergie atomique à des fins pacifiques, en 1958 *. Certains des problèmes techniques que pose la construction d'un réacteur de ce type seront analysés au cours de la présente Conférence **. Les problèmes scientifiques et techniques fondamentaux ont déjà été résolus et la centrale devrait être mise en service d'ici à 1968.

Nous estimons maintenant que les réacteurs du type mentionné peuvent servir de base à un programme de construction de centrales nucléaires pendant les 10 ou 15 prochaines années. L'expérience acquise grâce à la solution des problèmes scientifiques et techniques posés par la construction de la première centrale nucléaire, et les recherches et les travaux techniques entrepris par la suite, nous ont conduits à la conclusion que les centrales de cette catégorie peuvent produire de l'énergie électrique dans des conditions économiques satisfaisantes. C'est ainsi que pour la deuxième centrale de ce type, qui sera pourvue de deux réacteurs d'une puissance de 200 MW(e) chacun, les investissements de capitaux seront de 40% moins élevés que dans le cas du prototype. Le prix de revient de l'énergie électrique produite par cette centrale devrait être à peu près le même que le prix de revient moyen de l'énergie électrique distribuée par le réseau du Conseil central de l'énergie. Si l'on augmente par la suite la puissance des réacteurs — nous croyons possible d'atteindre 400 MW(e) — le prix de revient de l'énergie produite par les centrales nucléaires devrait être comparable à celui de l'énergie qui sera produite en 1975 par les centrales thermiques classiques les plus perfectionnées. C'est pourquoi nous pensons actuellement qu'en utilisant des centrales nucléaires d'un type bien déterminé il devrait être possible de combler dès 1980 une grande partie du déficit énergétique prévu, et que ces centrales pourront produire alors 15% environ de l'énergie électrique dont le pays aura besoin dans une conjoncture économique favorable.

Comme la plupart des pays qui étudient les problèmes que pose l'utilisation de l'énergie atomique, nous estimons que, dans un avenir plus éloigné, il sera possible de produire de l'énergie électrique avec des réacteurs à neutrons rapides, ce qui permettra d'utiliser plus complètement les disponibilités en combustibles nucléaires, dans des conditions techniques et économiques favorables.

Dans l'établissement et l'exécution de notre programme, nous attendons beaucoup de la coopération internationale, en particulier de celle de l'Union soviétique, qui ne nous ménage pas son assistance.

H. VON BÜLOW (Danemark): La situation de la production d'énergie au Danemark peut, en gros, se résumer comme suit. Premièrement, le Danemark ne dispose que de réserves insignifiantes de combustibles classiques; deuxièmement, son approvisionnement en énergie dépend entièrement de la situation du marché mondial, et, troisièmement, ce sont les considérations d'ordre économique qui priment pour ce qui est de la production d'électricité d'origine nucléaire, puisque nous n'envisageons d'utiliser l'énergie atomique qu'à des fins pacifiques.

Nous suivons de près l'évolution des ressources et des besoins en énergie de l'ensemble du monde et nous avons constaté, en particulier, que trois facteurs entrent en jeu: *a*) la consommation d'énergie par habitant ne cesse de croître, même dans

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* Voir, par exemple, Actes de la deuxième Conférence internationale sur l'utilisation de l'énergie atomique à des fins pacifiques, P/2092, vol. 5, p. 263-269, et Proceedings of the Second International Conference on the Peaceful Uses of Atomic Energy, P/2094, vol. 9, p. 34-44.

** Voir, par exemple, dans les présents Actes, P/522, vol. 8, et P/523, vol. 5.

les pays les plus développés; *b*) la population mondiale continue d'augmenter, et *c*) les besoins en énergie des pays en voie de développement augmentent également. A cet égard, il importe de tenir compte de plusieurs considérations. Tout d'abord, ce n'est que si l'on utilise des réacteurs surgénérateurs que l'énergie nucléaire permettra de répondre dans une mesure suffisante aux besoins en énergie de l'ensemble du monde. Ensuite, lorsque l'on évalue les besoins mondiaux à long terme, il faut tenir compte des effets de la saturation, sans présumer pour autant qu'ils freineront l'augmentation de la consommation mondiale d'énergie pendant les prochaines décennies. En outre, il existe une forte marge d'erreur, qui est au moins de l'ordre de 30 à 100 années, dans les évaluations du temps qu'il faudra pour épuiser toutes les ressources économiquement exploitables de combustibles classiques. Enfin, il existe d'autres facteurs dont il convient de tenir compte, notamment le délai qu'il faudra pour perfectionner la technologie des réacteurs surgénérateurs au point que leur exploitation soit économiquement viable, et la détermination du taux de régénération qui peut être atteint dans des conditions rentables.

Ces diverses considérations, qui laissent d'ailleurs de côté certains autres facteurs importants, nous ont persuadés qu'un pays comme le Danemark devra procéder à des investissements dans le domaine de la production d'énergie nucléaire aussitôt que cela sera justifié du point de vue économique, compte tenu des progrès qui sont encore à réaliser. Nous pensons également que les pays les plus développés devraient s'attacher à favoriser les progrès technologiques afin que l'énergie d'origine nucléaire puisse réellement concurrencer, sur le plan économique, l'énergie provenant des combustibles fossiles. Nous croyons donc que le Danemark doit prendre sa part, aussi modeste soit-elle, des efforts déployés en vue d'atteindre cet objectif.

I. H. USMANI (Pakistan): Il est, je crois, universellement reconnu que l'énergie atomique doit dorénavant être considérée comme une nouvelle forme exploitable d'énergie, et que les tendances qui marqueront à l'avenir le développement de la technique nucléaire permettront probablement de construire des réacteurs plus efficaces et plus rentables. Je constate toutefois que les pays industrialisés attachent une grande importance au caractère concurrentiel de l'énergie nucléaire, et ne mentionnent jamais que les grands réacteurs et que les énormes quantités d'énergie que ceux-ci mettront à la disposition de leurs réseaux nationaux de distribution. Pour le Pakistan, ces considérations sont purement théoriques: pour nous, les questions de concurrence ne se posent pas, car nous avons besoin d'énergie pour assurer notre développement économique, quel qu'en soit le coût.

Le Pakistan compte environ 98 millions d'habitants. Il fait partie du sous-continent indo-pakistanais et est divisé en deux provinces principales: le Pakistan oriental, dont la population est de 54 millions d'habitants, et le Pakistan occidental, avec une population de quelque 44 millions d'habitants. Au Pakistan oriental les conditions climatiques et géographiques sont les mêmes que dans l'Asie du Sud-Est, tandis qu'au Pakistan occidental elles se rapprocheraient plutôt de celles du Moyen-Orient.

Le Pakistan oriental est une contrée humide, verdoyante et fertile; c'est une des régions les plus peuplées du monde. Comme aux Pays-Bas, le potentiel hydroélectrique y est presque nul. La plus grande partie du pays est occupée par un delta, entouré d'une région plate qui s'étend du pied de l'Himalaya, au nord, jusqu'au golfe du Bengale, avec une dénivellation totale de quelque 58 pieds. Il existe un faible potentiel hydroélectrique, de 100 MW approximativement, dans les collines de Karnaphuli, aux environs des Chittagong Hill Tracts, près de la frontière birmane; un barrage a déjà été construit en cet endroit. Jusqu'à présent, on n'a pas découvert de pétrole dans la région, ni de gisements de charbon. On n'y a trouvé qu'une faible quantité de gaz naturel, que l'on utilise pour produire de l'énergie et à d'autres fins. Même si toutes les réserves connues de gaz du Pakistan oriental, qui se trouvent concentrées dans une moitié de la province, étaient utilisées pour produire de l'électricité — énergie dont nous avons un besoin urgent étant donné que la consommation annuelle par habitant dans la province est de 15 kWh contre 4 000 à 5 000 kWh aux Etats-Unis ou au Canada — la puissance totale que l'on pourrait obtenir pendant toute la durée de l'exploitation des centrales serait de 700 MW environ. En outre, ces réserves ne peuvent pas être utilisées exclusivement pour la production d'énergie: nous en avons également besoin pour l'industrie des engrais, l'industrie pétrochimique, etc. Même si nous consacrions 50% de ces réserves à la production d'énergie, la puissance ainsi obtenue ne dépasserait pas quelque 350 MW, ce qui permettrait seulement de répondre aux besoins des usines dont on a déjà approuvé ou prévu la construction au Pakistan oriental d'ici à 1970. Six ans après la mise en service d'une centrale de 350 MW alimentée au gaz, toutes les réserves de gaz naturel seraient épuisées. Il ne suffirait pas d'augmenter les importations de pétrole, puisque l'énergie produite en utilisant du pétrole importé coûte environ 79 cents des Etats-Unis par million de Btu. Nous devons donc rechercher d'autres solutions. Grâce à des études exécutées avec l'assistance de l'Agence internationale de l'énergie atomique et de nombreux bureaux de consultants de réputation mondiale, nous avons découvert que, dans la partie occidentale de la province, complètement dépourvue de toute ressource énergétique, une centrale nucléaire utilisant un réacteur à eau bouillante ou à eau sous pression, d'un type ayant fait ses preuves, pourrait, avec une puissance de 70 MW, produire de l'énergie qui reviendrait à 9 ou 10 mills le kilowattheure.

Le Pakistan occidental dispose d'un potentiel hydroélectrique assez important, malheureusement concentré dans les régions montagneuses du nord et du nord-ouest, qui sont virtuellement inaccessibles. Même si nous continuions à construire chaque décennie des centrales hydroélectriques ayant une puissance globale de 2 500 MW environ (ce qui est un chiffre extrêmement élevé), la puissance totale à la fin du siècle ne dépasserait pas quelque 10 000 MW. Compte tenu de tous les gisements disponibles de charbon et de gaz, ainsi que des petits gisements de pétrole, la puissance disponible sur une période de 35 à 40 ans serait inférieure de 8 000 MW environ aux besoins, à supposer que d'ici à 1980 la consommation par habitant double tous les six ans. Je dois préciser que, si par la suite la consommation par habitant ne doublait que tous les dix ans, elle ne serait toujours que de 900 à 1 000 kWh par an environ à la fin du siècle, c'est-à-dire à peu près égale à la consommation actuelle au Japon.

C'est pourquoi nous avons décidé de construire à Karachi un réacteur à eau lourde de 132 MW, et un réacteur à eau légère de 70 MW à Rooppur dans le Pakistan oriental. Nous examinons actuellement les soumissions qui ont été faites, et nous espérons que les négociations entreprises avec des pays amis en vue d'obtenir une assistance financière seront prochainement menées à bonne fin, ce qui permettra à mon pays, pour lequel il n'est pas d'autre solution possible, de mettre en œuvre le programme envisagé, qui est très modeste.

K. E. Effat (République arabe unie): La République arabe unie entreprend actuellement l'exécution d'un programme intensif de développement, qui devrait permettre de doubler le revenu national tous les dix ans. A cette fin, nous avons préparé un vaste programme d'industrialisation et de mise en valeur des terres, en vue de répondre aux besoins d'une population qui augmente rapidement. Pour exécuter ce programme et pour faire face à la demande croissante d'énergie, il est essentiel que toutes les ressources énergétiques disponibles dans le pays soient pleinement exploitées.

La puissance installée globale des centrales hydroélectriques et des centrales thermiques du type classique, compte tenu des 2 100 MW(e) que produira la centrale du Haut barrage, atteindra 4 000 MW en 1970, alors qu'elle n'était que de 400 MW en 1952. Cela signifie que l'énergie produite aura passé de 1 milliard de kWh en 1952 à 11 milliards de kWh en 1970, ce qui signifie que, pendant cette période, l'énergie produite par habitant passera de 47 à 350 kWh. Les études économiques détaillées et les études de viabilité qui ont été faites montrent que, malgré cette augmentation, la puissance installée ne permettra de répondre aux besoins du pays que jusqu'en 1972, après quoi il faudra accroître la puissance installée de 150 à 200 MW(e) en moyenne par an.

Etant donné les progrès actuels de la technologie dans ce domaine, on s'attend que d'ici à 1970 les centrales nucléaires pourront être exploitées dans des conditions économiques beaucoup plus favorables, surtout les grandes centrales. Ainsi, nous envisageons de mettre en œuvre dans mon pays pendant la prochaine décennie un programme de plus en plus vaste de production d'énergie d'origine nucléaire. Nous avons donc décidé de construire notre première centrale nucléaire, dont la puissance nette sera de 150 MW(e). Cette centrale sera incorporée au réseau de distribution de 220 kV, et devrait entrer en service en 1969. Elle sera couplée avec une usine de fabrication d'éléments de combustible et une usine de dessalement prévue pour traiter 20 000 m^3 d'eau par jour.

Dans les conditions actuelles, les centrales nucléaires de la taille de celles dont nous envisageons la construction en République arabe unie ne sont pas dans une position concurrentielle favorable par rapport aux centrales thermiques de type classique, mais ce projet est entrepris en vue de permettre à mon pays de se familiariser avec les techniques de la production d'énergie nucléaire, d'acquérir l'expérience nécessaire et de former un personnel rompu aux diverses disciplines indispensables pour pouvoir faire face aux besoins créés par la mise en œuvre, dans les années 80, d'un programme de production d'énergie nucléaire dont l'importance ira croissant. En outre, des travaux de recherche seront entrepris en ce qui concerne les aspects économiques de la production et de l'utilisation d'eau dessalée dans les régions désertiques. Nous donnerons des détails complémentaires à ce sujet devant le groupe de discussion compétent qui doit se réunir vers la fin de la Conférence.

On a déjà choisi l'emplacement de la centrale nucléaire, qui sera située au bord de la mer Méditerranée, à quelque 30 km à l'ouest d'Alexandrie. Les travaux d'aménagement sont en cours et la construction commencera aussitôt que les soumissions auront été faites en réponse à l'invitation de la Direction de l'énergie atomique de la République arabe unie.

L. C. Prado (Brésil): Je voudrais signaler certains facteurs qui, ces dernières années, ont influé sur la production d'énergie au Brésil. Ces facteurs prennent une importance particulière lorsqu'on les étudie dans le contexte des plans actuels de production d'énergie électrique et de l'utilisation éventuelle de l'énergie atomique dans certaines régions du Brésil.

Si l'on veut se faire une idée exacte des besoins du Brésil en énergie électrique, il faut tenir compte des facteurs suivants: *a*) l'énergie produite est très insuffisante; *b*) la demande augmente avec l'accroissement de la population et l'industrialisation rapide du pays; *c*) les ressources en charbon sont insuffisantes et de mauvaise qualité; *d*) la quantité de pétrole extraite des gisements connus est limitée, et *e*) il existe des ressources hydroélectriques qui ne sont pas encore exploitées.

Ces trois derniers facteurs expliquent pourquoi la puissance installée est actuellement presque exclusivement hydraulique. On utilise des centrales thermiques de type classique uniquement pour compléter les réseaux hydroélectriques dans les régions les plus industrialisées, ou pour répondre aux besoins locaux. Dans ce dernier cas, il s'agit généralement de petites centrales.

Ces dernières années, un événement s'est produit qui a conduit les pouvoirs publics à faire preuve de moins d'optimisme quant au potentiel hydroélectrique du pays et à reviser leurs idées touchant l'importance possible des centrales thermiques. On a découvert, en effet, que les réserves d'eau de la retenue destinée à alimenter une grosse centrale hydroélectrique de l'une des régions les plus industrialisées du pays étaient presque épuisées. La retenue, qui est située près de la ville de São Paulo, se compose d'une série de lacs artificiels reliés entre eux, alimentés par l'eau de pluie et par certains cours d'eau situés en contre-bas. L'eau est pompée à une hauteur de 30 m environ. La retenue se trouve au bord d'un plateau de 720 m de haut, au pied duquel a été construite il y a 35 ans une centrale électrique, dont la puissance installée a augmenté progressivement pour atteindre maintenant 800 MW. La manière dont l'eau est utilisée est très ingénieuse, mais le fonctionnement de la centrale dépend essentiellement des précipitations. Comme les cinq dernières années ont été extrêmement sèches, le niveau moyen de la retenue a baissé régulièrement, de sorte qu'en 1963 l'eau accumulée représentait moins de 5% de la capacité théorique du réservoir. Il a donc fallu, pour assurer la charge de base, utiliser une centrale thermique de 400 MW(e) située à Piratininga (facteur d'utilisation allant jusqu'à 90%), qui à l'origine était essentiellement destinée à assurer les charges de pointe. La situation de l'industrie locale est devenue à ce point critique qu'il fallut redoubler d'efforts pour achever au plus vite la construction d'une centrale hydroélectrique assez éloignée (Furnas) et établir les lignes d'interconnexion nécessaires, afin de faire face à la demande d'énergie. On a dû procéder également à des échanges de charges à l'intérieur de la région. Tout cela n'a toutefois pas permis d'éviter certaines mesures de rationnement. La centrale thermique en question est de type classique, chauffée au mazout. Des études ont été entreprises aux fins de déterminer dans quelle mesure il serait possible d'installer une puissance supplémentaire de 500 MW(e) d'origine thermique, dont la moitié serait produite par une nouvelle centrale de type classique utilisant du charbon brésilien, et l'autre moitié par une centrale nucléaire.

Il y a un an et demi, un comité d'Etat a été chargé de coordonner les études sur les besoins en énergie de l'ensemble de la région centrale et méridionale du Brésil, qui est la plus industrialisée du pays. Ce comité a déjà recommandé plusieurs mesures qui permettraient de faire face à la plus grande partie des besoins de pointe jusqu'en 1970 (compte tenu d'un déficit énergétique persistant de 500 MW environ, qui pourrait être comblé grâce à des centrales thermiques). Les centrales nucléaires pourraient jouer un rôle dans le cadre général de ce programme.

Je voudrais également préciser que les réseaux les plus importants des régions centrale et méridionale du pays sont progressivement reliés entre eux en vue de créer un vaste système de réseaux interconnectés. Au stade initial, le réseau ne sera pas circulaire, comme cela est possible dans d'autres régions ou dans d'autres pays; sous sa forme définitive, il se composera d'un certain nombre de systèmes circulaires, reliés entre eux par des lignes d'interconnexion appropriées. Il convient de souligner que les travaux en vue d'assurer une interconnexion complète des deux principaux centres de charge du Brésil, Rio de Janeiro et São Paulo, qui ne sont éloignés que de 400 km, ont dû être reculés d'année en année, car ces deux villes utilisent des fréquences différentes, soit 50 et 60 Hz respectivement. Sur la recommandation du comité d'Etat dont nous venons de parler, un plan visant à porter de 50 à 60 Hz la fréquence utilisée à Rio de Janeiro a récemment été approuvé. La population de la région intéressée est actuellement informée des modifications qui devront être apportées aux appareils domestiques.

Alors que le réseau interconnecté est en voie d'achèvement, il devient de plus en plus évident qu'il faudra augmenter la production d'énergie en utilisant des centrales thermiques et, à cet égard, on devrait envisager la possibilité d'utiliser de l'énergie d'origine nucléaire.

Je voudrais également faire quelques observations sur le problème que pose la distribution d'électricité dans la région nord-est du Brésil, où existe une grande centrale hydroélectrique d'environ 400 MW. Cette centrale utilise le débit du São Francisco, qui est très fort, ainsi que les chutes naturelles de Paulo Afonso. Ces chutes comptent parmi les plus spectaculaires du pays, mais elles sont situées à quelque 500 km du centre géographique de la région à alimenter en énergie. Les pertes qui se produisent au cours du transport et le prix de revient pourraient justifier la construction dans un avenir proche d'une ou de plusieurs centrales nucléaires qui produiraient de l'énergie à l'intention des zones les plus isolées de cette région. En outre, l'industrialisation de certains districts, ceux de Fortalesa et de Recife notamment, pourrait être accélérée s'ils disposaient d'énergie produite par des centrales indépendantes. Ici encore, il pourrait être avantageux d'utiliser de l'énergie d'origine nucléaire.

DISCUSSION GÉNÉRALE

A. El-Guebeily (République arabe unie): Dans le mémoire (P/741) qu'a présenté M. Bhabha, les conclusions concernant l'Inde sont très importantes pour les pays en voie de développement. Au sujet de la conclusion selon laquelle le réacteur CANDU de 200 MW peut, dans certaines régions de l'Inde, faire concurrence aux centrales thermiques de type classique, je voudrais souligner qu'il semble généralement admis qu'un réacteur à eau sous pression, à eau bouillante ou à refroidissement par un gaz ne peut pas faire concurrence aux modes classiques de production d'énergie si sa puissance est inférieure à 500 MW(e).

H. J. Bhabha (Inde): En général, dans les pays industrialisés, l'énergie atomique peut faire concurrence aux autres formes d'énergie si l'on utilise des réacteurs de 500 MW(e) au moins. Dans certaines circonstances, toutefois, cela est possible avec des réacteurs moins puissants. C'est le cas notamment des réacteurs de 200 MW(e) du type Tarapur ou CANDU dans les régions de l'Inde où il faudrait transporter, par rail ou par mer, sur des distances de 500 milles au moins, le charbon destiné aux centrales de type classique. En outre, le pouvoir calorifique du charbon utilisé en Inde pour la production d'énergie ne dépasse pas 9 000 Btu par livre.

T. G. Church (Canada): Dans les études économiques sur les réacteurs à neutrons rapides, quel est le taux d'intérêt prévu en Union soviétique pour les capitaux considérables investis dans les stocks de combustible destinés aux réacteurs de ce type?

A. M. Petrosyants (URSS): Les caractéristiques économiques des réacteurs à neutrons rapides soulèvent des questions si complexes, si délicates du point de vue technique et d'une portée si vaste que le temps dont nous disposons à la présente séance ne permettrait pas de donner toutes les explications techniques nécessaires. Je pense que ce point devrait être examiné en détail à la séance qui sera spécialement consacrée aux réacteurs rapides (séance technique 1.4). Nombre de savants et d'experts n'ont pu se mettre d'accord sur cette question, au sujet de laquelle je ne crois d'ailleurs pas que l'unanimité puisse se faire.

B. Saitcevsky (France): Quel rôle joueront les réacteurs de type Magnox avancé dans le programme du Royaume-Uni? S'ils ne doivent jouer aucun rôle, quel est le sens de l'effort de développement dont ils font l'objet et dont il est question dans certains mémoires présentés par le Royaume-Uni?

Sir William Penney (Royaume-Uni): Les réacteurs du type Magnox qui sont construits actuellement fonctionneront pendant 20 ou 30 ans au moins. Après l'achèvement du programme en cours, le Royaume-Uni n'a pas l'intention d'en construire d'autres, mais les travaux de recherche et de développement dont ils font l'objet sont très utiles car ils aideront pour une grande part à mettre au point les réacteurs avancés à réfrigérant gazeux (AGR) et les réacteurs à réfrigérant gazeux à haute température (HTGC).

O. D. Kazachkovsky (URSS): Il me semble que certains des mémoires présentés à cette séance font preuve d'une prudence exagérée en ce qui concerne les réacteurs à neutrons rapides. On a affirmé que le développement industriel de ces réacteurs prendra 10, 20 ou même 100 ans et que d'ici là on utilisera les convertisseurs à neutrons thermiques pour produire du plutonium. Cela n'est pas souhaitable. Les réacteurs à neutrons rapides sont les meilleurs convertisseurs qui soient, à condition bien entendu que l'on dispose d'uranium enrichi. Il est bien connu que, dans ces réacteurs, le coefficient de conversion augmente proportionnellement au taux de combustion, alors qu'il diminue dans le cas des réacteurs thermiques. D'après les évaluations effectuées dans le domaine économique, les réacteurs à neutrons rapides ne reviennent pas plus cher que les réacteurs thermiques. Les principaux problèmes technologiques que posent ces réacteurs ont été résolus et des travaux très importants ont déjà été effectués en Union soviétique, aux Etats-Unis et au Royaume-Uni en ce qui concerne l'utilisation du sodium comme caloporteur dans les réacteurs rapides. En outre, on a déjà utilisé le sodium avec succès dans des réacteurs thermiques, par exemple dans le réacteur Hallam aux Etats-Unis. Dans le cas des réacteurs rapides, le problème de la sécurité est à peu près le même que dans celui des réacteurs thermiques, et il est parfois très exagéré. De toutes ces considérations, il ressort qu'il faudrait développer les réacteurs à neutrons rapides plus vite que ne le prévoient certains programmes.

H. J. Bhabha (Président): Si je puis me permettre de résumer la discussion, il paraît évident que la demande d'énergie va s'accroître très rapidement dans l'ensemble du monde, et qu'à la fin du siècle elle sera huit à dix fois plus élevée que maintenant. Il est reconnu généralement que l'énergie nucléaire, qui dans certaines régions peut déjà faire concurrence aux autres formes d'énergie, permettra d'assurer la production d'une quantité croissante d'énergie électrique, et que dans certains pays 50% au moins de l'énergie qui sera produite à la fin du siècle sera d'origine nucléaire. C'est ainsi que l'on peut, me semble-t-il, résumer la situation dans l'ensemble du monde.

On a affirmé que, dans bon nombre de pays industrialisés, où d'ailleurs l'énergie de sources classiques est relativement bon marché, les centrales nucléaires dont la puissance dépasse 500 MW seraient dès à présent dans une position concurrentielle favorable. Le mémoire que j'ai présenté indique que, dans les trois quart de l'Inde, les centrales nucléaires de 200 MW peuvent, dans les circonstances actuelles, faire concurrence aux autres types de centrale. C'est le cas sur la côte ouest, où nous construisons actuellement une centrale équipée de deux réacteurs à eau bouillante de 190 MW. C'est également le cas au Rajasthan, où nous construisons une centrale équipée de deux réacteurs CANDU de 200 MW, ainsi que dans la région de Madras sur la côte sud-ouest du pays. Il est évident en outre qu'il peut exister d'autres situations où même des centrales de puissance plus petite peuvent se justifier et être viables économiquement. Il n'existe pas, si je puis dire, d'énergie plus onéreuse que la « non-énergie », c'est-à-dire le fait de se passer complètement d'énergie. Lorsque les entreprises industrielles cessent de fonctionner faute d'approvisionnement suffisant en énergie, il est souvent justifié de recourir à de l'énergie de prix de revient très élevé. En l'occurrence, on a le choix entre deux solutions: soit construire des centrales de type classique et importer le combustible, soit construire des centrales nucléaires et importer le combustible. Ce choix pose des problèmes économiques très importants, surtout dans les pays qui manquent de devises. Il est notoire qu'envisagée du point de vue du coût par million de Btu, l'énergie d'origine nucléaire est bien meilleur marché que l'énergie provenant de sources classiques. Elle peut ne coûter que 14 cents par million de Btu, alors que l'énergie produite par des centrales utilisant du charbon, qui revient, par exemple, à 4 dollars la tonne, coûtera environ 21 cents par million de Btu. Ainsi, le fait que l'achat de combustible nucléaire exige une dépense moindre en devises que l'achat de combustible classique pourrait militer en faveur de l'énergie atomique.

Une autre conclusion semble ressortir de la discussion: lorsque nous examinons le prix de revient de l'énergie produite par un réacteur d'un type donné, nous ne devons pas nous borner à l'étude du seul réacteur, mais nous devons considérer le cycle complet de l'approvisionnement en combustible. Cela est particulièrement vrai dans le cas des réacteurs surgénérateurs, et c'est là un point qui mérite d'être étudié très attentivement. En outre, lorsque l'on évalue les investissements nécessaires pour construire des réacteurs de type nouveau, il faut tenir compte des investissements nécessités par les services et installations connexes. Cela est aussi très important dans le cas des réacteurs surgénérateurs puisque les usines procédant à la régénération du combustible ne peuvent traiter qu'une quantité limitée de combustible et qu'il faut augmenter le nombre de ces usines lorsqu'on augmente celui des réacteurs.

Toutefois, les considérations de ce genre ne valent pas seulement pour l'énergie d'origine nucléaire. Dans un mémoire que nous avons présenté à la Conférence de Genève de 1958*, mon collègue M. Prasad et moi-même avons étudié les prix de revient respectifs de l'énergie d'origine nucléaire et de l'énergie provenant de sources classiques. En Inde, nous devons améliorer la qualité du charbon, qui est relativement médiocre, et pour ce faire nous devons laver le combustible. Nous devons donc tenir compte de l'augmentation proportionnelle des prix de revient du fait des investissements de capitaux dans les laveries. En outre, lorsque le combustible doit être transporté sur de longues distances, nous devons également tenir compte de l'augmentation proportionnelle due aux investissements dans les chemins de fer.

L'effort technologique considérable qui a été accompli depuis 1955 a déjà porté ses fruits. Nous savons maintenant que nous devons désormais compter avec l'énergie atomique. D'ailleurs, cette forme d'énergie aurait déjà pu faire concurrence à l'énergie de type classique si elle n'avait pas eu pour effet de provoquer une baisse du prix de revient de celle-ci — et je crois que nous sous-estimons le service que, ce faisant, elle a rendu à l'humanité. Cela mis à part, il est évident que le coût de l'énergie nucléaire a baissé beaucoup plus rapidement que celui de l'énergie provenant de sources classiques.

Telle est donc la situation générale. Les aspects techniques seront étudiés plus en détail à certaines des séances techniques.

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* Bhabha, N. J., et Prasad, N. B., *Etude de la contribution de l'énergie atomique à un programme de développement de l'énergie en Inde,* Actes de la deuxième Conférence internationale sur l'utilisation de l'énergie atomique à des fins pacifiques, P/1624, vol. 1, p. 93, Nations Unies (1958).

Протокол заседания В

Новые экономические данные. Будущие потребности в энергии и роль атомной энергетики

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Доклад Р/294 (представил Б. Б. Батуров)
Доклад Р/1 (представил У. Б. Льюис)
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ДИСКУССИЯ ЭКСПЕРТОВ

Роль атомной энергетики в удовлетворении энергетических потребностей других стран

Дж. П. БАКСТЕР (Австралия): В настоящее время в Австралии не планируется производство электроэнергии атомными электростанциями. Поэтому я буду говорить о роли атомной энергетики в будущем. Австралия — это большая страна с небольшим населением; ее площадь равна приблизительно площади Соединенных Штатов Америки, а население несколько превышает 11 млн. человек, но оно быстро растет. Австралия — страна с быстро развивающейся промышленностью, по потреблению энергии на душу населения она значительно уступает только США.

Но с другой стороны, Австралия является слаборазвитой страной в том отношении, что огромные природные ресурсы еще не разрабатываются. В настоящее время основным источником энергии является уголь. Несколько меньшая часть энергии получается от гидроэлектростанций, и небольшая часть энергии получается за счет сжигания нефти. Запасы угля очень велики и в основном находятся в восточной части страны; в южной и западной частях страны также есть уголь, но не очень хорошего качества.

В настоящее время в больших промышленных районах, где уголь дешевый и его много, новые электростанции на угле могут вырабатывать энергию стоимостью ниже 0,4 *цент/квт · ч*, а получить атомную электроэнергию такой стоимости — задача не из легких. Это осложняется еще тем, что в большинстве штатов было бы практически невозможно в настоящее время подключить энергию от очень мощных атомных электростанций (АЭС) в общую распределительную энергосистему. Но возможно, что в недалеком будущем штат Новый Южный Уэльс, а несколько позднее штат Виктория смогут потреблять полностью всю энергию от станций мощностью свыше 500 *Мвт;* однако в большинстве других штатов мощность станций должна ограничиваться 200 *Мвт*. При таких условиях, по-видимому, мало надежды на немедленное строительство и эксплуатацию АЭС. С другой стороны, возможно, что атомная энергия сыграет важную роль в последующем развитии Австралии, частично из-за географического расположения угольных месторождений, частично благодаря быстрому росту населения. Это может произойти в следующем десятилетии в южной части Австралии, где, по крайней мере, существует возможность, что в середине семидесятых годов будет работать электростанция мощностью 200 *Мвт*. Однако этого может не случиться, если проводимые в настоящее время работы по разведке нефти и природного газа окажутся успешными. Другим штатом, где атомная энергия, возможно, начнет использоваться довольно скоро, является Тасмания, где используется почти исключительно энергия гидроэлектростанций. В связи с тем, что ресурсы гидроэнергии будут вскоре исчерпаны, стоит рассмотреть возможность сооружения в Тасмании в следующем десятилетии АЭС мощностью 200 *Мвт*.

Кроме государственных энергетических систем, которые эксплуатируются государственными организациями и которые не объединены между собой, за исключением линии через горы между штатами Виктория и Новый Южный Уэльс, в отдельных случаях могут возникнуть местные потребности в некотором количестве электроэнергии. На севере и северо-востоке были открыты очень большие запасы бокситов, и в настоящее время рассматривается возможность получения алюминия из этого минерала. Если месторождения будут разрабатываться, придется использовать атомную энергию, и это может оправдать строительство полномасштабной энергетической установки, мощность которой в дальнейшем может быть увеличена. В некоторых других районах во внутренних областях страны, как, например, в Маунт-Айза, где добываются медь, серебро, свинец и цинк и где потребление энергии может увеличиться до 100 *Мвт*, вероятно, появится необходимость в строительстве атомной электростанции, потому что другое топливо (уголь) должно доставляться на большое расстояние.

Таким образом, программа развития энергетики в Австралии рассчитана на много лет. Нас живо интересуют проводимые другими странами работы по уменьшению стоимости атомной электроэнергии, и нас весьма радуют усилия, предпринимаемые Канадой, США, Великобританией и другими странами в целях выполнения этой задачи.

С нашей точки зрения, выполнение этой задачи будет иметь очень важное значение. Однако наша деятельность в этой области рассчитана на длительный срок и наши исследования сконцентрированы на усовершенствованной, но еще не определившейся реакторной системе, так что у нас есть время для размышлений.

Хотя для нас опреснение воды не является первостепенной необходимостью, мы интересуемся этим с точки зрения возможности использования атомной энергии для этой цели в далеком будущем, так как Австралия является одним из самых сухих континентов.

Нас продолжает интересовать вопрос производства урана, которым мы все еще занимаемся и продолжаем проводить исследования с целью расширения наших запасов. Мы полагаем, что в нашей стране существуют потенциальные возможности производить дешевый уран, а также торий в больших масштабах. Несмотря на сокращение спроса в настоящее время, мы продолжаем работы в этом направлении.

Дж. НЕЙМАНН (Чехословакия): Мне бы хотелось вкратце дать экономическую характеристику энергетики Чехословакии и высказать соображения, которые привели нас к выводу о необходимости строительства АЭС, а также обрисовать основное направление в технике в связи с использованием атомной энергии в мирных целях.

Чехословацкая Социалистическая Республика является индустриальной страной. Быстрое развитие народного хозяйства, которое непрерывно будет повышать уровень жизни и способствовать культурному росту, требует и будет продолжать требовать большого количества электроэнергии для удовлетворения потребностей промышленности и сельского хозяйства.

Предполагают, что общее потребление энергетических ресурсов удвоится в последующие 15 лет. Характерной особенностью развития структуры потребления энергии является быстрый рост потребления обычных видов энергии, в частности электроэнергии, производство которой составит 55 000—60 000 млн. *квт · ч* в 1970 и 110 000—115 000 млн. *квт · ч* к 1980 г.

Бурый уголь низкого качества, за счет использования которого производится сейчас 90% общего количества получаемой в стране электроэнергии, в настоящее время, да и в ближайшем будущем, станет в Чехословакии основным источником энергии. Месторождения угля, пригодного для получения энергии, расположены в северо-западной части страны, и, следовательно, там находится большинство тепловых электростанций. Учитывая ухудшение условий добычи угля, ограниченность его запасов и неравномерность залегания по стране, можно сделать вывод, что дальнейшее увеличение выработки электроэнергии за счет собственного ископаемого топлива оказывается связанным со значительными техническими и экономическими трудностями. Ввиду ограниченности запасов ископаемого топлива производство электроэнергии тепловыми электростанциями не сможет увеличиваться с необходимой скоростью в последующие 10 или 15 лет и едва ли сможет вообще увеличиваться в дальнейшем.

Энергетические потребности покрываются за счет импортируемой энергии, которая в 1965 г. составит почти 20% от общего энергетического баланса и в дальнейшем ее доля увеличится. Одновременно разрабатывается программа широкого применения ядерной энергии для получения электричества для нужд промышленности.

Эта программа будет основана на энергетических реакторах на природном уране с тяжелой водой в качестве замедлителя и углекислым газом в качестве теплоносителя; в настоящее время в Богунице строится промышленный прототип электрической мощностью 150 *Мвт*. Технические параметры этой АЭС хорошо известны, они были приведены в ряде докладов, представленных на Вторую Международную конференцию по мирному использованию атомной энергии в 1958 г.* Некоторые технические вопросы, связанные со строительством реактора такого типа, описаны в докладах, представленных на настоящую конференцию**. Основные научные и технические вопросы, связанные с данным проектом, были уже решены, и атомная электростанция будет введена в действие к 1968 г.

Мы считаем, что программа сооружения АЭС в последующие 10 или 15 лет может основываться на реакторах указанного типа. На основе опыта, накопленного при решении научных и технических вопросов, связанных со строи-

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* Например, P/2092, т. 8, стр. 322—328 и P/2094, т. 9, стр. 36—44.

** Например, доклады P/522 т. 8, и P/523, т. 5 настоящего издания.

тельством первой АЭС, и последующих теоретических и экспериментальных исследований пришли к заключению, что электростанции такого типа могут вырабатывать электроэнергию, конкурентоспособную с энергией, производимой на обычных электростанциях. Так, удельные капитальные затраты на вторую АЭС такого типа, с двумя реакторами электрической мощностью 200 *Мвт* каждый, будут на 40—50% меньше, чем удельные капитальные затраты на сооружение прототипа. Стоимость электроэнергии, вырабатываемой такой станцией, должна приблизительно равняться средней стоимости электроэнергии в сети электростанций Центрального энергетического совета. Дальнейшее увеличение единичных мощностей реакторов (а мы полагаем, что можно будет получить электрическую мощность 400 *Мвт*) должно создать такое положение, при котором стоимость энергии атомных электростанций к 1975 году не превысит стоимости энергии, поставляемой лучшими тепловыми электростанциями. Мы полагаем, что при использовании АЭС указанного типа можно будет удовлетворить значительную часть потребностей в электроэнергии к 1980 г. (около 15%) при благоприятных экономических условиях.

Как и в других странах, которые столкнулись с вопросами использования атомной энергии, мы считаем, что в более отдаленном будущем для производства электроэнергии можно будет использовать реакторы на быстрых нейтронах, что позволит более полно использовать имеющиеся запасы ядерного топлива при благоприятных технических и экономических условиях.

В составлении и выполнении нашей программы мы надеемся на международное сотрудничество, в частности с Советским Союзом, который оказывает нам большую помощь.

Х. БЮЛОВ (Дания): Современное состояние энергетики Дании можно кратко охарактеризовать следующим образом. Во-первых, запасы ископаемого топлива в Дании незначительны, во-вторых, энергоснабжение страны сильно зависит от условий мирового рынка и, в-третьих, при рассмотрении вопроса использования атомной энергии (для получения электроэнергии) экономические показатели приобретают особенно важное значение, поскольку атомная энергия будет применяться исключительно в мирных целях.

Нас весьма интересуют запасы энергии и энергетические потребности всего мира в целом, в частности следующие положения: а) непрерывно растущее потребление энергии на душу населения, даже в наиболее развитых странах; б) непрерывный рост населения; в) увеличение энергетических потребностей развивающихся стран. В этой связи следует иметь в виду следующее. Во-первых, атомная энергетика может сыграть значительную роль в удовлетворении энергетических потребностей, если будут использоваться реакторы-размножители. Во-вторых, при оценке мировых потребностей в энергии в перспективе следует учитывать общие достоверные мировые запасы топлива, хотя нельзя предположить, что они повлияют на общее мировое потребление энергии в течение нескольких десятков лет. В-третьих, существует большая вероятность ошибки, по крайней мере порядок 30—100 лет, при определении времени, в течение которого израсходуются, доступные с экономической точки зрения, запасы обычного топлива. В-четвертых, следует принять во внимание другие важные факторы, например время, необходимое для решения технических проблем, связанных с созданием реакторов-размножителей, до такой степени, чтобы их эксплуатация могла быть экономичной, а коэффициент воспроизводства—высоким.

Эти особые соображения, на которые я сослался и которые не исчерпывают всех важных факторов, привели к заключению, что стране, подобной Дании, при рассмотрении будущих разработок, следует тогда вкладывать деньги в производство атомной электроэнергии, когда она будет экономичной. Мы также считаем, что все наиболее развитые страны должны взять на себя часть ответственности за дальнейшие усовершенствования технологии реакторов с целью сделать электроэнергию, производимую ядерными установками конкурентоспособной, с тем чтобы она действительно могла заменить энергию, получаемую на станциях, работающих на ископаемом топливе. Поэтому мы считаем, что Дания должна принять участие, хотя и весьма скромное, в достижении этой цели.

И. Х. УСМАНИ (Пакистан): Я думаю, что все согласятся с тем, что ядерную энергию следует считать еще одним источником получения электроэнергии и что в будущем развитие технологии реакторов должно быть направлено на улучшение технических и экономических характеристик энергетических реакторов. Замечу, однако, что развитые в промышленном отношении страны уделяют большое внимание конкурентоспособности атомной электроэнергии и все время говорят о мощных реакторах и большом количестве электроэнергии, которое атомные станции могут дать в общую энергосеть. Такие соображения для Пакистана представляют чисто теоретический интерес, так как вообще не возникает вопрос о конкурентоспособности, поскольку мы должны иметь энергию, необходимую для развития страны, вне зависимости от ее стоимости.

Население Пакистана составляет 98 млн. человек. Пакистан разделен на две провинции: Восточный Пакистан с населением 54 млн. человек и Западный Пакистан с населением около 44 млн. человек. Восточный Пакистан по своим климатическим и географическим условиям напоминает Юго-Восточную Азию, а в Западном Пакистане условия в основном похожи на условия, характерные для Средней Азии.

Восточный Пакистан с влажным климатом, богатой растительностью и плодородными почвами является одним из наиболее густо населенных районов на земном шаре. Как и Голландия, Пакистан практически не располагает гидроэнергетическими ресурсами. Есть равнинная область дельты, простирающаяся к северу от Бенгальского залива до подножья Гималаев с уклоном 17,6 м. Имеются небольшие, уже освоенные гидроресурсы порядка 120 *Мвт* в районе Карнапхульского плоскогорья в Читтагонг-Хилл-Трактс, возле границы с Бирмой. Нефтяных месторождений до сих пор не обнаружено, угля нет, а имеются только очень небольшие запасы природного газа, которые частично используются для производства электроэнергии, а частично для других целей. Если бы все обнаруженные запасы природного газа, расположенные в одной половине провинции, использовались только для производства электроэнергии, в которой страна очень нуждается, так как годовое потребление электроэнергии в провинции на душу населения составляет только 15 *квт* по сравнению с 4000—5000 *квт* в США и Канаде, они обеспечили бы общую мощность в 700 *Мвт* в течение срока службы установки. Кроме того, эти запасы нельзя полностью использовать только для выработки электроэнергии, поскольку они нужны также для получения минеральных удобрений, некоторых фракций нефти и т. д. Если бы 50% всех запасов использовались для получения электроэнергии, электрическая мощность в результате составила бы только 350 *Мвт*, в результате чего можно было бы покрыть энергетические потребности только тех установок, которые уже намечены или планируются к вводу в эксплуатацию в Восточном Пакистане к 1970 г. Всех запасов природного газа хватило бы на 6 лет работы электростанции мощностью 350 *Мвт*. Положение нельзя радикально облегчить путем ввоза нефти, так как стоимость энергии, получаемой на базе импортируемой нефти, составляет примерно 79 американских центов на 1 млн. БТЕ (252 000 *ккал*).

Рассматривались и другие пути. В результате исследований, проведенных с помощью МАГАТЭ и некоторых квалифицированных консультантов, определили, что в западной части провинции, где совершенно нет энергетических ресурсов, АЭС с кипящим реактором или реактором с водой под давлением мощностью 70 *Мвт* могла бы вырабатывать энергию стоимостью 0,8—0,9 *цент/квт · ч*.

В Западном Пакистане гидроэнергетический потенциал весьма большой, но, к сожалению, гидроресурсы сосредоточены в северном и северо-западном гористых районах, практически недоступных. Если бы мы продолжали строить каждое десятилетие ГЭС общей мощностью в 2500 *Мвт* (чрезвычайно большая цифра), то общая мощность к концу настоящего столетия не превышала бы 10 000 *Мвт*. Учитывая все имеющиеся ресурсы угля, газа и небольшого количества нефти, электрическая мощность за период свыше 35—40 лет была бы на 8000 *Мвт* менее необходимой, если допустить, что потребление энергии на душу населения удваивалось бы каждые 6 лет в течение периода от настоящего времени до 1980 г. Если бы потребление энергии на душу населения после этого периода удваивалось каждые 10 лет, то к концу столетия оно составило бы приблизительно 900—1000 *квт* в год, что соответствовало бы современному уровню потребления энергии в Японии.

Принято решение построить в Карачи тяжеловодный энергетический реактор мощностью 132 *Мвт* и водо-водяной энергетический реактор мощностью 70 *Мвт* в Руппуре, в Восточном Пакистане.

В настоящее время проводится оценка предложений подрядчиков, и я надеюсь, что переговоры с дружественными странами с целью получения финансовой помощи скоро успешно закончатся и моя страна, у которой нет другого выбора, сможет осуществить весьма скромную программу развития энергетики.

К. Э. ЕФФАТ (ОАР): В настоящее время ОАР ведет интенсивную разработку программы, направленную на удвоение национального дохода через каждые 10 лет. С этой целью намечена широкая программа индустриализации и мелиорации земель для удовлетворения потребностей быстро растущего населения, и, чтобы выполнить эту программу и удовлетворить энергетические потребности, необходимо полностью эксплуатировать имеющиеся в стране ресурсы.

Полная установленная мощность ГЭС и обычных тепловых станций, включая ГЭС мощностью 2100 *Мвт*, расположенную на высотной плотине в Асуане, составит в 1970 г. 4000 *Мвт* по сравнению с 400 *Мвт* в 1952 г. Это означает, что производство электроэнергии увеличится с 1000 млн. *квт* в 1952 г. до 11 000 млн. *квт* в 1970 г. и соответственно увеличится выработка электроэнергии на душу населения от 47 до 350 *квт*. Проведенный детальный экономический анализ и изучение возможностей показывают, что, несмотря на такое увеличение, эти станции смогут удовлетворять потребности страны только до 1972 г., после чего ежегодно потребуется в среднем дополнительная мощность в 150—200 *Мвт*. Предполагают, что при современном уровне развития технологии ядерных реакторов экономические характеристики таких установок (в особенности крупных) к семидесятым годам значительно улучшатся. Можно предположить, что в следующем десятилетии в нашей стране будет осуществляться еще более широкая программа развития ядерной энергетики. Поэтому решено построить первую АЭС полезной мощностью 150 *Мвт* (эл.). Эта станция даст промышленный ток в объединенную энергетическую систему напряжением 220 *кв*. Станция будет пущена к 1969 г. Она будет связана с заводом по изготовлению твэлов и с опреснительной установкой производительностью 200 000 $м^3$ воды в сутки. Несмотря на то что в существующих в ОАР условиях при заданной мощности атомные электростанции не могут успешно конкурировать с обычными тепловыми станциями, этот проект осуществляется для того, чтобы освоить технологию ядерных реакторов, накопить инженерный опыт и подготовить обслуживающий персонал, что необходимо для удовлетворения потребностей широкой программы развития атомной энергетики в 80-х годах.

Кроме того, будут проведены экспериментальные исследования экономики получения и использования опресненной воды в условиях пустыни. Более подробно эта тема будет рассмотрена на заседании экспертов, которое состоится в конце данной конференции. Уже выбрано место для строительства АЭС на побережье Средиземного моря в 30 *км* к западу от Александрии. Сейчас ведутся работы по подготовке строительной площадки и после поступления заявок от подрядчиков на предложение Комиссии по атомной энергии ОАР начнутся строительные работы.

Л. С. ПРАДО (Бразилия): Мне бы хотелось обратить ваше внимание на определенные факторы, которые в течение последних лет оказали влияние на производство электроэнергии в Бразилии. Эти факторы приобретают особое значение при рассмотрении современных планов производства электроэнергии и возможности использования для этого ядерных установок в некоторых районах Бразилии. Для того чтобы представить полную картину энергетических потребностей Бразилии, необходимо учитывать следующее:

а) большой дефицит в электроэнергии; б) увеличивающиеся потребности благодаря росту населения и быстрой индустриализации страны; в) плохое качество и незначительные запасы угля; г) ограниченная добыча нефти на известных месторождениях; д) наличие неиспользованных гидроресурсов.

В связи с изложенным в последних трех пунктах выработка электроэнергии идет в основном за счет гидроэлектростанций. Обычные теплоэлектростанции используются только в качестве дополнительных к ГЭС в наиболее плотно заселенных промышленных районах или для удовлетворения местных потребностей. В последнем случае они обычно небольшие.

Одно событие, которое имело место в последние годы, привело к пересмотру оптимистических взглядов на потенциальные возможности гидроэнергоресурсов и возможное значение теплоэнергетических ресурсов. Выяснилось, что подача воды в водохранилище для большой ГЭС в одном из наиболее развитых промышленных районов страны почти полностью прекратилась. Это водохранилище возле Сан-Паулу состоит из системы связанных между собой искусственных озер, которые собирают дождевую воду и воду, поступающую из рек. Вода подается насосами на высоту 30 *м*. Водохранилище находится возле конца плато высотою 720 *м*, а у основания плато находится ГЭС, построенная лет 35 тому назад, установленная мощность которой постепенно достигла на сегодня 800 *Мвт*. Способ использования воды весьма остроумен, но работа станции в основном зависит от дождевой воды. В результате серьезной засухи в последние 5 лет средний уровень воды в водохранилище постоянно уменьшался, так что в 1963 г. в водохранилище запас воды составил менее 5% от номинальной емкости. Таким образом, среднее количество энергии, вырабатываемой станцией, сократилось менее чем до 30% от обычной величины. В результате этого тепловая станция электрической мощностью 400 *Мвт*, расположенная в Пиратининге, которая была построена как пиковая, работала как базовая станция с коэффициентом использования до 90%.

Положение местной промышленности стало столь критическим, что были приложены огромные усилия для ускорения окончания строительства отдаленной ГЭС (Фурнас) и соответствующей линии передачи для восполнения энергетических ресурсов. Возникла необходимость перераспределения энергии внутри района, но даже это не дало возможности обойтись без рационализации. Тепловая станция, о которой говорилось выше, работает на нефти. Были проведены исследования с целью выявления возможностей получения дополнительно 500 *Мвт* (эл.); половину — от обычной станции на бразильском угле, а половину — от АЭС. Полтора года назад был создан правительственный комитет для осуществления координации исследований энергетических потребностей центрального и южного районов Бразилии, наиболее развитых в промышленном отношении. Этот комитет рекомендовал методы и способы покрытия большей части пиковых нагрузок вплоть до 1970 г. (Необходимо обеспечить еще около 500 *Мвт*, которые можно получить за счет тепловых станций.) В этих условиях АЭС могут сыграть определенную роль.

Мне хотелось бы также указать, что большинство важных энергосистем в центральном и южном районах постепенно связываются с целью создания большой взаимосвязанной сети. На первом этапе сеть не будет иметь форму кольца, что возможно в других районах или странах. Окончательно энергосистема будет состоять из ряда кольцевых энергосистем, связанных линиями передач.

Следует отметить, что установление полной взаимосвязи между двумя наиболее важными бразильскими центрами Рио-де-Жанейро и Сан-Паулу, которые разделяет только 400 *км*, задержалось на несколько лет ввиду различия в частоте в каждой энергосистеме: 50 и 60 *пер/сек* соответственно. Как уже упоминалось, по рекомендации правительственного комитета недавно одобрен план изменения частоты с 50 до 60 *ц/сек*. Специалистам уже сообщено, какие изменения должны быть внесены применительно к конкретным условиям.

В то время как завершается создание обширной взаимосвязанной энергосистемы, увеличивается потребность в получении дополнительной энергии от тепловых станций; в этой связи следует изучить возможность применения ядерной энергии.

Мне бы также хотелось прокомментировать проблему энергопитания в северо-восточном районе Бразилии, где большая гидроэлектростанция даст приблизительно 400 *Мвт*. Эта станция работает на полноводной реке Сан-Франциско, причем используется природная энергия водопада Паоло-Афонсо. Этот водопад наиболее значительный в Бразилии, но он расположен на расстоянии 500 *км* от географического центра, куда будет подаваться энергия. Потери за счет линий энергопередачи и их стоимость — это такие факторы, которые могут привести первоначально к созданию одной или больше атомных электростанций, от которых энергия будет передаваться на очень большие расстояния в этих районах. С другой стороны, некоторые районы растущей индустриализации, например Форталеза или Ресифи, будут пользоваться энергией от независимых установок. Здесь снова перспективным является использование атомной энергии.

ОБЩАЯ ДИСКУССИЯ

М. А. ЭЛЬ-ГЕБЕЙЛИ (ОАР): Выводы относительно Индии, сделанные в докладе P/741, представленном д-ром Баба, представляют особый интерес с точки зрения развивающихся стран. Что касается вывода, что реактор CANDU электрической мощностью 200 *Мвт* может конкурировать с обычными тепловыми станциями в известных районах Индии, то мне, однако, хотелось бы отметить, что, согласно общему мнению, энергия, получаемая на реакторе с водой под давлением, на кипящем или газоохлаждаемом реакторах электрической мощностью менее 500 *Мвт*, не сможет конкурировать с энергией, вырабатываемой обычными станциями.

Х. Дж. БАБА (Индия): В странах с развивающейся промышленностью ядерная электроэнергия становится конкурентоспособной, если используются реакторы минимальной электрической мощностью 500 *Мвт*. Однако в известных условиях конкурентоспособными могут оказаться и реакторы меньшей мощности. Реакторы электрической мощностью 200 *Мвт* типа CANDU или типа реактора Тарапурской станции в Индии являются конкурентоспособными в районах, где уголь для обычных электростанций транспортируется по железной дороге или морем на расстояние 500 миль или больше. Более того, теплотворная способность угля, применяемого в Индии для получения энергии, составляет 9000 БТЕ/фунт или меньше.

Т. Г. ЧЁРЧ (Канада): Какой ежегодный размер процентов используется в Советском Союзе в зависимости от капиталовложений на топливную загрузку для данной системы реакторов в процессе экономического исследования реакторов на быстрых нейтронах?

А. М. ПЕТРОСЬЯНЦ (СССР): Экономика реакторов на быстрых нейтронах настолько технически сложна и всеобъемлюща, что невозможно дать пространное техническое объяснение, которое требуется в данный момент для дискуссии на этом заседании, и я думаю, что этот вопрос следовало бы подробно обсуждать на заседании, специально посвященном реакторам этого типа (заседание 1.4). Целому ряду ученых и экспертов не удалось достичь соглашения по этому вопросу; действительно, здесь не может быть единогласия по этому вопросу.

Б. ЗАЙЧЕВСКИЙ (Франция): Какую роль будут играть усовершенствованные реакторы с топливом в оболочке из сплава магнокс в английской программе? Если они не будут играть никакой роли в программе, тогда почему продолжается их разработка, как сообщалось в нескольких английских докладах?

Сэр Уильям ПЕННИ (Соединенное Королевство): Реакторы с топливом в оболочке из сплава магнокс, строящиеся в настоящее время, будут работать по крайней мере 20—30 лет. Соединенное Королевство не намеревается строить их после того, как настоящая программа будет закончена, но значительная часть исследований и разработок реакторов с топливом в оболочке из сплава магнокс будет помогать разработке газоохлаждаемого реактора (AGR) и высокотемпературного газоохлаждаемого реактора (HTGR) и поэтому представлять значительную ценность.

О. Д. КАЗАЧКОВСКИЙ (СССР): Мне кажется, что в некоторых докладах, представленных на это заседание, проявляется чрезмерное предубеждение относительно реакторов на быстрых нейтронах. Говорится, что промышленная разработка этих реакторов начнется через десять, двадцать или даже сотни лет и что тем временем для производства плутония будут использоваться реакторы-конвертеры на тепловых нейтронах. Это нежелательно. Реакторы на быстрых нейтронах являются наилучшими конвертерами при условии, конечно, что имеется обогащенный уран. Следует отметить, что коэффициент воспроизводства таких реакторов соответственно увеличивается с увеличением выгорания и уменьшается в реакторах на тепловых нейтронах. На основе имеющихся экономических расчетов реакторы данного типа не дороже реакторов на тепловых нейтронах. Решены основные технологические проблемы, касающиеся реакторов на быстрых нейтронах; значительная работа проделана в Советском Союзе, США и Соединенном Королевстве по использованию натрия в качестве теплоносителя в этих реакторах. Более того, натрий уже успешно применяется в реакторах на тепловых нейтронах, например в Холлэмском реакторе. Проблема безопасности для реакторов на быстрых нейтронах мало отличается от таковой для реакторов на тепловых нейтронах, а иногда и значительно преувеличивается. Все эти доводы оправдывают более быструю разработку реакторов на быстрых нейтронах, чем это предусматривается в некоторых программах.

Х. Дж. БАБА (председатель): Если я попытаюсь суммировать итоги этого заседания, то станет ясно, что мировые потребности в энергии растут очень быстро и что в течение этого столетия по сравнению с настоящим моментом они увеличатся в 8—10 раз. Вообще полагают, что с помощью ядерной энергии, которая в известных областях уже является конкурентоспособной, будут удовлетворены неуклонно растущие потребности в электроэнергии и что в некоторых странах она составит 50% от энергии, которая будет произведена к концу столетия. Таким может быть действительное положение вещей во всем мире.

Отмечалось, что во многих странах с развивающейся промышленностью, где, между прочим, обычная энергия сравнительно недорога, атомные электростанции мощностью более 500 *Мвт* в данный момент могут быть конкурентоспособными. В докладе, представленном мною, показано, что в трех четвертых частях Индии в настоящих условиях атомные электростанции мощностью 200 *Мвт* могут также оказаться конкурентоспособными. Например, так обстоит дело на западном побережье, где мы в настоящий момент строим электростанцию с двумя кипящими реакторами мощностью 190 *Мвт*. Такое же положение в Раджастане, где мы строим электростанцию с двумя реакторами типа CANDU мощностью 200 *Мвт*, и в районе Мадраса, на юго-восточном побережье Индии. Также ясно, что могут быть и другие условия, когда применение даже небольших электростанций может быть оправдано, и они могут быть конкурентоспособными.

Если только можно так выразиться, нет такого вида энергии, который был бы так же дорог, как и «отсутствие энергии», то есть когда она отсутствует совсем. В таких условиях, когда развитие промышленности прекращается ввиду отсутствия соответствующих источников энергии, зачастую оправдывается и очень дорогая энергия. В таких случаях следует решить, строить ли обычные станции и импортировать топливо или строить атомные электростанции и импортировать топливо. Это обстоятельство поднимает очень важный экономический вопрос, особенно для стран, где ощущается недостаток иностранной валюты. Каждому известно, что, исчисляя в центах за 1 млн. БТЕ, энергия, получаемая от ядерного топлива, значительно дешевле, чем от обычного. Например, энергия, получаемая от ядерного топлива, может стоить 14 центов за 1 млн. БТЕ, а от обычного — 21 цент за 1 млн. БТЕ. Таким образом, тот факт, что потребуется меньшее количество иностранной валюты, чтобы заплатить за ядерное топливо, чем за обычное, может свидетельствовать в пользу атомной энергии.

Другой вывод, который вытекает из данной дискуссии, заключается в следующем. Когда мы рассматриваем вопрос о стоимости энергии, получаемой от определенного типа реактора, мы действительно должны не только изолированно рассматривать реактор, но и весь топливный цикл в целом. Это обстоятельство особенно справедливо для реакторов-размножителей и заслуживает очень тщательного изучения. Далее, оценивая капиталовложения в разработку новых типов реакторов, следует учитывать капиталовложения в создание вспомогательного оборудования. Это также особенно важно для реакторов-размножителей, так как на перерабатывающих заводах может регенерироваться только известное количество топлива, и, таким образом, когда увеличивается количество реакторов-размножителей, то увеличивается и количество перерабатывающих заводов.

Однако соображения такого рода применимы не только к ядерной энергии. В докладе, представленном на Женевскую конференцию 1958 г.* моим коллегой д-ром Прасадом и мной, обсуждается вопрос о стоимости ядерной и обычной энергии. В Индии, например, качество угля, которое является сравнительно низким, следует улучшать, для чего применяются моечные цеха. Поэтому соответствующие капитальные затраты на сооружение таких цехов нельзя не принимать во внимание. В случае транспортировки угля на большие расстоя-

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* Х. Дж. Баба и Н. Б. Прасад. Изучение роли атомной энергии в программе развития индийской энергетики, Вторая Женевская Международная конференция по мирному использованию атомной энергии, Р/1624, т. 1, стр. 89—101 (1958).

ния следует также учитывать соответствующие капиталовложения в железнодорожное оборудование.

Огромные усилия, приложенные к разработке реакторной технологии в 1955 г., уже дали плоды. Мы теперь знаем, что атомная энергия завоевала себе место. Действительно, она становится все более конкурентоспособной, чем в настоящий момент; кроме того, она привела к снижению стоимости обычной энергии; я не думаю, что этим самым исчерпывается значение роли атомной энергии для человечества. Кроме этого, абсолютно ясно, что стоимость ядерной энергии снижается значительно быстрее, чем обычной.

Такова общая картина. Технические стороны будут значительно подробнее рассматриваться на нескольких технических заседаниях.

Acta de la sesión B

Nuevos datos económicos. Necesidades de energía en los próximos años y función que puede desempeñar la energía nucleoeléctrica para satisfacerlas

Presidente: H. J. Bhabha (India)

Documento P/741 (presentado por H. J. Bhabha)
Documento P/715 (presentado por O. A. Quihillalt)
Documento P/559
Documento P/31 (presentado por J. Cabanius)
Documento P/192 (presentado por G. F. Tape)
Documento P/294 (presentado por B. B. Batorov)
Documento P/1 (presentado por W. B. Lewis)
Documento P/577 (presentado por S. Komagata)

DISCUSIÓN EN GRUPO

Función que puede desempeñar la energía nuclear para satisfacer las necesidades de energía de otros países

J. P. Baxter (Australia): En Australia no hay planes para producir inmediatamente energía nuclear. Por consiguiente, hablaré del papel de la energía nuclear tal como lo vemos en el futuro. Australia es un país extenso con una población reducida; su superficie es aproximadamente la de los Estados Unidos de América y su población, aunque sólo sea de unos 11 millones de habitantes, está aumentando con rapidez. Australia es un país muy industrializado, cuyo consumo de energía *per capita* es elevado y que sólo sobrepasan en proporción considerable los Estados Unidos de América.

Desde determinados puntos de vista puede considerarse que Australia es un país insuficientemente desarrollado, ya que posee grandes recursos todavía sin explotar. En la actualidad, el carbón constituye la principal fuente de energía. Son algo menos importantes los recursos en energía hidroeléctrica y el petróleo también permite obtener energía, aunque en pequeña cantidad. Los recursos carboníferos son bastante considerables y se hallan concentrados sobre todo en el este del país; en el sur y el oeste hay también algo de carbón de no muy buena calidad.

En la actualidad, en las zonas industriales más grandes, en las que el carbón es tan abundante como barato, se puede producir energía en nuevas centrales térmicas a un costo algo inferior a cuatro milésimas de dólar de los EE.UU. por kilovatio, lo que establece un objetivo muy difícil de alcanzar para la energía nuclear. Aún contribuye a agravar la situación el hecho de que, en la mayoría de los Estados, resultaría en la actualidad impracticable incorporar centrales nucleoeléctricas muy grandes al sistema de distribución. En un futuro no muy lejano, quizá Nueva Gales del Sur y, algo más tarde, Victoria, puedan absorber centrales con una capacidad superior a 500 MW, pero en la mayoría de los demás Estados habría que limitar la capacidad a 200 MW. En tales circunstancias, no parece que sean grandes las perspectivas inmediatas de construir y hacer funcionar centrales nucleoeléctricas. En cambio, parece probable, en parte por la distribución geográfica del carbón y en parte también por la rapidez del crecimiento demográfico, que la energía nuclear desempeñe algún día un papel importante en el desarrollo de Australia. Tal cosa puede suceder en el próximo decenio en el sur de Australia, donde existe por lo menos la posibilidad de que hacia 1975 esté funcionando una central de 200 MW. Sin embargo, quizá no sea así en el caso de que los actuales trabajos de prospección de petróleo y de gas natural en ese Estado den resultados muy positivos. El otro Estado en el que puede utilizarse muy pronto la energía nuclear es Tasmania, donde se utiliza casi exclusivamente la energía hidroeléctrica. Esta fuente de energía se explotará pronto en la mayor medida posible, por lo que merece la pena examinar las perspectivas de contar con una central de 200 MW en Tasmania en el próximo decenio.

Aparte los sistemas generadores de energía propiedad del Estado, administrados por empresas públicas del Estado y que no están interconectados, salvo un enlace tendido a través de las Montañas Nevadas entre Victoria y Nueva Gales del Sur, puede haber demandas aisladas de energía de cierta magnitud en uno o dos casos especiales. En el norte y el nordeste se han encontrado depósitos de bauxita muy importantes y se está considerando seriamente la posibilidad de fundir el mineral para producir aluminio. De hacerse esto, habrá que utilizar la energía nuclear y entonces podría estar justificada la construcción de una central, en escala industrial, cuyas perspectivas de crecimiento son considerables. En algunas otras zonas del interior, como la ciudad de Mount Isa, donde se explotan minas de cobre, plata, plomo y zinc y el consumo de energía puede aumentar hasta 100 MW, cabe pensar que la energía nuclear llegue a imponerse debido a la gran distancia a que hay que transportar el otro combustible posible, es decir, el carbón.

Por consiguiente, el programa energético de Australia ha de concebirse a largo plazo. Nos interesan muchísimo los trabajos que se están llevando a cabo en otras partes del mundo para disminuir el costo de la energía nuclear y nos complace sobremanera la actividad que se está desplegando en el Canadá, los Estados Unidos, la Gran Bretaña y en otros países para alcanzar este objetivo. Desde nuestro punto de vista, reviste la mayor importancia el dar cima a esta labor. Sin embargo, nuestras propias actividades en este campo son a largo plazo, y nuestros estudios se concentran en un tipo de reactor muy avanzado pero que todavía es un tanto teórico; en realidad, no necesitamos precipitar las cosas.

Aunque la desalinización no constituye en nuestro caso una necesidad urgente, a largo plazo nos interesa, ya que Australia es uno de los continentes más áridos del mundo.

Nos sigue interesando la producción de uranio, que todavía producimos, y también continuamos nuestro programa de exploración a fin de aumentar nuestras reservas. Creemos que nuestro país puede llegar a ser un productor en escala industrial de uranio barato, así como de torio y, a pesar del descenso actual de los precios en el mercado, continuamos con energía nuestra labor en este campo.

J. NEUMANN (Checoslovaquia): Deseo esbozar brevemente las características enonómicas básicas de la situación de Checoslovaquia en materia de energía, que nos han hecho llegar a la conclusión de que las centrales nucleoeléctricas son necesarias, y que también nos han hecho definir nuestra política básica en cuanto a la utilización de la energía atómica con fines pacíficos.

La República Socialista Checoslovaca es un país industrialmente desarrollado. La rapida expansión de nuestra economía nacional en el futuro, que permitirá elevar de manera gradual el nivel de vida y fomentar el desarrollo cultural, exige ya, y continuará exigiendo, un abundante suministro de energía para satisfacer las necesidades industriales y de la comunidad. Se espera que en los quince próximos años se duplique, aproximadamente, el consumo global de los recursos primarios de energía. La evolución estructural del consumo de energía se caracteriza, entre otras cosas, por el crecimiento más rápido de los tipos convencionales de energía, en particular la electricidad, cuya producción ascenderá aproximadamente a 55 000 ó 60 000 millones de kWh en 1970 y a 110 000 ó 115 000 millones de kWh en 1980.

El lignito de calidad inferior, del cual se obtiene en la actualidad el 90% del total de la producción nacional de energía eléctrica, es ahora (y seguirá siendo en el futuro próximo) la fuente básica de energía en Checoslovaquia. Los yacimientos de carbón que pueden utilizarse para producir energía se hallan concentrados sobre todo en el noroeste del país y, por tanto, las centrales de energía térmica están situadas allí. En vista de que las condiciones naturales en que se extrae el carbón son cada vez menos favorables, de lo limitado de las reservas carboníferas y de la irregularidad de su distribución en todo el país, la producción de energía eléctrica a partir de combustibles fósiles nacionales tropieza con dificultades crecientes de orden técnico y económico. Debido sobre todo a lo limitado de los yacimientos geológicos existentes, la producción de las centrales térmicas no puede aumentar al ritmo que sería preciso en los diez o quince próximos años, y difícilmente podrá aumentar transcurrido dicho período.

Se está haciendo frente a esta situación importando cada vez más energía. El total será casi el 20% de todos los recursos primarios en 1965 y todavía se importará más energía después de esa fecha. Al propio tiempo, se está preparando un programa para difundir la utilización de la energía atómica en la producción industrial de electricidad.

Este programa se basará en generadores nucleares que utilizarán el uranio natural, con moderador de agua pesada y conductor térmico de dióxido de carbono. En Bohunice se está construyendo un prototipo industrial cuya producción será de 150 MW(e). Los parámetros técnicos de esta central eléctrica son bien conocidos y han sido descritos en varios documentos presentados a la segunda Conferencia internacional sobre la utilización de la energía atómica con fines pacíficos en 1958 *. En

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* Véase, como ejemplo, *Actas de la segunda Conferencia internacional de las Naciones Unidas sobre la utilización de la energía atómica con fines pacíficos*, P/2092, Vol. 5, págs. 251 a 257, y *Proceedings of the Second International Conference on the Peaceful Uses of Atomic Energy*, P/2094, Vol. 9, págs. 36 a 44.

la presente Conferencia se expondrán algunos problemas técnicos relativos a la construcción de un reactor de esta clase*. Los problemas básicos que plantea el proyecto desde el punto de vista científico y técnico han sido ya resueltos y la central eléctrica podrá funcionar en 1968.

Estimamos ahora que un programa de construcción de centrales nucleoeléctricas dentro de los diez o quince próximos años puede basarse en reactores del tipo indicado. La experiencia adquirida en la solución de problemas científicos y técnicos relativos a la primera central nucleoeléctrica y el trabajo de investigación y experimentación subsiguiente han permitido llegar a la conclusión de que las centrales de esa clase pueden producir energía eléctrica en condiciones económicas satisfactorias. Así, por ejemplo, las inversiones concretas de capital en la segunda central nuclear de este género, con dos reactores de 200 MW(e) de potencia cada uno, serán inferiores entre un 40 y un 45% a las del prototipo. El costo de la energía eléctrica producida por dicha central equivaldría aproximadamente al costo medio de la obtenida en la red de centrales eléctricas del Consejo Central de Energía. Los nuevos aumentos en la potencia unitaria de los reactores — creemos que será posible alcanzar los 400 MW(e) — deben crear condiciones en las que el costo de la energía producida por las centrales nucleares sea comparable, en 1975, con el de la energía producida por las mejores centrales térmicas. Por consiguiente, creemos que, mediante la utilización de centrales nucleoeléctricas de un tipo seleccionado, sea posible compensar gran parte del déficit que se calcula existirá en la energía eléctrica hacia 1980 y que, para entonces, dichas centrales podrán producir alrededor de un 15% de la energía eléctrica que el país necesite, en condiciones económicas favorables.

Como la mayoría de los países que se preocupan por los problemas relativos a la utilización de la energía atómica, consideramos que en un futuro menos próximo se podrá producir energía eléctrica utilizando reactores de neutrones rápidos, lo que permitirá una mayor utilización de las existencias de combustible nuclear en condiciones técnicas y económicas favorables.

Para preparar y ejecutar nuestro programa, contamos con la cooperación internacional, en particular con la Unión Soviética que nos está prestando una gran ayuda.

H. VON BÜLOW (Dinamarca): En Dinamarca la situación, por lo que respecta a la energía, puede resumirse en grandes trazos de la siguiente manera: primero, Dinamarca sólo posee reservas insignificantes de combustibles nacionales de tipo convencional; segundo, las reservas de energía de Dinamarca dependen por entero de las condiciones del mercado mundial, y tercero, por lo que hace a la utilización de la energía atómica, sobre todo para producir electricidad, las consideraciones de orden económico son fundamentales, ya que sólo se prevén las aplicaciones de la energía nuclear con fines pacíficos.

Nos interesa mucho la cuestión de los recursos y las necesidades energéticas del mundo en su totalidad y observamos, en particular, los tres factores siguientes: *a*) el aumento constante *per capita* del consumo de energía, incluso en los países más adelantados; *b*) el aumento constante de la población mundial, y *c*) el aumento de las necesidades en energía de los países en desarrollo. En este orden de ideas hay que tener en cuenta las siguientes consideraciones: primero, la energía nuclear sólo puede contribuir considerablemente a satisfacer las necesidades energéticas si se utilizan reactores reproductores; segundo, hay que tener en cuenta los efectos de saturación al hacer la evaluación a largo plazo de las necesidades mundiales en energía, aunque no puede suponerse que dichos efectos influyan en el crecimiento del consumo mundial de energía en los próximos decenios; tercero, hay un margen muy considerable de error, al menos del orden de 30 a 100 años, en los cálculos del tiempo que se tardará en agotar los recursos en combustibles convencionales económicamente explotables; cuarto, otros factores importantes que deben tomarse en consideración son, por ejemplo, el tiempo que se tarde en perfeccionar la tecnología de los reactores reproductores hasta que puedan funcionar de un modo económico y la velocidad de reproducción que puede obtenerse en condiciones económicas favorables.

Las consideraciones concretas que acabo de indicar, que no abarcan todos los importantes factores que entran en juego, nos han hecho llegar a la conclusión de que un país como Dinamarca debe efectuar inversiones en la energía nuclear tan pronto como ello sea aconsejable desde el punto de vista económico, teniendo en cuenta la evolución futura. También consideramos que todos los países más adelantados deben participar en el fomento del desarrollo tecnológico a fin de hacer económicamente competitiva la energía nuclear, para que pueda realmente sustituir a los combustibles fósiles. Por tanto, creemos que Dinamarca debe desempeñar el papel que le corresponde, siquiera sea en una escala modesta, en el logro de este propósito.

I. H. USMANI (Pakistán): Creo que se estará en general de acuerdo en que debe considerarse desde ahora la energía nuclear como otra fuente de energía y que las tendencias que se manifiesten en el futuro en el desarrollo de la tecnología nuclear originarán probablemente un mejor rendimiento y un costo más satisfactorio desde el punto de vista económico de los reactores de potencia. Sin embargo, observo que los países industrialmente adelantados asignan gran importancia al precio competitivo de la energía

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* Véanse, por ejemplo, los documentos P/522 y P/523 de las presentes actas.

nuclear y hablan de un modo continuo de grandes reactores y de los importantes bloques de energía que las instalaciones nucleares pueden proporcionar a sus redes nacionales. Para el Pakistán, estas consideraciones son puramente académicas, ya que no se plantea en absoluto la cuestión del precio competitivo, pues debemos obtener energía eléctrica para nuestro desarrollo económico, sea cual fuere su costo.

La población del Pakistán es de unos 98 millones de habitantes. El Pakistán forma parte del subcontinente indopakistano y está dividido en dos provincias principales, el Pakistán oriental, que tiene 54 millones de habitantes, y el Pakistán occidental, que cuenta con unos 44 millones. Las condiciones climáticas y geográficas del Pakistán oriental son análogas a las del sudeste asiático y las del Pakistán occidental se parecen, en términos generales, a las del Oriente Medio.

El Pakistán oriental tiene clima húmedo, sus tierras están cubiertas de vegetación y son fértiles, y es una de las zonas más densamente pobladas del mundo. Como ocurre en Holanda, no existe prácticamente ningún potencial hidroeléctrico. Hay una zona llana, en forma de delta, que se extiende desde las colinas situadas en las estribaciones del Himalaya, en el norte, hasta la Bahía de Bengala, y cuya precipitación total es del orden de 58 pies. Existe un pequeño potencial hidroeléctrico de unos 120 MW en las colinas de Karnaphuli, en las regiones montañosas de Chittagong cerca de la frontera de Birmania, que ya se está explotando. Hasta ahora no se ha descubierto petróleo, no hay carbón y sólo existe una cantidad exigua de gas natural que se utiliza en parte para producir electricidad y en parte para otros fines. Aunque se emplearan todas las reservas de gas que se ha comprobado existen en el Pakistán oriental, y que se hallan situadas en una mitad de la provincia, para producir energía (que necesitamos urgentemente, ya que el consumo anual *per capita* de la provincia sólo es de 15 kWh contra 4 000 ó 5 000 en los Estados Unidos y el Canadá), incluso así, la capacidad total generadora de energía que podríamos mantener mientras existiera la central sería de unos 700 MW. Además, estas reservas no pueden utilizarse de un modo exclusivo para producir energía, ya que también se necesitan para la producción de abonos, derivados del petróleo, del gas natural, etc. Incluso si se consagrara a la producción de energía el 50% de las reservas, la capacidad generadora resultante sólo ascendería a unos 350 MW, que bastarían estrictamente para satisfacer las necesidades de las centrales ya aprobadas o planeadas que estuvieran funcionando en el Pakistán oriental en 1970. Seis años después de haberse establecido una central de 350 MW a base de gas se habrían agotado todas las reservas de este producto. No puede mejorarse mucho la situación aumentando las importaciones de petróleo, ya que el costo de la energía producida a base de petróleo importado es de unos 79 centavos de dólar de los EE.UU. por millón de Btu. Así, hemos tenido que estudiar otros medios. Hemos observado, en trabajos realizados con la ayuda del Organismo Internacional de Energía Atómica, y de un gran número de reputadas firmas de asesores, que en la mitad occidental de la provincia, carente en absoluto de toda clase de recursos energéticos, una central nucleoeléctrica que utilizara un reactor de agua hirviente o de agua a presión que haya demostrado su eficacia, incluso con una capacidad generadora de 70 MW, podría producir energía a un costo de 8 a 9 milésimas de dólar de los EE.UU. por kWh.

En el Pakistán occidental, el potencial hidroeléctrico es bastante considerable, pero, por desgracia, está limitado a las regiones montañosas del norte y del noroeste, prácticamente inaccesibles. Incluso si continuamos construyendo centrales hidroeléctricas con una capacidad total de unos 2 500 MW cada decenio (cifra elevadísima), la capacidad total obtenida a fines de este siglo no pasaría de unos 10 000 MW. Haciendo entrar en cuenta todo el carbón, el gas y las reducidísimas reservas de petróleo disponibles, la capacidad generadora en un período de 35 a 40 años sería inferior a la que se necesita en unos 8 000 MW, en el supuesto de que el consumo *per capita* se duplicara cada seis años desde ahora hasta 1980. Puedo decir que si, después de esto, se duplicara cada diez años, sólo llegaría a unos 900 ó 1 000 kWh anuales a fines de siglo, lo que representa una cifra muy aproximada a la actual del Japón.

En consecuencia, hemos decidido establecer un generador nuclear de agua pesada de 132 MW en Karachi y otro de agua ligera de 70 MW en Rooppur (Pakistán oriental). Estamos evaluando las propuestas presentadas, y espero que las negociaciones en curso a fin de obtener asistencia financiera de países amigos terminen pronto con un resultado positivo para que mi país, al que no le queda otra solución, pueda ejecutar el modestísimo programa previsto.

K. E. EFFAT (República Arabe Unida): La República Arabe Unida ha emprendido un intenso programa de desarrollo que debe duplicar el ingreso nacional cada diez años. A dicho efecto se ha planeado un extenso programa de industrialización y de bonificación de tierras a fin de satisfacer las necesidades de una población que aumenta con rapidez. Ahora bien, para ejecutar este programa y atender a la demanda creciente de energía es indispensable explotar plenamente todos los recursos energéticos del país.

La capacidad instalada total de centrales hidroeléctricas y de centrales térmicas de tipo corriente, comprendida una producción de 2 100 MW(e) en la central hidroeléctrica de la Alta Presa, ascenderá a 4 000 MW en 1970 frente a 400 MW en 1952.

Esto significa que la energía producida habrá aumentado, de 1 000 millones de kWh en 1952 a 11 000 millones de kWh en 1970, lo que corresponderá a un aumento en la energía producida *per capita*, de 47 a 350 kWh en el mismo período. Los estudios económicos detallados, así como los relativos a la posibilidad de efectuar los trabajos, han indicado que la capacidad generadora instalada, no obstante este aumento, sólo podrá satisfacer las necesidades del país hasta 1972, y a partir de entonces se necesitará cada año una capacidad media adicional de 150 a 200 MW(e).

Se espera que, con la tasa actual de progreso en la tecnología nuclear, mejore considerablemente el aspecto económico de dichas instalaciones, en particular el de las grandes instalaciones previstas para el decenio de 1970. Así, se espera poder ejecutar en mi país un programa de energía nuclear cada vez mayor en el próximo decenio. En consecuencia, hemos decidido crear la primera central nucleoeléctrica, cuya producción neta será de 150 MW(e). Dicha central quedará integrada en el sistema de la red de 220 kW y comenzará a funcionar en 1969. La central generadora estará conectada con una central de fabricación de elementos combustibles y con una instalación de desalinización que debe tratar 20 000 m^3 de agua salada por día. A pesar de que en las condiciones actuales y dentro de los límites previstos las centrales nucleoeléctricas no pueden competir favorablemente en la República Arabe Unida con las centrales térmicas de tipo corriente, se ha abordado este proyecto a fin de introducir la tecnología nuclear, proporcionar experiencia y capacitar al personal en las diversas disciplinas necesarias para satisfacer las futuras necesidades de un programa nucleoeléctrico de importancia creciente en el decenio de 1980. Además, se realizarán trabajos experimentales sobre la economía de la producción y la utilización de agua desalinizada en las condiciones propias del desierto. Se darán más detalles al respecto en la reunión pertinente del grupo especial, que debe celebrarse hacia fines de la Conferencia.

Se ha seleccionado ya un emplazamiento para la central nucleoeléctrica en el litoral del Mediterráneo, a unos 30 km al oeste de Alejandría. Se está preparando la zona destinada al emplazamiento y en breve se iniciará la labor de construcción, poco después de haberse presentado propuestas como consecuencia de la invitación hecha por el Organismo de Energía Atómica de la República Arabe Unida.

L. C. **Prado** (Brasil): Quisiera señalar algunos factores que han influido en la producción de energía del Brasil en los últimos años. Estos factores adquieren una significación especial cuando se consideran en relación con los planes actuales para producir electricidad y la posibilidad de utilizar la energía nuclear en algunas regiones del Brasil.

Para poderse formar una idea completa de las necesidades en fuerza motriz del Brasil, hay que tener en cuenta los siguientes factores: *a*) la gran deficiencia en el suministro de energía; *b*) la demanda cada vez mayor ocasionada por el crecimiento demográfico y la rápida industrialización del país; *c*) la mala calidad y la insuficiencia de los recursos carboníferos; *d*) lo limitado de la producción de petróleo obtenido de las reservas conocidas, y *e*) la existencia de recursos en energía hidráulica aún no explotadas.

Debido a los tres últimos factores, la capacidad generadora de energía depende en la actualidad casi exclusivamente de los recursos de tipo hidráulico. Las centrales térmicas de tipo corriente sólo se utilizan como complemento de los sistemas de redes hidroeléctricas en las zonas más industrializadas o para satisfacer las necesidades locales. En este último caso suelen ser pequeñas.

Un acontecimiento sorprendente que se registró en los últimos años indujo a las autoridades a revisar los criterios optimistas que venían sosteniendo en cuanto al potencial de energía hidráulica y a considerar de nuevo la posible utilidad de los recursos de energía térmica. Se descubrió que estaba casi agotada el agua de un depósito construido para alimentar una gran central hidroeléctrica en una de las zonas más industrializadas del país. Este depósito, situado cerca de la ciudad de São Paulo, consiste en un sistema de lagos artificiales comunicantes que recogen el agua de lluvia que cae en dicha zona, así como el agua procedente de ríos a niveles inferiores. Una bomba eleva el agua a unos 30 m de altura. El depósito se encuentra cerca del borde de una meseta de una altura de 720 m y en cuya base hay una central eléctrica, construida hace unos 35 años, cuya capacidad instalada aumentó gradualmente hasta la cifra actual de 800 MW. El modo de utilizar el agua es muy ingenioso, pero el funcionamiento de la central depende sobre todo del agua de lluvia. Sin embargo, debido a la grave sequía registrada en los cinco últimos años, el nivel medio del depósito bajó de un modo constante, hasta el punto de que en 1963 la reserva de agua representaba menos del 5% de su capacidad nominal. Así, el promedio de energía suministrada por la central se redujo a menos del 30% de la cifra normal, lo que hizo que una central térmica de 400 MW(e), situada en Piratininga, que se construyó inicialmente sobre todo para satisfacer las necesidades de la carga punta, ha venido funcionando desde entonces como central para la carga base (factor de utilización hasta el 90%). La situación de la industria local llegó a ser tan crítica que fue necesario hacer cuanto se pudo para acelerar la terminación de una central hidroeléctrica distante (Furnas) y la línea de transmisión correspondiente para complementar de un modo considerable el suministro de energía. También se recurrió a efectuar intercambios de carga en el interior de la zona, pero ni aun así se pudo evitar el tener que efectuar algunos cortes de corriente. La central térmica mencionada es de tipo corriente y funciona a base de petróleo. Se emprendieron estudios a fin de determinar la posibilidad de producir otros 500 MW(e) de origen térmico, la mitad por una nueva central de tipo corriente a base de carbón brasileño y el resto por una central nucleoeléctrica.

Hace año y medio se constituyó un comité gubernamental para coordinar los estudios acerca de las necesidades energéticas de toda la región centromeridional del Brasil, la zona más industrializada del país. Ese comité ya ha recomendado medios para satisfacer en su mayoría la demanda de carga punta hasta 1970 (queda un déficit de energía de unos 500 MW que debe ser cubierto mediante centrales térmicas). En este sistema general, las centrales nucleoeléctricas tendrán que desempeñar un papel.

Deseo también agregar que los sistemas de redes más importantes situados en la región centromeridional van conectándose gradualmente unos con otros a fin de llegar a poseer una red interconectada muy amplia. En la fase inicial, la red no tendrá forma anular, cosa posible en otras regiones o países; la red definitiva estará integrada por cierto número de sistemas de forma anular, enlazados mediante líneas de transmisión adecuadas. Cabe advertir que se viene aplazando desde hace varios años la interconexión completa entre los dos centros de carga más importantes del Brasil, es decir, Río de Janeiro y São Paulo, que sólo se hallan a 400 km de distancia, debido a la diferencia que existe en las frecuencias utilizadas en cada red, o sea, 50 y 60 Hz, respectivamente. Por recomendación del comité gubernamental ya mencionado, se ha aprobado en fecha reciente un plan para cambiar la frecuencia en Río de Janeiro de 50 a 60 Hz. Se está informando a la población de la zona correspondiente sobre las modificaciones que deben introducir en sus aparatos eléctricos.

Mientras que se termina la vasta red interconectada resulta cada vez más evidente que conviene producir energía adicional utilizando centrales térmicas y, en este orden de ideas, debe estudiarse la posibilidad de utilizar la energía nuclear.

También deseo hacer algunas observaciones acerca del problema que plantea el suministro de energía en el nordeste del Brasil, donde se producen unos 400 MW en una gran central hidroeléctrica, la cual utiliza el gran caudal del río San Francisco y el desnivel natural de las cataratas de Paulo Afonso. Estas cataratas figuran entre las más impresionantes del Brasil, pero se hallan situadas a unos 500 km del centro geográfico de la zona que se ha de abastecer. Las pérdidas en las líneas de transmisión y el costo que esto supone son factores que pueden aconsejar la pronta creación de una o más centrales nucleoeléctricas para suministrar energía a algunas zonas bastante distantes de la región de que se trata. En cambio, la industrialización creciente de algunos distritos, como Fortaleza o Recife, contaría con un suministro de energía procedente de centrales independientes. También aquí son prometedoras las perspectivas que brinda la energía atómica.

DISCUSIÓN GENERAL

M. A. El-Guebeily (República Arabe Unida): En el documento (P/741) presentado por el Dr. Bhabha, las conclusiones a que se llega con respecto a la India son particularmente importantes desde el punto de vista de los países en vías de desarrollo. Pero en cuanto a la conclusión de que el reactor CANDU de 200 MW puede competir con las centrales térmicas tradicionales en algunas partes de la India, deseo señalar que parece reconocerse en general que un reactor de agua a presión, de agua hirviendo o refrigerado por gas y de una capacidad inferior a 500 MW(e) no podría entrar en competencia con la energía convencional.

H. J. Bhabha (India): En los países industrializados, la energía atómica llega a ser en general competitiva cuando se utilizan reactores con una capacidad mínima de 500 MW(e). Sin embargo, en determinadas circunstancias los reactores de un tamaño menor pueden ser competitivos. Los reactores de tipo Tarapur o CANDU, con una potencia de 200 MW(e) son competitivos en la India en aquellas zonas en las que el carbón destinado a centrales térmicas tradicionales tendría que haber sido transportado por ferrocarril o por vía marítima a distancia de 500 millas o más. Además, el carbón utilizado en la India para producir energía sólo tiene un valor calorífico de 9 000 Btu por libra, o menos.

T. G. Church (Canadá): En los estudios económicos acerca de los reactores de neutrones rápidos, ¿qué tipo de interés anual se cobra en la URSS por las grandes cantidades de capital invertido en las existencias de combustible para este tipo de reactor?

A. M. Petrosyants (URSS): La economía de los reactores de neutrones rápidos es una cuestión tan compleja, que plantea tantas dificultades técnicas y tiene alcance tan vasto que sería imposible dar las extensas explicaciones técnicas necesarias dentro del tiempo asignado a la discusión en esta sesión. A mi juicio, es necesario examinar detenidamente ese problema en la sesión dedicada especialmente a los reactores rápidos (sesión técnica 1.4). Varios hombres de ciencia y expertos han tratado, sin éxito, de llegar a un acuerdo sobre esta cuestión. A decir verdad, no puede haber unanimidad sobre este particular.

B. Saitcevsky (Francia): ¿Qué papel desempeñarán los reactores avanzados de magnox en el programa del Reino Unido? Si no han de desempeñar ninguna función en el programa, ¿por qué se despliegan esfuerzos para perfeccionarlos, como se declara en algunos documentos del Reino Unido?

Sir William PENNEY (Reino Unido): Los reactores de magnox que en la actualidad se están construyendo funcionarán de 20 a 30 años como mínimo. El Reino Unido no se propone construir más reactores de este tipo una vez que se haya terminado el programa actual, pero gran parte de la labor realizada en la investigación y el perfeccionamiento de los reactores de magnox será útil para los reactores avanzados refrigerados por gas (AGR), así como para los reactores de alta temperatura refrigerados por gas (HTGR) y, por consiguiente, dicha labor tendrá un valor considerable.

O. D. KAZACHKOVSKY (URSS): Me parece que algunos de los documentos presentados en esta sesión demuestran una prudencia excesiva con relación a los reactores de neutrones rápidos. Se ha dicho que el desarrollo industrial de estos reactores comenzará dentro de 10, de 20 años o quizá dentro de varios siglos, y que mientras tanto seguirán utilizándose convertidores de neutrones térmicos para la producción de plutonio. Tal resultado no es de desear. Los reactores de neutrones rápidos son los mejores convertidores, a condición, por supuesto, de que se disponga de uranio enriquecido. Merece la pena señalar que el aumento del coeficiente de conversión de dichos reactores es proporcional al incremento del grado de quemado, mientras que dicho coeficiente disminuye en el caso de los reactores térmicos. Según los cálculos de tipo económico que se han efectuado, los reactores de neutrones rápidos no son más costosos que los reactores térmicos. Se han resuelto los problemas tecnológicos fundamentales propios de los reactores rápidos, y en la Unión Soviética, los Estados Unidos y el Reino Unido se ha efectuado una labor considerable sobre la utilización del sodio como medio de transmisión de calor en los reactores rápidos. Además, se está utilizando ya con éxito el sodio en los reactores térmicos como, por ejemplo, el reactor Hallam de los Estados Unidos. En los reactores rápidos el problema de la seguridad difiere poco del que se plantea en los reactores térmicos, y a veces se exagera demasiado. Todas estas consideraciones justifican un desarrollo más acelerado de los reactores de neutrones rápidos que lo previsto en algunos programas.

H. J. BHABHA (Presidente): Si se me permite, trataré de resumir esta sesión diciendo que, al parecer, se desprende de la misma claramente que la demanda de energía va a aumentar con gran rapidez en todo el mundo y que, al finalizar el siglo, será de ocho a diez veces superior a la actual. Se cree en general que la energía nuclear, que ya es competitiva en algunas zonas, proporcionará cantidades cada vez mayores de electricidad y que, en algunos países, permitirá obtener hasta el 50% de la energía producida a fin de siglo. A decir verdad, ésta puede ser la situación en todo el mundo.

Se ha dicho que en muchos países industrializados, en los que la energía tradicional es relativamente barata, las centrales nucleares de capacidad superior a 500 MW serían ya competitivas. Entre los documentos presentados, el 1 demuestra que en las tres cuartas partes de la India las centrales nucleoeléctricas de 200 MW pueden ser competitivas en las circunstancias actuales. Así ocurre, por ejemplo, en la costa occidental en la que estamos construyendo una central nuclear con dos reactores de agua hirviendo de 190 MW. Así sucede también en Rajasthan, donde estamos construyendo una central con dos reactores CANDU de 200 MW, y en la zona de Madrás, en la costa del sudeste de la India. Es evidente que puede haber también otros casos en que las centrales de un tamaño menor puedan estar justificadas y ser competitivas.

Si puedo expresarme así, no hay ninguna forma de energía tan costosa como "la falta de la energía", es decir, carecer en absoluto de ella. Cuando la industria debe detenerse por falta de suministro adecuado de energía, con frecuencia está justificado obtener ésta aun cuando resulte muy cara. En tales casos, hay que considerar si se pueden construir centrales convencionales o construir centrales nucleares importando el combustible correspondiente en uno y otro caso. Esta cuestión suscita una consideración de orden económico muy importante, en particular en aquellos países en los que escasean las divisas. Es bien sabido que, desde el punto de vista de los centavos de dólar que cuesta cada millón de Btu, la energía producida a base de combustible nuclear es mucho más barata que la producida mediante el combustible de tipo corriente. Puede, por ejemplo, no ser superior a 14 centavos de dólar por millón de Btu, mientras que la energía producida a base de carbón y que costara, por ejemplo, cuatro dólares la tonelada, costaría unos 21 centavos de dólar por millón de Btu. Así, el hecho de que se necesiten menos divisas para pagar el combustible nuclear que si se tratara de combustible convencional puede militar en favor de la energía atómica.

Otro aspecto que parece haberse desprendido del debate es que cuando consideramos el costo de la energía producida por un tipo particular de reactor, en realidad, no debemos considerar sólo el reactor aisladamente, sino todo el ciclo de los combustibles. Esto es sobre todo cierto en el caso de los reactores reproductores y es un aspecto que necesita un estudio muy considerable. Además, al evaluar el capital que es preciso invertir para crear nuevos tipos de reactores, hay que tener en cuenta la inversión del capital en servicios e instalaciones auxiliares. Esto reviste una importancia particular cuando se trata de reactores reproductores, ya que las centrales de tratamiento sólo pueden regenerar cierta cantidad de combustible y, por consiguiente, cuando aumenta el número de reactores reproductores, se necesitan más centrales de ese tipo.

Sin embargo, las consideraciones de este género no se aplican sólo a la energía nuclear. En un documento presentado en 1958 a la Conferencia de Ginebra *, mi colega el Dr. Prasad y yo examinamos el costo de la energía nuclear y la de tipo corriente. En la India, por ejemplo, hay que mejorar la calidad del carbón, que es relativamente inferior, y a dicho efecto se utilizan lavaderos. Así, hay que tener en cuenta la inversión de capital a prorrata en lavaderos. Cuando se trata del transporte a gran distancia, también hay que tener presente la inversión de capital a prorrata en los ferrocarriles.

El tremendo esfuerzo tecnológico que ha venido haciéndose desde 1955 ha dado ya sus frutos. Sabemos ahora que la energía atómica es algo con lo que hay que contar en lo sucesivo. En realidad, habría resultado más competitiva de lo que ya es si no hubiera hecho disminuir el costo de la energía tradicional y creo que no se le agradece bastante el servicio que ha prestado a la humanidad con ello. Sin contar con esto, es evidente que el costo de la energía nuclear ha bajado mucho más rápidamente que el de la energía convencional.

Esto por lo que toca a las líneas generales de la cuestión. Los aspectos técnicos se tratarán de un modo más detenido en algunas de las sesiones técnicas.

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* Bhabha, H. J., y Prasad, N. B., *Un estudio de la contribución de la energía atómica a un programa de energía de la India,* segunda Conferencia internacional de las Naciones Unidas sobre la utilización de la energía atómica con fines pacíficos (1958), *1,* págs. 94 a 106.

Session 1.6

TECHNICAL AND ECONOMIC ASPECTS OF THE USE OF NUCLEAR POWER

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The initiation of a national nuclear power programme

By G. F. Kennedy* and R. F. W. Guard**

This paper discusses the problems faced by a country about to install its first nuclear power reactor. It is assumed that the country is one which normally imports heavy plant, and its first power reactor will be the subject of a commercial contract with a foreign supplier. Much preparatory work is required before such a contract can be signed, and a number of special problems may arise.

THE REASONS FOR BUILDING A NUCLEAR POWER STATION

A decision to proceed with the construction of a nuclear power station would probably be made for one or more of the following reasons:

(*a*) Because calculations indicate that the energy produced will be cheaper than from any other source;

(*b*) Because domestic sources of energy are becoming exhausted;

(*c*) To act as a deterrent to an increase in the price of conventional fuel;

(*d*) To obtain operating experience and operator training facilities in anticipation of nuclear power being required in larger quantities in the future;

(*e*) To provide manufacturing industry with experience.

Almost no reactors have been built for reason (*a*) above; most were built for a combination of the other reasons.

The nuclear alternative is more attractive when the country possesses some uranium deposits. Even if this uranium cannot be extracted as economically as it can be purchased abroad, the presence of an indigenous source and the security of knowing that a nuclear power station can be kept running even if outside supplies are cut off often proves an attractive consideration to a country possessing no other natural sources of energy.

THE CHOICE OF REACTOR SIZE

The optimum size of any power station can only be determined by analysis of the estimated electricity demand over the predicted life of the station. It is valueless to consider the nuclear station in isolation; the annual cost of operating the entire interconnected system must be calculated, and the calculations repeated for each alternative considered. In an all-thermal system the first nuclear station will have a lower fuel cost than any other station and it will therefore be most economical for base-load operation. When the system contains a significant proportion of hydro-power the calculation of the correct position of the nuclear station in the loading table becomes more complex [1].

The optimistic assumption is sometimes made that a nuclear station will run throughout its life at a very high load factor. This will only be the case if stations with lower fuel costs are not built subsequently. For example, if an enriched reactor is succeeded some years later by natural uranium reactors with a lower running cost, the newer stations will take priority on the duration-of-load curve and the enriched reactor may find its load factor falls so much that it is operating uneconomically. The down-grading of operation of existing stations is the reason why the electrical system must be studied as a whole.

The cost of building and operating a power reactor falls as the size increases, more rapidly than for a conventional plant. It is usually good economics to build a nuclear station slightly larger than is required at the time when it is first to be operated. As demand increases and the station load factor improves, the cost savings of the larger unit quickly outweigh the small loss made in the first few years.

THE CHOICE OF A NUCLEAR FUEL CYCLE

After settling the size of plant most suited to the system and the annual load factor at which it will operate, a policy with regard to nuclear fuel supplies has to be considered. There are three possibilities:

(*a*) To develop the country's own uranium-extraction industry, if suitable ores are present;

(*b*) To purchase uranium ore on the open market, and in the case of either (*a*) or (*b*) above, to lay down a fuel fabrication facility;

(*c*) To enter into a commercial agreement with a foreign supplier for a complete fuel service, including the return of irradiated fuel for credit, if necessary.

There are a number of reasons, such as availability of uranium ore, which may greatly influence

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a country towards a natural uranium cycle. A highly irradiated natural uranium fuel element has no value except for its plutonium content, and at the present time the value of this is best assumed to be zero. Although for the time being the "buy-back" and plutonium credit can be ignored for natural uranium systems, the future value of this material is uncertain but may be considerable. The purchaser of a natural uranium reactor may therefore have to provide permanent storage facilities for spent fuel.

In the case of a reactor requiring enriched fuel, the economy of the fuel cycle nearly always depends on recovering the valuable fissible material remaining in the spent fuel elements, which therefore require reprocessing. Such a cycle is more attractive for a country which already has reprocessing facilities, than for one which has to ship the spent elements to a foreign country. The cost of shipment is considerable and seriously reduces the credit received for the fissile material. Part of this credit depends on the value of the contained plutonium, for which foreign authorities may or may not be willing to guarantee long-term prices.

The conclusion is that in considering enriched uranium fuel cycles it is important to calculate actual costs for the country concerned, and not to assume that costs published in one country are valid in another.

THE CHOICE OF REACTOR TYPE

The purchaser who wishes to buy a proved reactor with guarantees of performance will soon realize that there is not a very wide choice available. The only systems with actual full-scale operating experience are the gas-cooled reactor (GCR) fuelled with natural uranium and developed in Britain and France, and the light water-cooled reactor fuelled with enriched uranium developed in the USA and the USSR. Of the latter, the two types commercially available are the closed-cycle or pressurized-water reactor (PWR) and the direct-cycle boiling-water reactor (BWR).

It is suggested that a country buying its first power reactor might reasonably decide not to consider a reactor which is larger or more advanced than any of the same type with actual operating experience under commercial conditions in the manufacturer's own country. On this basis the purchaser would have to reject in advance potentially valuable developments such as spectral shift control or nuclear superheating. He will also have to eliminate many other systems, however tempting their potential might appear to be.

Among the near-term apparently attractive systems may be mentioned three which now have medium-sized prototypes in actual operation. These are the advanced gas-cooled reactor (AGR) — called the experimental gas-cooled reactor in the USA — the pressurized heavy-water reactor (PHWR), in either the pressure vessel or pressure tube form, and somewhat further away, the Sodium Graphite Reactor (SGR).

For the type of country we are considering, there would at present be some risk of incurring extra development charges if it were to pioneer the commercial development of one of these newer systems. By comparison, the GCR, PWR and BWR may be regarded as proven systems. Table 1 illustrates how very much more practical experience there is at present with these reactors than with the others, and Table 2 briefly surveys the principal characteristics of the six systems mentioned.

THE SELECTION OF A SITE

A suitable site for a nuclear power station must satisfy five requirements:

(*a*) It must fulfil nuclear safety requirements;

(*b*) There must be sufficient cooling water available for the station and for any planned extensions, and sufficient fresh water for boiler make-up and general use;

(*c*) The site must not be so far from the electrical load centre that the cost of transmission would be excessive;

(*d*) The ground must be capable of supporting the heavy loads imposed;

(*e*) Good access must be available for heavy loads and constructional materials.

While the other requirements are conventional, (*a*) above is peculiar to nuclear reactors. The most important requirement is the prevention of damage to health in the event of an escape of radioactive material. Theoretically it should be possible to contain a reactor in an impenetrable and leaktight vessel capable of withstanding any conceivable accident, thus making it possible to site the plant anywhere. Whilst this possibility is now being seriously studied in the USA, the principle has not yet been accepted, mainly because of the difficulty of agreeing a definition of the "worst credible accident". It would seem prudent for a new country to conform to accepted exclusion principles at the present time.

As no siting criteria have yet received international acceptance, a comprehensive study of the existing national standards should be made, as reported in recent conferences [2]. One of the most useful mathematical assessments was developed by Farmer [3] and enables a given site to be given a numerical rating. By applying this method a site can be easily compared with practice in Britain, which is a fairly densely populated country with a large nuclear programme. The US criteria are less precise but take some account of reactor type and size [4] on which Farmer offers no guidance.

The essence of all siting policy is control; that is, the ability of the operators to prevent the release of radioactive material which might be dangerous to health. In the case of gaseous and liquid effluent,

Table 1. Operating experience of principal reactor types

	GCR	BWR	PWR	PHWR	SGR	AGR
Number of prototype power reactors operating	10	2	1	1	1	1
Number of power reactors operating [a]	6	3	2	Nil	1	Nil
Number of power reactors in construction	18	9	5	1	Nil	Nil
Operating date of first prototype power reactor	1956	1957	1957	1962	1957	1962
Operating date of first commercial power reactor	1962	1959	1960	Nil	1963	Nil
kWh generated by prototype power reactors × 10^6	15 000 [b]	100	1 800	150	—	150
kWh generated by power reactors × 10^6	4 000	4 000	4 000	Nil	30	Nil
Burn-up achieved in prototype power reactors MWd/te	5 300	—	—	3 800	—	4 400
Burn-up achieved in power reactors MWd/te	2 000	8 000	20 000	Nil	400	Nil
Typical design burn-up, MWd/te	3 000	15 000	24 000	10 000	10 000	12 000
Percentage of design burn-up achieved in power reactors	66	53	83	Nil	4	Nil
Lowest total installed cost of any contract to date ($/kW)	252	135	183	380	880	—

[a] Power reactors are defined as those above 45 MW(e).

[b] Prototype GCR were military reactors and this figure is estimated. All performance figures are rounded off and approximate.

Table 2. Comparison of principal reactor types which are commercially available

Type	Advantages	Disadvantages	Remarks
Gas-cooled graphite moderated (GCR)	1. Low operating pressure 2. Fuel changing on load 3. Coolant leakage unimportant 4. Superheated steam 5. No exotic materials 6. Natural uranium fuel	1. High capital cost 2. Large and heavy 3. Particularly uneconomic in small sizes 4. Unsuitable for following wide rapid load changes; more subject to Xenon poisoning 5. Non-replaceable core 6. Large amount of skilled erection on site	First prototype in operation 1956. Very large amount of operating experience available. Design burn-up of fuel achieved and exceeded in prototype reactors. Nearing limit of development
Pressurised light-water (PWR)	1. Compact and has high-core power density 2. Most components prefabricated 3. Indirect steam cycle and non-active turbine 4. Easily controllable due to strong negative temperature coefficient 5. Good load-following characteristics	1. Strong containment essential 2. Enrichment essential 3. Poor steam conditions 4. Off-load refuelling leads to : Long shutdown for new core insertion Shutdown if large fuel element failure Reactor power difficult to maintain for long periods between refuelling 5. High proportion of components can only be manufactured by the most industrialized countries 6. Radioactive deposits in the steam generators difficult to eliminate	First prototype in operation 1957. Two large stations in operation. Design burn-up of fuel has been achieved with stainless steel but not yet proved with zirconium. Nearing limit of development in present form, but chemical shim and spectral shift control may lead to lower costs

Table 2. Comparison of principal reactor types which are commercially available (*continued*)

Type	Advantages	Disadvantages	Remarks
Boiling light-water (BWR)	1. Compact and has high-core power density 2. Most components prefabricated 3. Lower operating pressure than a PWR 4. Direct cycle eliminates steam generators and reduces cost 5. Natural circulation possible in small sizes 6. Exceptionally good load-following characteristics	1-5. As for PWR 6. Radioactive turbine and auxiliaries 7. Complete containment difficult to achieve	First prototype in operation 1956. Two large stations in operation. Design burn-up of fuel not yet proved but experience accumulating rapidly. Nuclear superheating is great potential improvement
Sodium-cooled graphite moderated (SGR)	1. High temperature coolant at low pressure 2. Compact core due to good heat transfer properties of sodium 3. High temperature superheated steam	1. Chemical dangers of sodium 2. Oxidisation of coolant 3. Sodium technology not fully understood 4. Stainless steel must be used throughout primary circuit 5. An intermediate sodium circuit is necessary	First prototype in operation 1956. Only one commercial power reactor built and very little operating experience obtained yet. Fuel burn-up not yet proved
Pressurised heavy-water (PHWR) . . .	1. Natural uranium possible 2. High fuel rating possible 3. On-load fuel changing 4. In-core structural components can be replaced	1. Containment necessary 2. Complex construction 3. Pressure tube type has highly stressed components in centre of core 4. Heavy water leakage leads to cost and health hazard 5. Poor steam conditions 6. Subject to Xenon poisoning after large load swings	First prototype in operation 1962. First commercial power reactor not yet built. Fuel burn-up not yet proved
Advanced gas-cooled reactor (AGR) . . .	1-4. As for GCR 5. High fuel rating, small compact core	1. Non-replaceable core 2. Fuel must be enriched 3. Graphite technology not fully understood	First prototype in operation 1962. First commercial power reactor not yet built. Fuel burn-up not yet proved

it is not sufficient that the discharge should be below a certain tolerance, because living substances may absorb certain isotopes preferentially and eventually become an undesirable source of food. It is not practicable to explore this problem completely before a site is chosen, but the specification should define the maximum discharge of effluent which is considered by expert opinion to be tolerable, so that the plant designers may allow for the necessary extraction equipment. Zero discharge is expensive to achieve, and it may be more prudent for the District Survey organization to keep a watch on the sensitive areas after the station has begun to operate, and to recommend extra effluent treatment equipment if it is shown to be necessary.

After a number of sites have been selected which are satisfactory from the point of view of nuclear safety, it will be found that all the other considerations are subject to economic analysis, and normally the site with the lowest total cost will be chosen.

ADMINISTRATION

Most of the work involved in planning and building a nuclear station is identical to that for a conventional station. It is essential that the project be managed by power station engineers advised by nuclear scientists rather than the reverse. In some countries there may be more qualified scientists than there are experienced engineers; the administration must then reinforce the team as required by recruiting staff from other organizations, or preferably by seeking the help of consultants who have themselves had the necessary experience. Temporary professional assistance is also valuable in the preparation of a Specification and in the evaluation of tenders, in order to have the benefit of past experience elsewhere.

However, the use of foreign experts in the planning and construction stages does not diminish the need to bring into being a fully qualified "home" organization as quickly as possible, staffed with people competent to operate the station safely and efficiently. Years of training and experience are required by the senior staff. They must not only be familiar with reactors and radioactivity and have adequate administrative ability, but must also have had thermal power station experience. It is this last which often causes difficulty, particularly in countries that have relied principally upon hydro plant in the past. Records of experience with existing power reactors show how frequently lost output is caused by poor design or inexpert operation of the conventional plant.

It is suggested that a fairly large team, say 30 to 40 qualified people including consultants, should be assembled as soon as the project commences. A typical administrative organization is shown in Fig. 1.

As soon as the project has been authorized, a target programme of work will be drawn up. A new organization should not expect to have the station in full operation in less than six years, and if difficulty in recruiting suitable staff is expected, the early stages may take longer. Fig. 2 shows the principal stages in a six and a half year programme. Naturally, the time spent by the contractors on site depends on many factors including the reactor type and size and the local conditions.

The first duty of the administration is to clear away any legal barriers that may impede progress. Government control of nuclear energy is essential to some degree in all countries, and the setting up of national safety standards, licensing requirements, and third-party nuclear insurance regulations can be tedious and time-consuming. Foreign suppliers may be eager to sell nuclear equipment but can be barred from doing so if international agreements have not been ratified.

The next most important priorities are the studies referred to above: the system economics and the selection of a site. It may be found that data is lacking on water flow or meteorology which require months to collect. The purchaser should endeavour to have complete information to hand before he invites tenders, otherwise he will receive tentative and non-firm prices, which are not a sound basis for the award of a contract. Once the Invitation to Tender has been issued, the purchaser is morally committed to the project and every effort should be made to maintain the agreed programme.

THE SPECIFICATION

Since reactors differ so widely, a Specification must necessarily emphasize the functions desired rather than the detailed aspects. The performance and behaviour of the station may be specified but not the various temperatures, flows, fluxes and other design characteristics. These are matters for optimization by the reactor designer, who will produce the best design only if he is given full details of the purchaser's requirements.

On the other hand, the conventional equipment (which amounts to at least half the total contract value) can be precisely specified in respect of standards and quality. An important part of a good Specification is the Schedule section, in which the

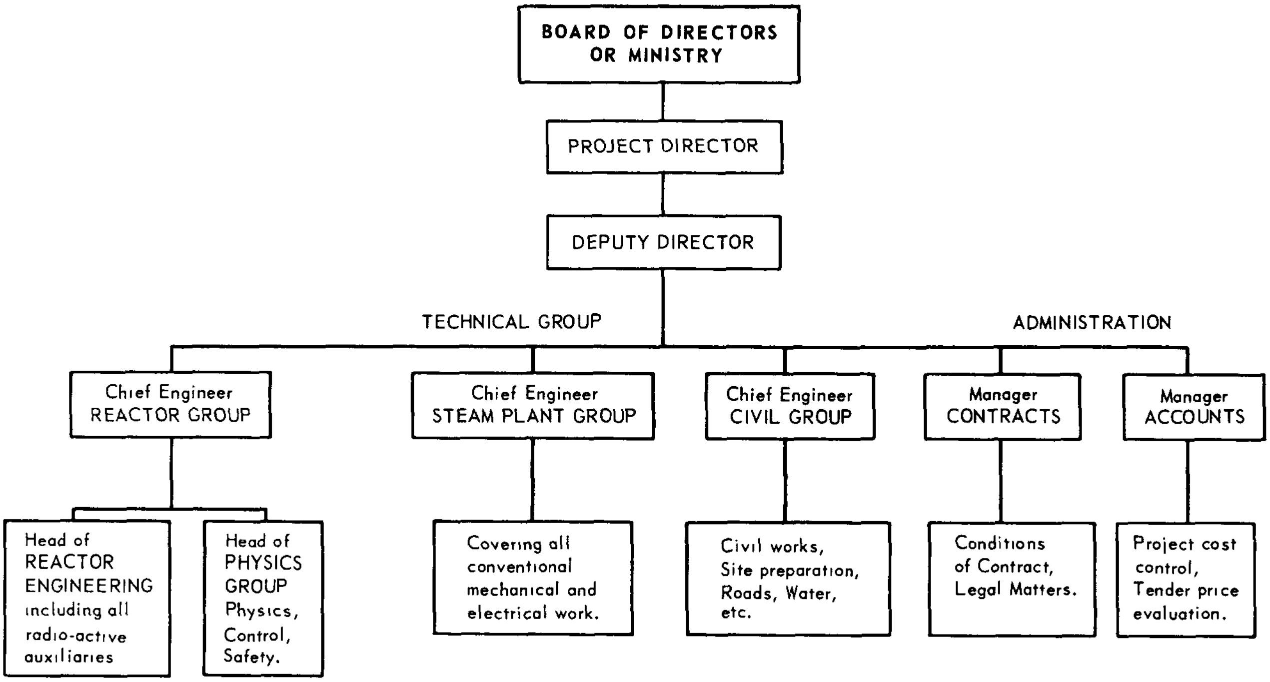

Figure 1. Typical purchaser's administration

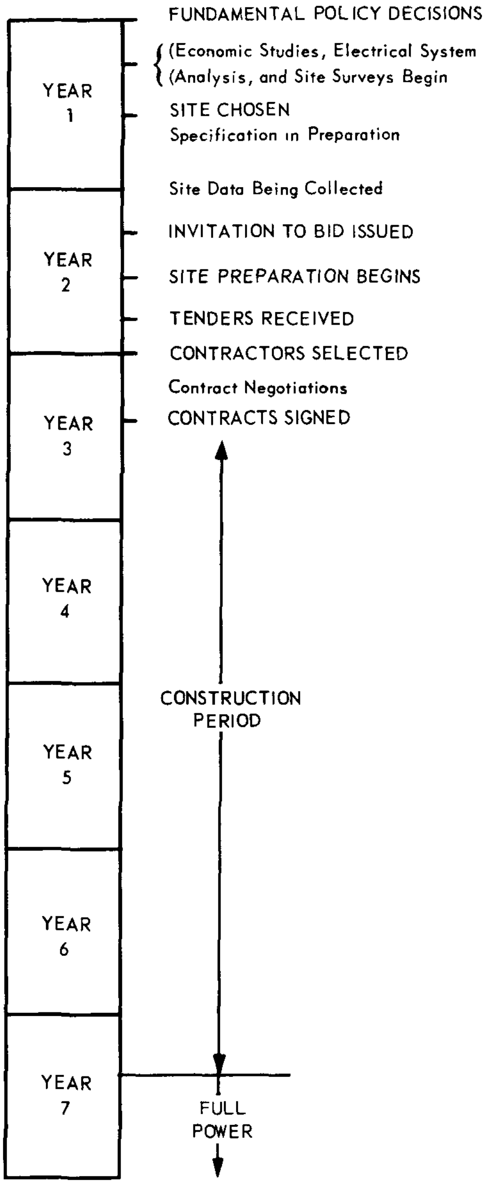

Figure 2. Typical programme for installing a nuclear power plant

tenderer is told precisely what information he is expected to provide. He is also told the form and order of presenting this information, which greatly simplifies the work of comparing the tenders.

The first decision to be made is on the scope of the contract or contracts which will be awarded to foreign suppliers. At one extreme a purchaser may decide that all or nearly all the station will be built in his own country; he may contract to import no more than basic design data. The other extreme, to which a less industrially developed country will tend, is to negotiate a "turnkey" contract: that is, a single contract which covers the supply, construction and setting to work of a complete power station, with the purchaser supplying little more than the land and the transmission. Between these two extremes are many variations, and purchasers are often faced with the problem of how to ensure the maximum participation by local industry. Since a nuclear power station depends for its operation on the correct functioning of a very large number of components whose quality must be beyond question, it is hazardous for all concerned to place orders with inexperienced manufacturers. The conclusion which must be reached is that the contractor should only use those local products for which he is prepared to take full responsibility. This can be made one of the criteria in judging competitive tenders. But to force local equipment on an unwilling contractor only gives him an opportunity to escape from his contractual guarantees.

Since guarantees may be included in the contract for completion of work by a certain date and the achievement of a certain minimum power output, a realistic appreciation of the value of a guarantee is necessary. Minor failures to achieve guaranteed dates are rarely the subject of litigation, as the onus would then be on the purchaser to prove genuine loss. Burn-up of fuel is an important and necessary guarantee, perhaps the most difficult of all to formulate in a meaningful way because of the immense number of variables such as uranium cost, spent-fuel value, if any, and the mode of operation of the reactor. There is no possibility of a purchaser obtaining a burn-up guarantee if he makes his own fuel elements, but he may obtain a reactivity (and therefore power output) guarantee from the reactor designer if he can show that the fuel has been correctly fabricated to specification.

THE CALL FOR TENDERS

Before sending out the Invitation and Specification to manufacturers, the purchaser should be reasonably well acquainted with the background, experience and speciality of each. The most favourable offer is likely to be a near-replica of a reactor which has been built before. There is no point in inviting tenders for a station of, say, 175 MW output if no designs between 150 and 200 MW exist. Many thousands of man-hours are required to optimize a reactor design for a specific output, and although manufacturers will do this for a fee, they cannot be expected to do so speculatively.

Manufacturers will require between six and eight months to prepare tenders, and during this period will require to inspect the site and discuss the interpretation of the Specification. The purchaser must arrange facilities for these visits and must ensure that any additional information given to one tenderer is made available to all. During this period the purchaser's organization will be extremely busy preparing the machinery for examining and comparing the tenders, as every effort should be made to carry out this process in as short a time as possible.

The organization for examining the tenders will be similar to that for preparing the Specification (Fig. 1), with the difference that the economic section is now much more important. The tender evaluation will follow three distinct stages:

(a) Technical review

The scientific and engineering groups will examine the designs; clearly, weeks of work are required to read and digest the technical information.

Recommendations will be passed to the Economic Group on cost adjustments, which will affect both the tendered capital cost (e.g., inadequacies of design) and the running cost, which is particularly affected by local conditions, staffing policy, transport costs and so on. The Technical Group also reports on the technical suitability and safety of the design.

(b) Economic review

Having received from the Technical Group recommendations on adjustments to the tenderers' quoted figures, the Economic Group has the task of making the cost comparisons which will be vital in the choice of contractor. This task is very personal to the purchaser and the Economic Group may be required not to disclose their findings for a time so that cost considerations do not influence the judgment of the Technical Group. If, as often happens, the purchaser has asked for credit terms to be offered by the tenderer, then these are obviously going to be vital to the choice. There may be different rates of interest applicable to different parts of the work, for example to the foreign loan component, the local loan, the fuel capital investment, the fuel "pipeline" investment, and so on.

In the ideal situation, the tenderer should know in advance what economic criteria the purchaser tends to apply in his choice. Does he want minimum capital cost or minimum energy cost? Such a decision can affect the optimization of a reactor design considerably. In practice, unfortunately, the correct engineering decision is often blurred because the purchaser does not know what capital charges he will be using in his calculations until his financial arrangements are known, and this often coincides with the receipt of the tenders and may vary from one tender to another.

(c) Contractual review

The Contracts Group is concerned with the question of reliability of prices and the validity of guarantees. A very favourable offer of a less proven reactor system may be in competition with a more expensive but more reliable system. Such a choice can only be made as a matter of national policy after a thorough review of the known facts and after the best advice of independent experts has been taken. A good measure of the reliability of a system is, of course, the extent to which the manufacturer will back his guarantees by accepting penalties for failure.

CONTRACT NEGOTIATIONS AND CONSTRUCTION

The selection of the main reactor contractor is followed by some months of negotiation leading to contract signature and the beginning of construction. It is essential that at the time of signing the contract the purchaser should possess full details of the design, otherwise there will be endless disputes about the inevitable modifications which arise as the work proceeds.

The purchaser must also be sure that no cause for delay in the works can be attributed to default on his part. If he has agreed to provide roads, water, housing, etc., these must be available on the agreed dates. If the station has been divided into a number of contracts, the co-ordination will be the purchaser's responsibility and he must ensure that small contracts do not delay large ones.

The economic risk inherent in a project engineered by an inexperienced purchaser explains the preference for the single comprehensive or "turnkey" contract which exists in some countries. In such cases, the purchaser need not leave the work unsupervised, as his interests extend far beyond the limited guarantee period. It is desirable to examine all designs before manufacture, to arrange for independent inspection at works, and to supervise site construction. An experienced contractor will welcome the second opinion given at every stage, and on site work the local experience of the purchaser's resident engineer can be invaluable.

The construction period gives an unequalled opportunity for all grades of staff to become acquainted with the details of design and operation. Some of the more senior staff will require theoretical training and experience of a type which is best gained in existing nuclear power stations, but this should be completed at least two years before the completion of the station which they are going to operate, so that they can become completely familiar with the plant and their subordinate staff.

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ABSTRACT - RÉSUMÉ - АННОТАЦИЯ - RESUMEN

A/131 Royaume-Uni

Etablissement d'un programme national de production d'énergie d'origine nucléaire

par G. F. Kennedy et R. F. W. Guard

Le mémoire discute quelques-uns des problèmes pratiques se présentant pour un pays sur le point d'installer son premier réacteur de puissance. On admet que ce pays importe normalement du matériel lourd et qu'il voudra obtenir son premier réacteur de puissance par passation de contrats commerciaux avec des fournisseurs étrangers. Un travail préparatoire important doit être effectué avant que de tels contrats puissent être signés et l'objet du mémoire est de passer ce travail en revue et de faire ressortir certaines des difficultés qui peuvent se poser.

Un pays peut décider de construire une centrale nucléaire pour un certain nombre de raisons, que cette forme de production d'énergie soit vraiment la plus économique ou non. Cependant une fois construite, la centrale doit être gérée de telle sorte que le coût d'exploitation total de l'ensemble du réseau électrique interconnecté soit le plus faible possible. Il faut donc faire une étude à long terme des besoins nationaux d'énergie avant de pouvoir calculer la puissance optimale de la centrale.

Il faut reconnaître que parmi tous les types de réacteurs possibles il y en a très peu que l'on puisse considérer comme ayant fait leurs preuves. Le mémoire décrit l'expérience pratique acquise dans l'étude et l'exploitation des principaux types de réacteurs, et discute les possibilités de certains systèmes qui n'en sont encore qu'au stade du prototype. On examine les principaux domaines d'incertitude.

Le choix de l'emplacement suit la pratique normale dans la production d'énergie thermique, assortie de certaines exigences spéciales. Il faudra établir des règlements nationaux concernant l'exclusion de la population, l'émission et l'évacuation des matières radioactives, l'assurance nucléaire pour les tiers et autres questions juridiques compte tenu de l'expérience acquise ailleurs sur le plan national et international.

Une fois prises les décisions de principe, il faut mettre sur pied un organisme administratif de gestion, aidé, selon les besoins, par des spécialistes et consultants. Cet organisme doit se fixer un calendrier pour l'achèvement du travail préliminaire incombant à l'acheteur, la passation des principaux contrats de construction et la mise en service de la puissance installée totale pour une certaine date.

L'appel d'offres idéal comprend une spécification précise, afin que les soumissions reçues puissent être correctement évaluées et comparées. L'acheteur devrait proposer des conditions qui permettent de négocier les contrats définitifs dans les plus courts délais. Un bon contrat est satisfaisant pour les deux parties, et dans le domaine nucléaire l'acheteur devrait comprendre ce qu'un constructeur de réacteur peut ou ne peut pas raisonnablement garantir dans l'état actuel de la technique.

La comparaison d'un certain nombre de soumissions concernant des types de réacteurs très différents soulève des problèmes intéressants. Il est désirable d'établir, dès que possible, les règles économiques de base à utiliser pour faire une comparaison d'ordre économique, laquelle peut ne pas conduire au choix du système entraînant le minimum de frais d'investissements. Le coût de l'énergie produite peut même ne pas être le critère principal, car les calculs peuvent être influencés par des considérations qui sont particulières à l'acheteur, tel que le degré de participation désiré de la part de l'industrie locale. Ces considérations devraient être mentionnées dans l'appel d'offres.

La coordination et la surveillance des travaux sur les lieux suivent la passation des principaux contrats.

A/131 Соединенное Королевство

Начальный этап национальной программы развития атомной энергетики

Г. Ф. Кеннеди, Р. Ф. У. Гард

В настоящем докладе обсуждаются некоторые из практических проблем, с которыми придется встретиться любой стране при сооружении первого энергетического реактора. Предполагается, что данная страна обычно импортирует промышленное оборудование и планирует построить свой первый энергетический реактор по контракту с иностранными поставщиками. Однако перед подписанием такого контракта необходимо провести большую подготовительную работу, и целью данного доклада является рассмотрение характера этой работы и обсуждение некоторых трудностей, которые могут при этом возникнуть.

По определенным соображениям любая страна может решить построить атомную электростанцию независимо от того, будет это в действительности самой экономичной формой производства электроэнергии или нет. Построив, однако, атомную электростанцию, необходимо эксплуатировать ее таким образом, чтобы общие эксплуатационные расходы для всей объединенной системы электроснабжения были минимальными. Поэтому перед определением оптимальной мощности атомной электростанции необходимо осуществить перспективное изуче-

ние национальных потребностей в электроэнергии.

Следует признать, что из всех возможных реакторных систем лишь очень немногие можно считать «проверенными». В докладе суммируется практический опыт проектирования и эксплуатации основных типов реакторов и обсуждаются потенциальные возможности некоторых из этих систем, находящихся пока на стадии прототипов. Рассматриваются основные нерешенные проблемы.

Требования при выборе строительной площадки для атомной электростанции соответствуют требованиям, предъявляемым к площадке при строительстве обычной тепловой электростанции, с добавлением некоторых специальных требований. После изучения национального и международного опыта необходимо разработать национальные правила обеспечения безопасности населения, распределения и удаления радиоактивных материалов, обеспечения радиационной безопасности третьей стороной и другие законодательные меры.

После принятия основных решений на строительство атомной электростанции должен быть создан соответствующий административный аппарат для обеспечения руководства проектом с привлечением необходимых консультантов и специалистов. Эта группа должна наметить сроки завершения предварительных работ, за которые несет ответственность заказчик, подписать затем основные контракты на строительство и обеспечить к определенной дате достижение атомной электростанцией полной проектной мощности.

Идеальное рассмотрение предложений на строительство предусматривает наличие четкой спецификации, обеспечивающей необходимую оценку и сравнение полученных заявок. Заказчик должен подготовить условия контракта, обеспечивающие скорейшее заключение окончательных контрактов. Хороший контракт необходим обеим сторонам, и заказчик должен ясно представлять себе, кого из поставщиков реакторов можно считать сравнительно надежным при существующем уровне развития реакторостроения.

При сравнении нескольких предложений на строительство сильно отличающихся друг от друга реакторных систем возникают некоторые интересные проблемы. Желательно как можно скорее разработать определенные экономические критерии, необходимые для проведения экономических сравнений, которые могут привести к выбору реакторной системы, не обязательно отличающейся самыми низкими капитальными затратами. Даже стоимость электроэнергии может не быть главным критерием, так как расчеты могут быть «обременены» специальными соображениями заказчика, например степенью желаемого участия местной промышленности. Об этих соображениях необходимо.упомянуть при объявлении о подаче предложений на строительство атомной электростанции.

За подписанием основных контрактов следует координирование и контроль всех работ.

A/131 Reino Unido

La iniciación de un programa nacional de energía nuclear

por G. F. Kennedy y R. F. W. Guard

Esta memoria discute algunos de los problemas prácticos con que se enfrenta un país al instalar su primer reactor nuclear de potencia. Se supone que el país en cuestión importa normalmente los equipos pesados y, por tanto, se supone que su primer reactor de potencia será objeto de contrato con proveedores extranjeros. Antes de que se puedan firmar tales contratos habrá que hacer mucho trabajo preparatorio. El objetivo de esta memoria es revisar dicho trabajo y señalar algunas de las dificultades que se presentan.

Un país puede tomar la decisión de construir una central nuclear para generar energía eléctrica por numerosas razones, tanto si ésta es claramente la forma más económica de producción de energía como si no lo es. Sin embargo, una vez construida, la central debe explotarse de forma que el coste global de explotación de toda la red eléctrica interconectada sea mínimo. Por tanto, antes de que se pueda calcular el tamaño óptimo de la central se deben determinar las necesidades nacionales de energía a largo plazo.

Hay que reconocer que de todos los tipos posibles de reactor solamente muy pocos se pueden considerar como "probados". La memoria resume la experiencia práctica en el proyecto y explotación de los principales tipos de reactor y discute las posibilidades de algunos de los sistemas que todavía se encuentran únicamente en la fase de prototipo. Se comentan las principales zonas de incertidumbre.

La elección del emplazamiento sigue la práctica normal en la producción térmica clásica con la adición de ciertos requisitos especiales. Se han de establecer reglamentaciones nacionales referentes a exclusión de la población, emisión y eliminación de materiales radiactivos, seguro nuclear frente a terceros y otras cuestiones legales, todo ello después de estudiar la experiencia nacional e internacional.

Una vez que se han tomado las decisiones básicas, debe constituirse una organización administrativa que dirija el proyecto, reforzada cuando sea preciso, por consultores y especialistas. Este grupo debe fijarse fechas topes para completar el trabajo preliminar, que es de la responsabilidad del comprador, al que debe seguir la adjudicación de los principales contratos de construcción y posteriormente alcanzar la producción a plena potencia en una cierta fecha.

La solicitud de oferta ideal debe incluir una especificación clara que asegure que las ofertas que se reciban pueden valorarse y compararse correctamente. El comprador debe proponer condiciones de contrato que conduzcan a un retraso mínimo al negociar los contratos finales. Un buen contrato es satisfactorio para ambas partes y, en el campo nuclear, el comprador debe comprender, en el estado actual de conocimientos, qué garantías puede pedir, razonablemente, al proyectista del reactor.

La comparación de varias ofertas para tipos de reactor muy diferentes plantea algunos problemas interesantes. Es conveniente establecer, tan pronto como sea posible, las bases económicas a utilizar en la evaluación económica que pueden conducir a que no se seleccione el tipo cuya inversión sea la menor. Incluso es posible que el coste de la energía no sea el criterio principal, ya que los cálculos pueden ser "modificados" por consideraciones peculiares del comprador, tales como el grado en que se desea que participe la industria local. Estas consideraciones se deben mencionar al solicitar las ofertas.

La coordinación y supervisión del trabajo en el emplazamiento siguen a la adjudicación de los contratos principales.

P/598 Portugal

Prospects of integrating nuclear plants within the Portuguese power system

By A. Leite Garcia*, J. Cruz Morais** and Sidónio Pais***

As the Portuguese energy resources were described in a paper presented to the 1958 Conference [1], in introducing this paper we would emphasize that at present the Portuguese power system consists almost entirely of hydroelectric installations (97% of the power produced in 1964).

Since approximately half the hydroelectric resources have already been built (the total approaching 14 to 15 TWh/normal year), increasing development of thermal capacity is expected in the future. This tendency is shown in Table 1 which gives the structure of the electrical system up to the end of 1963, together with a firm forecast for 1973 and a tentative one for 1985.

The large increase in thermal capacity during the next decade should be noted, together with the even greater increase for the one following that. In the hydroelectric system, running-water power plants are expected to predominate, at least, in the near future.

The irregularity of our hydrological regime necessitates construction of storage water reservoirs; these had a capacity of 1 000 GWh in 1963 and will probably be increased to approximately 2 600 GWh by 1973 (of this 1 000 GWh having an interannual character).

The aim of this paper is to analyse the features which are relevant for the integration of nuclear power stations in the planned development of the Portuguese thermoelectric power plants.

TECHNICAL REQUIREMENTS

Place in the load diagram

Since the investment costs of nuclear power plants are higher than those for conventional ones, the integration of the former mainly depends on the possibility of giving them a high load factor.

In order to study this basic requirement, a calculation method is presented in the appendix. It is, however, necessary to justify the values assumed for some of the parameters, as well as the operating criteria selected.

(*a*) As long-term storage reservoirs are likely to be an appreciable part of the development of our hydroelectric system, it seemed quite reasonable to assume that the average annual inflow would be given by the curve *EH(p)* in Figs. 1 and 2. This curve derives from a simplified simulation study carried out on an IBM 1620 computer.

(*b*) Having a good annual regularization, we may assume that the daily regularization could be economically reached with both extra capacity and pumping schemes. Such means would not only be desirable for the resolution of the peak problems, but also because it would enable thermal power generation costs to be minimized due either to the smaller capacity plant that could be installed or to the better alternative of concentrating the thermal power production in plants with the smallest running costs. Thus we will assume an average available hydraulic capacity *(PH)* given by

$$PH = \frac{1.5}{\Theta}\,\overline{EH}$$

where

$\overline{EH}$ = average inflow to the hydraulic system
Θ = load factor, set by simplicity on 0.575.

It should be noted that if part of the hydraulic capacity *(PH)* were replaced by peak thermal capacity, the energy it would generate would probably be negligible, thus the load factor of the remaining thermal power plants would be practically unaltered.

(*c*) In spite of the amount of extra hydraulic capacity and the annual regularization assumed, the integration of the supplementary thermal plants in the empty hours of the load diagram is barely attained, in so far as there will probably be a large number of running water plants not compensated by pumping schemes. So, we felt it would be reasonable to take two values for the load duration of the supplementary power plants.

(*d*) We have assumed that the hydroelectric system has sufficient interannual water storage to assure a guaranted hydraulic production *(EHG)* equal to 70% of the average annual inflow.

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Table 1. Estimated development of the electrical system

Year	Type of plant	Installed capacity MW	Installed capacity %	Producibility in average year GWh/year
End 1963	Running-water power plants	535	40.5	2 408
	Hydraulic power plants (water storage schemes)	635	48.0	2 310
	Thermal power plants	152	11.5	—
	Total	1 323	100	—
1973	Running-water power plants	1 165	36	5 400
	Hydraulic power plants (water storage schemes)	990	36	3 400
	Thermal power plants	800	28	—
	Total	2 955	100	—
1985	Running-water power plants	1 450	22	7 000
	Hydraulic power plants (water storage schemes)	2 350	35.5	6 000
	Thermal power plants	2 800	42.5	—
	Total	6 600	100	—

(*e*) It has been assumed that, if the thermal plants had to cover peak periods, their load factors would be set for technical reasons independent of the diagram, on: $u_d = 0.25$.

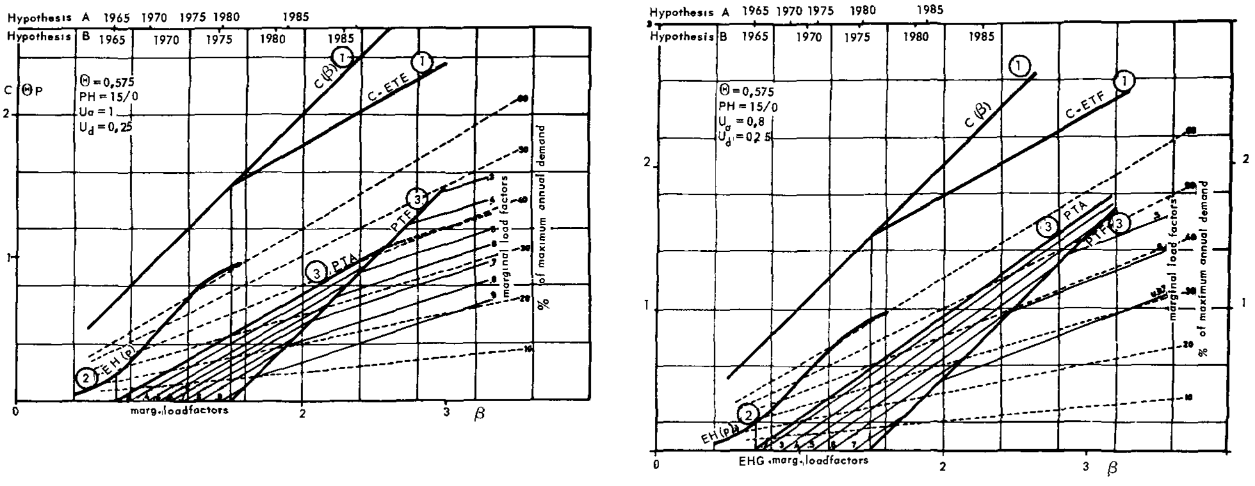
According to all these hypotheses, the calculation method presented enables us to compute the amount of supplementary thermal power necessary to the system, as well as the load factors derived from the supplementary energy and from the contribution during peak periods. The results reached are drawn in Figs. 1 and 2.

Though the scales of those figures are only depending upon the load factor of the diagram (Θ) and upon the producibility factor (β)—total production divided by the annual average inflow—two plausible hypotheses A and B on the development of the hydraulic system are presented (see Table 2).

From the analysis of the figures we can come to the following conclusions:

(*a*) Comparing the results of both of them, one can see the difficulty of integrating thermal plants in the empty hours of the diagram, given by the minor value of u_a, this means an increase in the thermal capacity, and it considerably decreases the load factor of the power plants of smaller running costs —two factors which increase the cost of the thermal energy necessary to the system.

(*b*) One notices how the thermal production is scattered, due to the need for applying to supplementary power plants for peak demands. In spite of the extra hydraulic capacity considered such a phenomenon will occur from 1975-80 onwards, and



Figures 1 and 2. Marginal load factors of thermal capacity

1: Consumption (Unity = annual mean hydraulic producibility); 2: Probability; 3: Mean available capacity (Unity = annual mean hydraulic producibility/load utilization period)

Table 2. Estimated nuclear capacity

		Hydroelectric system		Total consumption with losses		If there is good regularization in the hydroelectric system ($u_a = 1$)		If there is not good regularization in the hydroelectric system ($u_a = 0.8$)	
						Nuclear available capacity with load factor more than (in MW)			
	Year	Mean producibility TWh/year	Available capacity MW	TWh/year	MW	0.5	0.7	0.5	0.7
Hypothesis A	1965	6.2	1 208	5.20	925	—	—	—	—
(faster hydro	1970	7.9	1 666	8.74	1 580	96	—	—	—
system	1975	10.1	2 208	13.20	2 400	354	192	284	—
development)	1980	12.3	2 833	19.10	3 500	776	644	777	291
	1985	13.3	3 166	26.60	4 950	1 734	1 247	1 784	1 066
Hypothesis B	1970	7.0	1 417	8.74	1 580	199	114	163	—
(slower hydro	1975	8.4	1 792	13.20	2 400	608	413	608	162
system	1980	9.7	2 125	19.10	3 500	1 193	839	1 375	680
development)	1985	11.0	2 500	26.60	4 950	1 808	1 406	2 237	1 393

it may accelerate the obsolescence of the supplementary power stations now being installed, if they are not flexible.

(*c*) When the producibility factor is high enough to allow the use of nuclear stations in economically good conditions, those stations will take a share in the total thermal capacity. That share will grow quicker than the maximum demand, even if we assume that the load factor, which defines the competition with the conventional thermal plants, will not decrease with time.

Size of the biggest thermal power unit in operation

The economy of size being more important in nuclear power units than in conventional ones, the enlargement of capacity per unit has a greater interest for the former than for the latter. However, the integration of large nuclear units in small electric grids, as in our present case, can be conditioned by the limitation in size for the largest unit.

Theoretically such capacity can be optimized by determining the equilibrium point between the size savings and the risks of load shedding, due either to the unavailability or to the instability of the electric grid caused by start-up operations which forces an increase in the stand-by reserves (with an increase in the equipment investment) and still keep the running reserve (with a decrease in the operation savings).

In the case of electric grids only fed by thermal plants various optimization studies have been performed on the size of the sets, and it has been concluded that it amounts to about 10% of the maximum demand [2]. In the case of electric grids also fed by hydraulic plants, as in our case, the problem seems to be more complex because it involves the seasonal character of hydroelectric inflows. Nevertheless, everything makes us believe that the capacity of the largest thermal power unit can be comparatively higher than that of electric systems involving thermal plants only.

Owing to the fact that we were also unable to define that question for our electric system, we shall have to formulate it now on the following terms, which are only qualitative ones:

(*a*) According to the estimates of consumption growth, the maximum and the minimum demand of the country's total load curve will be of the order or 1 700 and 700 MW, in 1970, and 2 600 and 1 000 MW, in 1975. The capacity in running-water power plants will most likely be at that time 1 000 to 1 300 MW, so we can realize the previous difficulty in the integration of large plants in the load diagram, at least during the wettest months in winter. Simulation studies already performed, show that in 1975, a nuclear power unit of 250 MW(e) would have to decrease its load daily during an average period of 4 months per year. However, in 1985, a nuclear power unit of 500 MW(e) would have a 10% probability of undergoing such variations, since the amount of inflow to our hydraulic system tends to be reduced in the future (see Table 1).

(*b*) With regard to the stand-by capacity, the excess of 25% to 40% between the installed capacity and the maximum demand in 1970-75, would not raise difficulties with the integration of a nuclear power unit within certain limits. At that time the amount of thermal capacity would be determined by the thermal energy that is necessary to meet the consumption demands during a hydrologically critical period (dry year or a dry month of November). Under these circumstances, it would be wise not to exaggerate the size of the first nuclear set in order to avoid an excessive increase in the risks of load shedding.

(*c*) As far as there will be a hydraulic preponderance and the corresponding excess of available capacity, the question of the running reserve will not become pressing. In what concerns the stability of the linked grid, operational experience has proved that it is sound since there is sufficient effective running capacity.

(*d*) In 1970 there will probably be in operation three conventional thermal sets of 125 MW. We will not be worried by the fact that during the next five years the capacity of the largest set in operation may be increased to 250 MW (which would represent, in 1975, about 10% of the maximum demand) provided that its load following flexibility would be guaranteed. In the period from 1980 to 1985, this maximum capacity may be duplicated.

Siting

One last condition is concerned with possible sites for future thermal power plants. In our country there are only two rivers with sufficient summer water flow required by large thermal power plants —the Tagus and the Douro. We also possess in addition, a long seashore, although it is not always a very suitable one, because of the sands or high rocks.

Taking into account that our hydraulic resources are found in the northern part of the country, the future thermal power plants will be located in the region of Lisbon, where, on the other hand, about ⅓ of the country's electricity consumption is concentrated. As there are in this region some suitable sites on the coast-line, the siting of the first nuclear power plants would raise neither any technical problems nor heavy charges on the transport system.

PROSPECTS OF INTEGRATING NUCLEAR POWER PLANTS

Hypotheses considered

From what we have written with regard to the capacity and to the flexibility in load which appear most convenient for the 1970s, it seems to us that our first nuclear power station should be of the slightly-enriched uranium type with sets of about 250 MW(e).

It is important to formulate the hypotheses required to determine the date when the integration of the first power plant will take place, as well as the prospects of development of nuclear power generating facilities in the future.

If we could set the parameters which define either the costs of capital—interest rate, discounting period, social costs, etc.—or the operation charges, any sound economical criteria would lead us to the selection of a range of economic load factors for each type of power plant.

As such parameters are not officially fixed for our country, we preferred to follow a hypothetical consideration of two instances of competitive utilization of the available nuclear power. The conditions we can foresee at present make us believe that a 0.5 load factor is not too low for nuclear power plants in Portugal [3]. However, we are also taking an alternative hypothesis for the case that the construction of nuclear stations shows to be suitable only for a utilization of the available capacity higher than 0.7, which can give us, on the other hand, an idea of the reactor types and the fuel cycles to be used.

We are assuming a development of the consumption as quoted in Table 2 [4], including the power supplies to some special industries—electrochemistry and electrometallurgy, for instance. Though such industries have a reduced guarantee of supply, we are still considering that they will normally be fed with nuclear power, except during dry years.

Two further hypotheses on the development of the hydroelectric system have also been adopted here (columns 1 and 2 of Table 2).

Possible programmes of nuclear power development

From the application of the calculation method summarily described in the appendix, to the conditions referred to in the preceeding sub-section, we obtained the evolution trend of the nuclear power capacity available as listed in the last columns of Table 2. From such results we may come to the following conclusions:

(*a*) The first nuclear power set to be installed has a very good probability of being integrated in 1975, or even somewhat earlier.

(*b*) Nuclear power development is considerably dependent on both the rhythm of expansion and the characteristics of the hydraulic system built up to that date, and may vary between 9 and 11 sets of 250 MW (or any other combination of sets amounting to an equal capacity) if the present conditions prevail so as to keep the threshold of competition at 0.5.

(*c*) The number of sets with 250 MW will be kept between 5 and 7 if the competition from the nuclear power stations calls for a load factor of the available capacity higher than 0.7.

Some predictable incidences on the economy of the country

We have neither space nor sufficient information available to develop here such an important point as this, which can affect the circumstances of nuclear power plant projects. So, we will take in brief only three relevant aspects.

(*a*) The fact that the investment cost per unit is usually rather higher in nuclear power plants than in conventional ones is a disadvantage in our case, where the quick increase of consumption rates (11%/year in the last decade) forces us to invest in electricity production equipment increasing fractions of the national income. However, as the available up-to-date data seems to show, the income rate from investment in a nuclear power plant to be integrated in the grid during the period of 1970-75 may reach a value of the order of 8 to 10%. In such a hypothesis, its integration is not likely to be postponed unless events at that time indicate that the capital market is rather tight.

(*b*) The Portuguese industry expects to be prepared to meet an equipment supply amounting to approximately 45% of the investment in the first nuclear power plant. Its participation can be increased up to 75% ten years later. If we deduct from those supplies either the technique or the amount of imported materials, we will get a value added by the home industry of the order of 30% and 45%, respectively. Though such rates are lower than those corresponding to conventional power plants with the same capacity, yet the quantitative values will probably be higher for the former than for the latter. Thus the utilization of nuclear power plants will grant, particularly to the metallurgical industry, a bigger market and the opportunity to fit itself with modern equipment and technology.

(*c*) The national industry is also interested in fuel fabrication. Owing to the existence of uranium resources on Portuguese territory, it is expected that our share in the total cost of the nuclear fuel will go from 45 to 70%, depending on either the use of enriched oxide or natural metal. The establishment of this new industry represents another benefit, resulting from the use of nuclear power plants.

(*d*) In the last decade the electricity production industry had almost no effect on the balance of payments due to the (preponderance of) hydroelectric plants. In the near future, the enlargement of the conventional thermal capacity will compel Portugal to make considerable imports of equipment and fuel (185 thousand contos * per year on an average for the next five years, in a total of 470 thousand contos in the respective customs section). The advent of nuclear energy will initially increase the gravity of the situation, due to a greater investment cost per unit. But afterwards, due to either the minor cost of the nuclear fuel or the increasing participation of the national industry, it is expected that there will be a tendency towards the alleviation of this aggravation of the balance of payments.

This short résumé on the economic effects favourable to nuclear energy helps to stress our conviction of the feasibility of integrating nuclear power plants in the national electric grid, according to the conclusions outlined in the sub-section entitled "Possible programmes of nuclear power development."

APPENDIX

Calculation method

C being the consumption to be met (including losses in transmission), and *EHG* the power guaranteed by the hydroelectric system—water-flows in critical year plus guaranteed interannual reserves—the thermal power required in dry years will be *C*—*EHG*, which calls for an average available capacity

$$PTA = \frac{C - EHG}{u_a} \qquad (1)$$

where u_a is the load factor of the supplementary capacity to the system during the dry year which determines the power supply.

If there is a good annual and daily regularization and sufficient hydroelectric capacity available, u_a can be deemed to approach unity, particularly so if the installed capacity is 20% greater than the average calculated effective capacity, its unavailability being scheduled so as to be concentrated upon wet periods.

Owing to the fact that the hydro capacity is somewhat insufficient to meet the maximum demand, the contribution of thermal power stations is needed, even in very wet months, to solve the peak problems. Thermal power generated by such an auxiliary capacity we will call fated thermal power, *ETF*, and the smaller the plant's flexibility and its thermal contribution to the maximum demand, the greater this fated thermal power will be.

In a first approach, we can assume that the fated thermal power is independent of the load curve and only characterized by the thermal contribution to the maximum demand, *PTF*, and by one coefficient peculiar to the plant's flexibility, that is, we can assume

$$ETF = u_d \, PTF \qquad (2)$$

The fated thermal capacity, which is the thermal capacity required to meet the peak load, depends on both the maximum demand and the hydraulic extra-capacity. It can be estimated by means of

$$PTF = P - PH \qquad (3)$$

where *P* and *PH* are respectively, annual mean values of the diagram maximum demand and the effective hydroelectric capacity.

Taking into account the technical minima of the steam power plants which usually limits frequent shut-downs, and whereas $PTF \leqslant 0.30\,P$, u_d can be considered equal to 0.25, the power generated by each plant at peak-hours being practically independent of its turn to enter the load diagram.

Whenever the hydraulic resources are shown to be insufficient to fit the base of the load diagram, the power produced by thermal power units of lower marginal costs, is used as subsidiary energy, which is thus placed at the base of the diagram. So, the power plants of lower costs are most often utilized as a support, and only if the water flow continues to be insufficient, we will then make use of power plants having higher costs.

There are two bad decisions one should avoid taking:

(*a*) To request too soon the thermal power support of a given power plant which proves to be

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* 1 conto ≈ US $35.

useless later. That power could have been produced by those power plants of lower costs when extending their working-time;

(*b*) To delay too much the support granted by a supplementary power station. It would be necessary to replace later the energy that could in the meantime be supplied, by the energy produced in power plants of higher costs. As the prediction of the future water flows is rather difficult, if not impossible, the entering of each power plant into the supplementary energy supply system will have to be controlled by "guide-lines" which are properly determined from the tables of the preceding water flows and estimated so that the errors may be minimized in successive years.

Thus, if we have sufficient water storage for a good annual regularization of the water flows, we can easily determine the rate at which a certain capacity is requested for supplementary energy supply. In fact, if we wish to reach a value of PT (supplementary capacity), less than PTF, it will be necessary that the inflows have the value of

$$EH = C - ETF - PT\ (u_a - u_d) \qquad (4)$$

Once the value of EH is known, it will be easy to estimate the probability of demand for supplementary energy that the capacity PT is asked to supply, provided that u_a and u_d are assumed as constant values. So, p being the probability of EH not to be exceeded, the marginal utilization for PT resulting from both the supplementary power supply and its presence at the peak load, in case PT is less than $PTF = P - PH$, will be

$$u = p\, u_a + (1 - p)u_d \qquad (5)$$

If $PT \geqslant PTF$, that is for the power plants which may be left out for reasons of capacity and are only utilized as a supplementary power source during very dry years, when

$$EH = C - PT\ u_a \qquad (6)$$

p being the probability the power flows will have not to exceed EH, then the utilization got for the latest fraction of PT will be

$$u = p\, u_a \qquad (7)$$

This system of equations has a very simple analytical or graphic resolution provided that the function $EH(p)$ is known. Hence it is possible to draw the curves of the capacity greater than or equal to a given value according to the producibility factor of the hydraulic system, provided that the values of C, P, PH, u_a and u_d are known.

This method seems to fit well into long-term planning. Moreover, it enables us to ascertain the consequences of a possible change in any of the parameters taken, by means of a graphic resolution. However, in a most careful short-term analysis, it is advisable to follow up a simulation method involving those possible combinations of the electricity production system closer to the one pointed out by the present global method.

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ABSTRACT - RÉSUMÉ - АННОТАЦИЯ - RESUMEN

A/598 Portugal

Perspectives d'intégration de centrales nucléaires dans le réseau électrique du Portugal

par A. Leite Garcia *et al.*

Dans une courte introduction, les auteurs présentent la description de l'actuel réseau portugais de production d'électricité, essentiellement hydroélectrique; ils évoquent ensuite son évolution future en relation avec la croissance prévue des consommations. Ils donnent aussi une brève indication des ressources énergétiques du pays. Ces sujets ne sont pas toutefois développés en détail.

Un premier chapitre est consacré à l'analyse des principaux facteurs de caractère technique qui conditionnent l'intégration de centrales thermiques classiques et nucléaires dans l'actuel système de production d'électricité.

Le facteur essentiel a trait aux possibilités d'intégration des centrales thermiques dans le diagramme de charge. Pour l'étudier, les auteurs définissent un modèle de calcul essayant d'évaluer les possibilités de concentrer la production d'énergie dans les centrales thermiques ayant les frais variables les plus

bas sans compromettre l'utilisation optimale de l'énergie hydroélectrique, et éventuellement avec la nécessité d'un complément de puissance thermique aux heures de pointe.

De l'application de ce modèle on déduit les courbes représentant l'évolution des puissances thermiques qui peuvent être placées dans le diagramme selon un critère marginal constant. Ce modèle est complété par des considérations sur les conditions de fonctionnement à différents niveaux de puissance thermique, définis en partant des courbes citées. Ces conditions ont trait aux variations de charge journalières et hebdomadaires.

Les éléments déterminant la puissance de l'unité la plus grande en service sont ensuite évalués. Faute d'études économiques sur ce sujet, en ce qui concerne le réseau portugais, on s'est borné à une analyse qualitative. Un dernier point relatif à l'implantation des futures centrales thermiques de différents types est examiné, les aspects géographiques et économiques étant traités en relation avec la distribution régionale des besoins.

On essaie d'analyser dans un deuxième chapitre les possibilités d'intégration de centrales nucléaires dans le réseau électrique national, en prenant en considération les facteurs techniques étudiés précédemment. Les caractéristiques techniques et économiques à considérer pour les différents types de centrales—hydroélectriques, thermiques classiques, thermiques de pointe et nucléaires—sont fixées. En faisant ensuite varier quelques paramètres économiques fondamentaux, on établit quelques programmes possibles d'intégration de centrales nucléaires.

Dans le dernier chapitre, les principales incidences sur l'économie nationale que l'on peut attendre des programmes établis plus haut sont énoncées. On prend notamment en considération l'évolution prévisible du prix de revient de l'énergie électrique ainsi que les effets indirects sur le développement de l'industrie, sur la balance des paiements et sur le marché des capitaux.

A/598 Португалия

Перспективы включения атомных электростанций в общую энергетическую систему Португалии

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В кратком вступлении авторы описывают существующую в настоящее время в Португалии энергетическую, в основном гидроэнергетическую, систему и касаются будущих путей ее развития по сравнению с расчетным ростом потребления электроэнергии. Дается также краткая оценка национальных энергетических ресурсов. Эти вопросы не рассматриваются в деталях.

Первая глава посвящена анализу основных технических факторов, от которых зависит объединение обычных и ядерных тепловых установок в одну существующую в настоящее время энергосистему.

Основным фактором, который представляет интерес, является способ подключения тепловых электростанций в момент пиковой нагрузки. Для изучения этого фактора разработана модель, с помощью которой делается попытка определить возможности концентрации производства энергии на этих тепловых установках, имеющих очень низкие и самые разнообразные затраты, не уменьшая при этом оптимального использования гидроэнергии и по возможности без ущерба для нужд по обеспечению дополнительной тепловой мощности при пиковых нагрузках во время высоких потоков воды. Применение этой модели позволило получить такие кривые, показывающие будущее развитие тепловых мощностей, которые могут быть введены в действие во время загрузки при постоянном крайнем критерии. Приведено несколько замечаний относительно эксплуатационных характеристик различных уровней тепловых мощностей на основе вышеназванных кривых. Эти характеристики связаны с различиями в дневной и недельной загрузке.

Затем дается оценка факторов, определяющих размеры наиболее крупных генерирующих объектов, находящихся в эксплуатации. Этот анализ носит качественный характер и зависит от недостатка экономических данных относительно португальской энергосети. Что касается расположения будущих тепловых электростанций различного типа, то рассматриваются географические и экономические аспекты в связи с региональным распределением потребностей в электроэнергии.

Во второй главе делается попытка дать оценку возможностей объединения ядерных установок внутри единой национальной энергосистемы, при этом должное внимание уделяется техническим факторам, о которых говорилось выше. Технические и экономические характеристики касаются установок различного типа, которые подлежат рассмотрению, а именно: гидроустановки, тепловые электростанции, тепловые электростанции для пиковых нагрузок и ядерные установки. Кроме того, принимаются в расчет измерения в целом ряде основных экономических параметров и определено несколько возможных программ для объединения ядерных установок.

В последней главе вкратце отмечается основное влияние на экономику страны, которого можно ожидать от принятия этих программ. Дается оценка тенденций на ближайшее будущее относительно основных расходов по электроэнергии, косвенного влияния на промышленное развитие, на платежные балансы и на рынок долгосрочного ссудного капитала.

A/598 Portugal

Perspectivas de la integración de centrales nucleares en la red eléctrica de Portugal

por A. Leite Garcia *et al.*

En una breve introducción los autores describen el actual sistema portugués de producción de electricidad, hidroeléctrico en su mayor parte, pasando seguidamente a examinar su evolución futura en relación con el aumento previsto del consumo. Hacen también una sucinta exposición general de los recursos energéticos del país.

El primer capítulo se dedica al análisis de los principales factores de carácter técnico que condicionan la integración de centrales térmicas clásicas y nucleares en el actual sistema de producción de electricidad.

El factor principal es el que se refiere a las posibilidades de localización de dichas centrales en el diagrama de cargas. Para estudiar este factor, los autores definen un modelo de cálculo con objeto de evaluar la posibilidad de concentrar la producción de energía en las centrales térmicas cuyos gastos variables son los más reducidos, lo que ha de ser compatible con la utilización óptima de la energía que afluye del sistema hidroeléctrico y, eventualmente, con la necesidad de reforzar la potencia térmica en las horas de punta durante las épocas de crecida. De la aplicación de este modelo se deducen las curvas que representan la evolución de la potencia térmica y que pueden situarse en el diagrama según un criterio marginal constante. Este modelo se completa con consideraciones relativas a las condiciones de funcionamiento en los diferentes intervalos de potencia térmica, definidos sobre la base de las curvas citadas. Esas condiciones se refieren a las necesidades de variación cotidiana y semanal de la carga.

Seguidamente se examinan los factores que determinan las dimensiones del mayor grupo generador en servicio. Como en lo que respecta a la red de Portugal se carece de datos económicos sobre este punto, los autores se han limitado a un análisis cualitativo. En lo que se refiere al emplazamiento de futuras centrales térmicas de varios tipos, los aspectos geográficos y económicos se examinan en relación con la distribución regional del consumo de energía.

En el segundo capítulo se procura analizar las posibilidades de integración de centrales nucleares en la red eléctrica nacional, teniendo en cuenta los factores técnicos antes mencionados. Primeramente se indican las características técnicas y económicas de los diferentes tipos de centrales: centrales hidráulicas, térmicas tradicionales, térmicas de punta y nucleares. Haciendo variar seguidamente algunos parámetros económicos fundamentales, se definen diferentes programas posibles de integración de centrales nucleares.

En el capítulo final se indican las principales repercusiones sobre la economía nacional que cabría esperar de la ejecución de dichos programas. Se examinan en particular la evolución previsible del precio de costo de la energía eléctrica y los efectos indirectos sobre el desarrollo de la industria, la balanza de pagos y el mercado de capitales.

The power outlook in Australia

Australian Atomic Energy Commission and Department of National Development

In Australia electricity is generated mainly in thermal power stations. Coal is the main fuel used in New South Wales, Victoria, Queensland, South Australia and Western Australia. Relatively small quantities of other fuels, mainly fuel oil, are used in these States. Hydroelectric plant provides all electricity in the island of Tasmania. Comparatively small hydro-stations are operating in Queensland, and large ones are in use in New South Wales and Victoria. The latter States will receive increasing quantities of power from further development of the Snowy Mountains Hydroelectric Scheme.

Generation and supply is largely under the control of central statutory bodies in each State which produce 97 per cent of the electricity consumed. The balance is produced by local authorities in remote towns using mainly diesel generating plant. Relevant details of the electricity industry are shown in Table 1.

In most developed countries the utilization of electricity during the last few decades has increased some 7 to 8 per cent annually, and thus energy generated has doubled approximately every ten years. Australian requirements have increased greatly in recent decades, as shown in Table 2.

Post-war industrial expansion, a rise in the living standard, and increase in population have resulted in a higher rate of electricity consumption than in many other developed countries. The average annual increase in electricity generated over the last decade was 9.7 per cent and it is expected that this trend will be followed for many years ahead.

ENERGY RESOURCES AND UTILIZATION

Coal

Australia's premium black-coal deposits are located in the eastern part of the continent, generally close to the seaboard (Fig. 1). This uneven distribution has been partly responsible for the opening up of low grade coal, especially in Victoria and South Australia.

Recent information on coal reserves is summarized in Table 3 [1]. The reserves are not large in comparison with those of other countries; most of the measured and indicated reserves of black coal are regarded as recoverable reserves, but in the case of such reserves of brown coal it is unlikely that more than 50 per cent could be recovered with present or planned technology. However, bearing in mind the small population and the relatively low cost of coal production, the reserves allow Australia to be regarded as one of the fortunate countries of the world.

Oil

Australia has an area of some 7.7 million km^2 and approximately one half of the geological structure of the continent consists of sedimentary basins. Recently, intensified search for oil has been undertaken, with success to date only at Moonie, about 300 km west of Brisbane. In 1964 the first commercial production of oil in the country commenced at this field. It will, however, supply only 3 to 4% of the current annual demand, the remainder being imported.

Refinery capacity before 1953 was not significant, but now totals 19 million tons annually. One result of this rapid expansion has been a large increase in the production of fuel oil, which totalled 5.2 million tons in 1962-1963. However, for the past six years the consumption of fuel oil for power generation in Australia has been decreasing; in 1962-1963 this fuel contributed less than 3% of all fuel used for this purpose.

Unless there is a significant change in relative costs it seems unlikely that fuel oil will take over a greater part of power station fuel requirements in those States now mainly dependent on indigenous coal. In South Australia, however, fuel oil may be used extensively for future electricity production.

Natural gas

Recent discoveries of natural gas in Australia indicate the possibility of a production potential in particular areas, which may justify piping to cities and industrial centres, most of which are on or near the seaboard. Such discoveries have been made in the Roma and Rolleston districts in Queensland, in the Gidgealpa district in South Australia, and near Alice Springs, Northern Territory. Extensive drilling programmes are being undertaken to determine the reserves.

In Queensland, pipelines to the seaboard of approximately 450 and 275 km in length would be required from Roma and Rolleston respectively. The minimum economic gas flow required for either has been suggested as between 500 000 and 600 000

Table 1. *Australian electricity industry* [a]

Item	Steam plant	Hydro plant	Internal combustion plant	Total
Installed capacity (June 1963) (MW)	5 213	1 860	155	7 228
Electricity generated (1962-63) (million kWh)	20 533	6 599	254	27 386
Coal consumed (1962-63), black	8.8 million tons delivered at $5.95/ton			
Coal consumed (1962-63), brown	13.3 million tons delivered at $0.92/ton			

[a] Figures are for public electricity supply only.

Table 2. Generation and consumption of electricity in Australia [a]

Item	1942-43	1952-53	1962-63
Electricity generated (million kWh)	5 700	10 900	27 400
Consumption (kWh/*capita*)	780	1 250	2 070

[a] See note [a] under Table 1.

Table 3. Australian coal reserves [a]

State	Type of coal	Reserves (million tons)	
		Measured and indicated	Inferred
Black coals			
New South Wales	Bituminous	3 420	Very large [b]
Victoria	Bituminous	20	10
Queensland	Bituminous-Sub-bituminous	980	Very large
Tasmania	Bituminous	Very small [c]	150 [d]
South Australia	Sub-bituminous	140	-
Western Australia	Sub-bituminous	310	1 800
Brown coals			
Victoria	Brown	61 200	48 200
South Australia	Lignite	590	-

[a] Figures are for "total reserves *in situ*", with the exception of that for measured and indicated reserves in New South Wales, which is regarded as recoverable coal. (See text for comment on recoverable reserves generally.)

[b] In New South Wales inferred reserves are more than 11 000 million tons.

[c] Measured reserves in Tasmania amount to only several hundred thousand tons.

[d] Figure includes both indicated and inferred reserves.

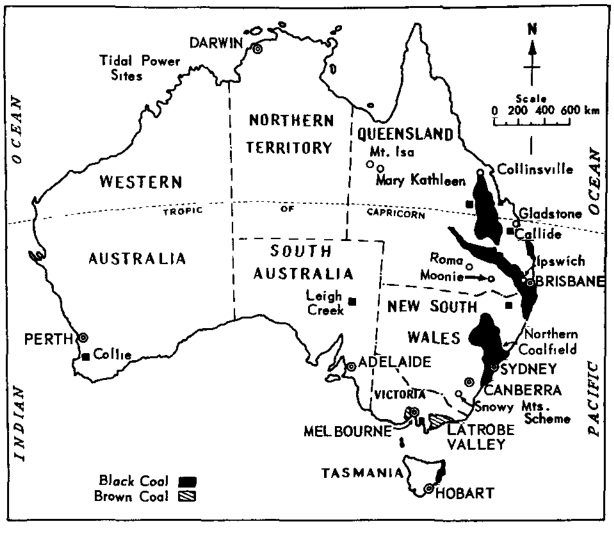

Figure 1. Location of coal measures and other energy resources in Australia

m^3/day for at least 20 years, in order to be competitive with alternative fuels at the seaboard. For the Rolleston gas, a market of at least this magnitude can be seen in the major industrial developments planned around the port of Gladstone, including a 670 000 ton/annum alumina plant to be built by 1967. There are, however, extensive coal deposits in this area. For the Roma gas, the market is expected to lie mainly in the Brisbane area, although relatively small quantities may be drawn from the pipeline at intermediate points.

Although the Gidgealpa deposit is some 970 km northwest of Melbourne, a connecting gas pipeline would also serve a number of provincial cities en route. Alternatively the gas could be piped about 800 km to Adelaide to be used for electricity generation and for industrial and domestic purposes. Natural gas could provide South Australia with the indigenous energy source which it has hitherto lacked.

Hydroelectric power

Australia is a relatively dry continent, the average annual rainfall being only 432 mm, and three quarters of the land mass lies between altitudes of 150 and 460 m. The mean annual run-off is about 48 mm, compared with an average of 248 mm for all land surfaces of the globe, so that hydroelectric potential is not large.

Approximately 60 per cent of the estimated potential of 23 000 million kWh/annum is provided by Tasmania, the remainder being divided between the southern highlands in New South Wales and Victoria (Snowy Mountains and Kiewa Schemes), and also Queensland.

Only a small part of the hydro resources has been exploited to date, but further developments should continue to provide about 26 per cent of the country's generating capacity up to about 1975. In that year the total installed capacity of hydro plant will be some 5 300 MW, and the Snowy Mountains Scheme will be virtually completed. After this date the percentage generating capacity provided by hydro resources will steadily decline.

Tidal power

The tidal power potential of the north-west coast of Australia has been roughly estimated at some 300 000 MW [2], possibly one of the greatest concentrations of tidal power in the world.

Preliminary studies have been made of about 25 tidal power sites in the north-west of Australia, and the Western Australian Government is now investigating in detail the more promising ones. Reliable cost estimates are unlikely to be available for some time, but it has been stated that a 2 000 MW plant operating at 26% capacity factor might be constructed for about $450 million [2].

Early exploitation of these resources is unlikely. The area is remote from centres with a large electricity demand (1 800 km from Perth, and over 3 000 km from the interconnected systems of New South Wales and Victoria), and there are no prospects of large power consuming industries being established in the region.

Uranium and thorium

Uranium minerals are mainly confined to the Northern Territory and Queensland. Reserves (U_3O_8 content) are as follows: measured 3 160 tons; indicated 9 320 tons; inferred 3 580 tons. It is estimated that 11 500 tons of U_3O_8 could be recovered at $5/lb, and the remainder at $6–10/lb. Undoubtedly further exploration would discover additional resources.

Measured reserves of thorium minerals amount to 5 700 tons of contained ThO_2 from the monazite in heavy beach sands on the eastern and western Australian coasts. In addition there are indicated and inferred reserves of 3 300 tons of contained ThO_2 in the Mary Kathleen area of Queensland.

Only uranium concentrate has been produced in Australia. There has been little incentive to produce thorium concentrate.

FUTURE DEVELOPMENTS

Future developments in power generation should be studied in the light of the present position in the industry. Relevant data for 1962-1963 are shown in Table 4 [3].

Power station developments

Table 5 gives estimates of future maximum demand on the interconnected systems of the main generating authorities.

All central electricity authorities are engaged on major construction programmes. Of 4 880 MW of thermal plant under construction or approved, 4 000 MW will be in coalfield stations on the mainland.

Table 4. Australian electricity statistics 1962-63

State or area	Electricity generated (million kWh)	Generating plant installed (30 June) (MW)	Principal fuel(s) used (thousand tons)	Average coal cost ($/ton)	Average fuel cost (mills/kWh generated)	Electricity used by consumers (million kWh)	Average price of electricity sold to consumers (mills/kWh)
New South Wales	9 439 [a]	2 536 [d]	4 813 coal	5.53	3.2	8 598 [e]	23.8
Victoria	6 923 [b]	1 715 [d]	13 293 brown coal 795 briquettes	0.92 brown coal 12.33 briquettes	3.7	6 064 [e]	22.8
Queensland	2 727	767	1 602 coal	8.47	6.0	2 275	25.7
Tasmania	3 145	617	Nil	Nil	Nil	2 776	8.2
South Australia	2 176	559	1 548 Leigh Ck. coal 125 N.S.W. coal	3.32 Leigh Ck. coal 9.77 N.S.W. coal	3.8	1 764	22.4
Western Australia	1 068	331	704 coal	7.71	6.3	867	27.7
Commonwealth Territories [c]	89	43	17 oil	Nil	11.8	256	27.8
Snowy Mountains Scheme	1 819 [f]	660	Nil	Nil	Nil	1 774 [g]	9.1 [g]

[a] Excludes purchase of 1 110 million kWh from Snowy Mountains Scheme.

[b] Excludes purchase of 463 million kWh from Snowy Mountains Scheme, and 343 million kWh from N.S.W.

[c] Figures are for 1961-62; later data are not available.

[d] Excludes entitlements of plant in the Snowy Mountains Scheme, namely 466 MW for New South Wales and 194 MW for Victoria.

[e] Includes electricity purchased as shown in [a] and [b] respectively.

[f] Figure refers to electricity sent out.

[g] Figures refer to peak load electricity supplied to the Commonwealth, New South Wales, and Victorian authorities for consumption in their respective areas.

Table 5. Forecast system maximum demand (MW)

Year	New South Wales[a]	Victoria[a]	Queensland Southern	Queensland Central	Queensland Northern	Tasmania	South Aust.	West. Aust.
1964	2 690	1 866	519	44	114	609	510	254
1966	3 280	2 193	622	51	136	669	585	302
1968	4 000	2 565	726	72	164	749	690	359
1970	4 890	2 882	846	82	197	855	805	426
1972	5 950	3 377	987	93	237	972	945	506
1974	7 290	3 958	1 151	106	282	1 081	1 100	602
1975	8 000	4 285	1 243	113	307	1 144	1 185	656

[a] Maximum demand on these systems will be filled in part by power entitlements from the Snowy Mountains scheme.

Table 6 shows relevant data for the main power station developments [4,5,6,7]. It does not include stations for which plans have not yet been finalized. However, further developments in the years up to 1975 are expected to follow closely those now being undertaken as far as type and location of plant are concerned but unit sizes will be larger in the mid seventies.

Transmission system developments

In all States gradual extension of transmission and distribution systems can be expected during the next decade, and higher voltage transmission lines will be required between new power stations and load centres. The significant interconnection of the New South Wales and Victorian systems made possible by the Snowy Mountains Scheme is being strengthened. Interconnection of the three supply areas in the northern region of Queensland was effected recently, and rationalization of generation and distribution was accomplished in the southern region. Further rationalization of supply in northern Queensland is expected in 1964. The feasibility of interconnecting the Victorian and Tasmanian systems by an underwater link across Bass Strait is being investigated; considerable economies might be achieved by operating Victoria's low-cost brown-coal stations on base load, and Tasmania's hydro-stations on peakload. It is unlikely that interconnection of other State supply systems will occur within the next decade.

PROSPECTS FOR NUCLEAR POWER

Considering Australia as a whole there is unlikely to be any shortage of indigenous fuel for power-station use for many decades ahead. The installation of nuclear-power plants can be justified only if it results in some over-all saving in the cost of electricity.

Over the past ten years generation costs have shown a significant downward trend in most States. As larger units are installed on the coalfields, this trend will continue. The exceptions are South Australia, where future stations will rely initially on imported fuel and possibly later on natural gas, and Tasmania where hydro costs are increasing because of rising civil construction costs.

The cost of coal, and hence the cost of electricity from new and proposed stations in the remaining States, will be quite low by any standards, making it difficult for nuclear power to compete. Table 7 shows estimated approximate costs of fuel and electricity for the largest conventional units that may be installed in the main State generating networks around 1975. Energy costs are based on 7.1% capital charges, 80% capacity factor (for thermal plant), and assume present day money values.

Nuclear power plant

At present only three types of nuclear power stations may be regarded as commercially proven. They are:

(*a*) Pressurized water;
(*b*) Boiling water; and
(*c*) Natural uranium Magnox.

However, by 1970, when a decision would be required on plant to be commissioned by 1975, the following may be considered:

(*d*) Heavy-water moderated and cooled;
(*e*) Heavy-water moderated, light-water cooled;
(*f*) Advanced gas-cooled; and
(*g*) Sodium graphite.

Many other systems are being developed but they are unlikely to be of commercial interest by 1975. Fast breeders come in this category; the USAEC gives a time scale of 25 years for their development.

It is extremely difficult to give meaningful estimates of the cost of nuclear power from the above systems, even for the first three which are being built in considerable numbers. Recent published figures indicate that capital costs can differ by as much as 30 to 40 per cent for apparently almost identical plants. Some of the difference can be accounted for by siting considerations, but most of it is no doubt due to commercial factors such as the state of the market at the time tenders are called and hence the amount included in the tender price to cover design and development costs, and profit. For many systems there are further uncertainties regarding fuel cycle costs, the costs of transporting

Table 6. New power stations in Australia

State or scheme	Station and location	Capacity or number and size of units (MW)	Commissioning period	Estimated capital cost ($/kW sent out)[d]
New South Wales	Vales Point (N'thn coalfields)	1-200[a] 1-275	1965-1966	157
	Munmorah (N'thn coalfields)	4-350	1967-1970	134
Victoria	Hazelwood (Latrobe Valley)	6-200	1964-1970	171
Queensland	Swanbank (Ipswich coalfield)	6-60	1966-1970	169
	Calcap (Callide coalfield)	5-30	1965-1966[b]	234
	Collinsville (Collinsville coalfield)	6-30	1968-1969[c]	234
Tasmania[f]	Lower Derwent Scheme	85 (total)	1966-1967	314[e]
	Mersey–Forth Scheme	300 (total)	1969-1973	388[e]
South Australia	Torrens Island (near Adelaide)	4-120	1967-1971	168
		2-200	1973-1975	134
Western Australia	Muja (Collie coalfield)	4-60	1965-1969	157
Snowy Mountains Scheme	Six new stations on Snowy, Murray and Tumut Rivers	2 805 (additional)	1966-1975	250[e]

[a] Excludes two 200 MW units commissioned in 1963 and 1964.

[b] Initially only two 30 MW units will be installed. A station with 120 MW units will be built at Callide if it is decided to use these coal resources for electricity supply to both central and southern Queensland.

[c] Initially only two 30 MW units will be installed. Future installation of thermal plant depends on possible further hydroelectric developments in northern Queensland.

[d] Includes capitalized interest during construction.

[e] Capacity factors for hydro plants are: Lower Derwent 59%; Mersey-Forth 54%; and Snowy Mountains (future plant) 14%.

[f] The Great Lake Power Scheme (Poatina Station) was commissioned in 1964 with five 50 MW machines, and provision for a sixth machine later.

Table 7. Forecasts of approximate future demand, fuel, and production costs

State	Maximum demand in 1975 (approx.) (MW)	Maximum size units in 1975 (MW)	Fuel cost (approx.) (cents/ million Btu)	Base load fuel cost (approx.) (mills/kWh sent out)	Base load production cost (approx.) (mills/ kWh sent out)[b]
New South Wales	8 000	500	11–15	0.8–1.4	2.7–3.1
Victoria	4 290	350	14	1.6	3.8
Queensland					
Southern–Central	1 360	120[a]	10	1.1	4.2
Northern	310	60	21	2.5	5.6
South Australia	1 190	200	34–41	3.1–3.8	5.2–6.0
Western Australia	660	120	19	2.0	4.3

[a] Assumes a large station will be built in central Queensland – see note [b] under Table 6.

[b] Calculated for 7.1% total capital charges and 80% capacity factor for thermal stations. No allowance has been made for transmission costs in these figures.

new and spent fuel elements, chemical reprocessing and reenrichment, especially for countries remote from the UK and USA. Hence there is little point in attempting to estimate precisely the cost of producing power from the above mentioned reactor stations. However, the prospects for nuclear power in each State and the types of plant which hold most promise can be judged from general fuel and capital cost considerations.

The capital cost of nuclear power stations, particularly if located near large towns or cities, necessitating additional safety features, can be expected to remain somewhat higher than for conventional stations of equivalent size. This will certainly be true for units smaller than 400 MW, although the cost of very large units of particular types may approach that of conventional plant. Operation and maintenance costs may be lower for certain types of nuclear plant but any savings would be off-set by higher insurance charges; for some types of plant, operation and maintenance costs could be appreciably higher. For nuclear-power plants to be competitive they must provide lower unit fuel costs than conventional plants. Costed as given above, one could afford to pay almost $100/kW extra for nuclear plant for each mill/kWh saved on fuel. However, owing to uncertainties and because most authorities would expect some additional return on the increased investment it is suggested that each mill/kWh saved on fuel could justify an additional plant investment of only $50/kW. The position in each State is now briefly examined on this basis.

Large central power stations

New South Wales

New South Wales will be able to accommodate 500 MW units by 1975, and in such sizes nuclear plants generally show to advantage. However, since conventional fuel costs would be very low—0.8 to 1.4 mills/kWh based on present day costs—the only nuclear plants that might improve on these fuel costs are those moderated with heavy-water and cooled with either heavy or light-water, although the high capital costs would offset this gain. Systems such as PWR, AGR, SGR and Magnox would be ruled out.

With the development of economic thorium cycles nuclear power could prove competitive beyond 1975.

Victoria

By about 1975, units would normally be limited to 350 MW capacity in Victoria, and conventional fuel costs of approximately 1.6 mills/kWh are expected. Table 7 shows that such plant is estimated to produce energy for 3.8 mills/kWh. With further development of heavy-water moderated systems there would be reasonable prospect of nuclear plant being competitive around 1975 or some years later.

Queensland

(a) *Southern–Central Region*

By 1975, units not less than 120 MW capacity may be considered. With expected conventional fuel costs of about 1.1 mills/kWh, nuclear power has little prospect of being competitive in the unit sizes of interest, even if the cost of transmission is included for coalfield stations.

(b) *Northern Region*

Conventional fuel costs are expected to be about 2.5 mills/kWh, but maximum unit size would be only 60 MW. Although slightly enriched, heavy-water moderated reactors could show some saving in fuel costs, it would be insufficient to off-set the additional plant cost.

Tasmania

Average costs of all units sent out from planned hydro stations are estimated at 4.7 to 5.1 mills/kWh for generation at an annual load factor of about 55 per cent. If thermal stations were installed they would probably be limited to units of 120 MW capacity in the early seventies. However, in order to compete with projected hydro developments, base load nuclear plant would have to produce energy for less than 5.0 mills/kWh, in order to allow for the production of complementary peakload power which the resulting integrated hydro/nuclear system would need. Nevertheless, the hydro resources of Tasmania are not unlimited and unless easily recoverable coal in discovered, nuclear stations could ultimately play an important role.

South Australia

In the short term South Australia will probably depend on imported coal or fuel oil for its power developments, and fuel costs of 3.1 to 3.8 mills/kWh are predicted for units of 200 MW capacity. All the above types of nuclear stations should achieve fuel-cycle costs appreciably lower than these, but for some, the unit size is too small, e.g., Magnox, AGR, and probably SGR; with these the fuel cost saving would be insufficient to off-set the additional capital expenditure. PWR and BWR stations with fuel costs of about 2.0 mills/kWh could be competitive with specific capital costs of about $190 to $225/kW. Natural uranium heavy-water reactor stations having a fuel cost of about 1.0 mill/kWh would be attractive with costs in the range of $240 to $275/kW. There seems little doubt that such costs will be met with multi-unit stations of these types.

At some future time natural gas may be used for power generation in South Australia, but at present it is not possible to predict the effect of this energy resource on power developments.

Western Australia

With fuel costs of 2.0 mills/kWh and plants limited to 120 MW units, nuclear power has little prospect of competing in Western Australia in the seventies.

Isolated power plant

Many isolated towns depend on locally-generated power but the number is gradually being reduced as the main State systems extend inland. Some will remain isolated but in general their demand will be less than a few MW. Nuclear power may possibly compete on a generation cost basis in some locations but the capital cost of nuclear units compared with the cost of diesel plants is likely to remain prohibitive. This opinion would seem to be confirmed by the recent USAEC decision [8] not to proceed with development of the 1 MW second generation portable nuclear plant, reached only after considering 17 proposals from 15 different industrial firms. Nevertheless, developments in this field in other countries, e.g., the USSR "ARBUS" project, are being watched with considerable interest.

There is little reliable cost information available on small nuclear plants but judging from the USAEC programme it would appear that the development of reasonably low-cost nuclear units of less than 50 MW capacity is a long-term matter. Installation of 50 MW nuclear units in isolated areas would require a high-load factor demand of the order of 100 MW. In the next ten years or so the number of isolated areas with demands of this size will be very few. The best prospects would appear to be for mineral processing such as copper at Mt. Isa in Queensland and aluminium in the Northern Territory. However, in the longer term, plants of larger capacity will certainly be required, and in this field nuclear power could make a very significant contribution in Australia.

CONCLUSION

The costs of production of electricity in the various Australian State supply systems have reduced significantly in recent years. Further improvements will occur in the foreseeable future, but the rate of the cost reduction for conventional power generation is likely to decrease.

Introduction of nuclear power into Australia in the future can be expected to concern central stations on interconnected systems and isolated power requirements in remote areas. By 1975 or so, on the basis of presently known developments, more than 99% of the electricity consumed will be supplied from the State interconnected systems. Therefore, central power plant will be the most important application.

The data presented indicate that within the next ten or so years the prospects for the introduction of competitive nuclear-power plant into the State supply systems of mainland Australia are not encouraging, except possibly in South Australia, where by the mid-seventies unit sizes of 200 MW could be considered. In this size range certain types of nuclear plant are expected to give production costs rather lower than conventional plant using coal or oil. However, by this time natural gas may be used and this could delay the introduction of nuclear plant in this State. Some years later the hydro-electric resources of Tasmania will be fully utilized, and nuclear plant in sizes of 200-250 MW should be competitive with fossil fuel plants. Power developments in the other States in the distant future become necessarily speculative, but even so, the prospects for introduction of very large nuclear plant (over 1 000 MW capacity) into the combined New South Wales and Victorian systems cannot fail to be recognized.

In remote areas nuclear power may find limited application up to 1975 for mineral processing industries where units larger than 50 MW could be installed. In the longer term it is believed that such industries could require very much larger nuclear plants, and this could play a vital role in the development of the more isolated parts of Australia.

ACKNOWLEDGEMENT

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ABSTRACT - RÉSUMÉ - АННОТАЦИЯ - RESUMEN

A/866 Australie

Perspective de l'énergie en Australie

Australian Atomic Energy Commission
et Department of National Development

Le mémoire décrit la structure actuelle de la production et de la distribution de l'énergie électrique et donne un aperçu de la demande et de son accroissement pour le présent et pour l'avenir (jusqu'en 1975).

Il traite des ressources en combustible, des problèmes particuliers aux divers Etats, des tendances actuelles de collaboration entre les Etats pour la production et la distribution du courant électrique, ainsi que des perspectives d'utilisation de la houille et du lignite, du pétrole, du potentiel hydraulique, du gaz naturel et des énergies nucléaire et marémotrice.

Comme les grands réseaux électriques australiens disposent de ressources abondantes et relativement peu coûteuses en houille et lignite, il est peu probable que des centrales nucléaires y soient mises en service durant la période examinée.

Dans quelques petits réseaux, particulièrement ceux de l'Australie du Sud, le combustible local est moins abondant ou entièrement utilisé à d'autres fins, et il faut donc importer du combustible. Dans ces conditions, l'énergie d'origine nucléaire pourrait être compétitive. Toutefois, ces réseaux ne sont pas encore suffisamment développés — la demande dans chacun d'eux ne dépasse pas 500 MW — pour qu'on puisse installer dès maintenant de grosses unités nucléaires, lesquelles sont moins coûteuses. Néanmoins, étant donné l'évolution actuelle de la technique et des coûts en matière d'énergétique nucléaire, il est possible que des unités nucléaires ayant une puissance de l'ordre de 200 MW puissent être installées durant la période examinée.

A/866 Австралия

Перспективы развития энергетики в Австралии

Комиссия по атомной энергии и Министерство национального развития Австралии

В докладе рассматриваются существующие предприятия по производству и передаче электроэнергии, а также вкратце указаны потребности и темпы роста потребностей в настоящее время и в будущем (до 1975 года).

Обсуждаются топливные ресурсы, проблемы энергетики для отдельных штатов, существующие тенденции сотрудничества между штатами в области производства и поставки электроэнергии, а также перспективы использования каменного и бурого углей, нефти, гидроресурсов, природного газа, атомной энергии и энергии морских приливов и отливов.

Указывается, что имеется небольшая вероятность (для рассматриваемого периода) включения атомных электростанций в крупные энергетические системы Австралии, в которых используются сравнительно дешевые и обильные источники каменного и бурого углей.

Некоторые небольшие системы, в частности на юге Австралии, располагают небольшим количеством местного топлива или топливом, которое полностью предназначено для других целей, поэтому приходится ввозить топливо из других районов. При таких условиях атомная энергия могла бы стать конкурентоспособной. Однако эти системы еще недостаточно развиты (*потребности отдельной системы составляют* меньше 500 *Мвт*), чтобы можно было немедленно включать в них более крупные, а следовательно, менее дорогие атомные электростанции. Тем не менее, учитывая существующие тенденции в развитии атомной энергетики и цен, не исключена возможность введения в строй в рассматриваемый период атомных электростанций мощностью порядка 200 *Мвт*.

A/866 Australia

Las perspectivas de energía en Australia

Australian Atomic Energy Commission
y Department of National Development

Se describen las instalaciones existentes de generación y transporte de la energía eléctrica y se resume la demanda y su crecimiento, en la actualidad y en el futuro (hasta 1975).

Se mencionan los recursos de combustible, los problemas particulares de cada estado, las tendencias actuales para la colaboración entre estados a los efectos de la generación y distribución de la energía eléctrica, las perspectivas para el uso de hulla y lignito, petróleo, energía hidráulica, gas natural, energía nuclear y fuerza de las mareas.

Se sugiere que, en los sistemas eléctricos más importantes existentes en Australia que utilizan los recursos de hulla y lignito, relativamente baratos y abundantes, existen pocas probabilidades de que se introduzca la energía nuclear durante el período que se examina.

En algunos de los sistemas más pequeños, especialmente en el sur de Australia, el combustible local es menos abundante o está enteramente comprometido y por ello debe importarse combustible. En

estas circunstancias la energía nuclear podría resultar competitiva. Sin embargo estos sistemas no están todavía suficientemente desarrollados (la demanda de cada sistema aislado es inferior a los 500 MW) como para permitir que se introduzcan inmediatamente en los mismos centrales nucleares del gran tamaño que se requiere para una buena economía. No obstante, si se consideran las tendencias actuales en el desarrollo y en los costes de la energía nuclear, resulta posible que centrales nucleares del orden de los 200 MW de capacidad pudieran ser instaladas dentro del período de tiempo que se analiza.

Introduction of Rooppur nuclear power plant in EPWAPDA grid

By M. Yusuf*

POWER DEVELOPMENT IN EAST PAKISTAN

EPWAPDA

The population of East Pakistan is estimated to be 54 million in 1964, based on the census of 1961. It has a net land area of 52 000 sq. miles, excluding the rivers and those areas which remain perennially under water. Consequently, the density of population there is one of the highest in the world—1 040 persons per square mile. The river Brahmaputra divides East Pakistan virtually into two halves which are usually referred to as zones for the purpose of power planning. In 1947, when Pakistan became independent, the total generating capacity of electric power stations in East Pakistan was about 20 MW and the *per capita* consumption of power 0.4 kWh. There was very little industrial activity in East Pakistan at that time. Since then, electric power industry has grown steadily both in public and private sectors, to meet the growing needs of industry. With the passage of time, it was felt that the power projects, especially of hydroelectric category, should be developed in close conjunction with water projects on a unified basis to reduce wastage in terms of manpower, financial resources, and to avoid delay. Thus an organisation known as the East Pakistan Water and Power Development Authority (EPWAPDA) was created in 1959. Its authority extends over the whole of East Pakistan in the public sector for generation, transmission and distribution of power, as well as for irrigation, flood control, construction of embankments, etc.

Present status of the electric power industry in East Pakistan

EPWAPDA has made remarkable progress in its power sector programme since it took over in 1959. The construction of a 80 MW hydroelectric station at Kaptai in the eastern zone, the building of a 132 kV transmission line from Kaptai to Siddirganj, and the expansion of the Dacca-Tongi secondary transmission and distribution system, are some of the major achievements of EPWAPDA. The total generating capacity of all the stations at present owned by EPWAPDA is about 190 MW. The total generating capacity in the province, including all the plants used exclusively by industry, is about 300 MW. The *per capita* consumption of electric power in East Pakistan in 1963 was about 15 kWh. The generating capacity in East Pakistan increased fifteen times in the course of 16 years, and the *per capita* consumption of power increased 40-fold, even taking the increase in population into account. The EPWAPDA grid is at present under rapid expansion. A 132 kV line from Comilla to Sylhet and another 132 kV line from Khulna to Ishurdi are under construction. The construction of the third unit of Kaptai, having a capacity of 40 MW, and the extension of Siddirganj thermal power station, having a capacity of 44 MW, have been recently taken in hand. The engineering work has been started for the 132 kV transmission line from Siddirganj to Ishurdi across the river Brahmaputra. In addition, many other small generating stations and secondary transmission and distribution lines are also under construction. The existing and proposed expansion of the grid is shown in Fig. 1.

Future programme of EPWAPDA and the anticipated load growth

Nearly 85% of the people of East Pakistan live in villages and almost all of them depend upon agriculture. The total cultivable land is only 21 million acres, and the production per acre is one of the lowest in the world. There is no room for expansion of the cultivable land. It is realised that the best way to raise the standard of living of the population is by developing industries based on the raw materials available within the country, and increasing the agricultural production by intensive cultivation and improved techniques. Both industry and intensive cultivation need power. The Third Five Year Plan, which will start as from July 1965, envisages an investment of nearly $1 500 million in the industrial sector, and about $800 million in the agricultural sector, in East Pakistan. Using the achievements of the Second Five Year Plan as a yardstick, it can be expected that the targets of the Third Five Year Plan will be achieved. It has been modestly estimated that the demand for power in East Pakistan by 1970 on the basis of the investment envisaged will rise to about 500 MW, of which about 150 MW will be in the western zone, and the rest in the eastern zone. The total generating capacity envisaged in 1970 is about 700 MW, of which about

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* Pakistan Atomic Energy Commission.

Figure 1. East Pakistan: major electrical power production and transmission facilities

215 MW will be in the western zone and the rest in the eastern zone (Figs. 2 and 3). By that time, however, many of the existing old steam power stations and diesel electric stations will have been withdrawn from service. A list of the generating stations existing and proposed up to 1970 is given in Table 1. The four sub-grids, namely, Kaptai-Dacca, Sylhet-Mymensingh, Khulna-Ishurdi and Rangpur-Dinajpur, will be interconnected among themselves into a major East Pakistan grid. Most of the transmission lines for this purpose have either been constructed, or are under construction.

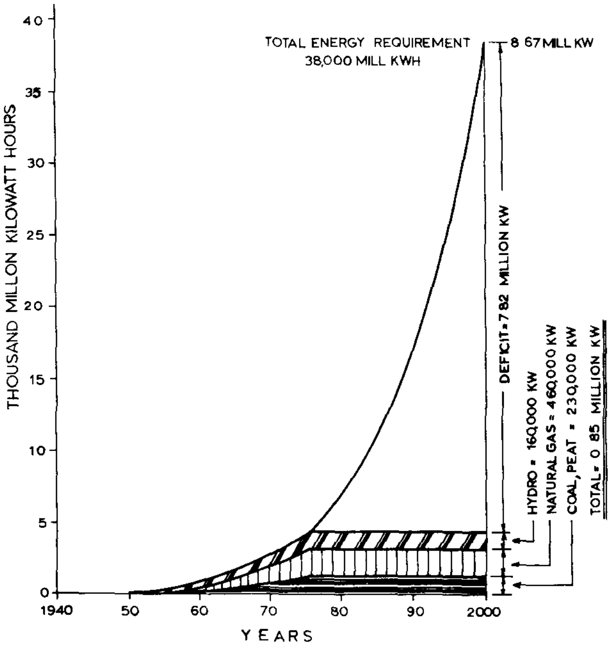

Figure 2. Energy requirements and resources, East Pakistan, 1950-2000

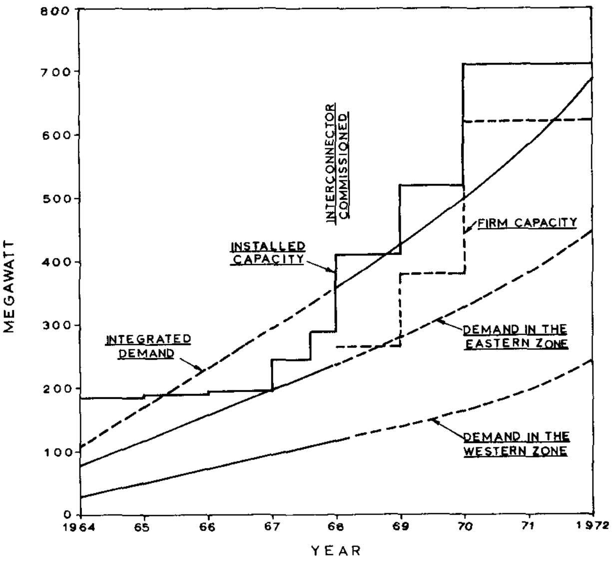

Figure 3. Projected load growth curve, EPWAPDA grid

Table 1. List of major generating plants of East Pakistan existing, under construction and proposed (including large industrial units)

	Rated capacity (MW)	Firm capacity (MW)	Expected year of commissioning
EASTERN ZONE			
Existing stations			
Kaptai, hydro	80	44	
Karnafuli Paper Mill [b], steam (bamboo waste)	14	14	
Chittagong, diesel [a]	10	8	
Fenchuganj Fertilizer [b], steam (gas)	36	36	
Siddirganj, steam (oil)	30	27	
Siddirganj, diesel [a]	12	10	
Dhanmondi, steam [a] (coal)	10	6	
Total	192	145	
Under construction			
Siddirganj extension, steam (oil/gas)	44	44	1966
Kaptai, hydro	40	–	1967
Total	84	44	

	Capacity (MW)	Expected year of commissioning
Proposed stations		
Ashuganj, steam (gas)	120	1968
Tongi, steam (gas)	120	1969
Chittagong, steam (oil)	60	1970
Total	300	

	Rated capacity (MW)	Firm capacity (MW)	Expected year of commissioning
WESTERN ZONE			
Existing stations			
Khulna, steam [a] (coal)	17	15	
Khulna, diesel [a]	8	7	
Khulna, newsprint, steam [b] (coal)	15	15	
Bheramara, steam [a] (coal)	8	6	
Total	48	43	
Under construction			
Thakurgaon, steam	10	10	1964
Saidpur, diesel (oil)	8	8	1965
Bogra, diesel	7	7	1966
Total	25	25	

	Capacity (MW)	Expected year of commissioning
Proposed stations		
Khulna, steam (oil)	60	1968
Rooppur, nuclear	70	1969
Saidpur, steam (oil)	60	1970
Total	190	

SUMMARY

Total generating capability of all EPWAPDA stations in 1970 excluding industry-based plants	Eastern zone	494
	Western zone	215
	TOTAL	709 MW

The firm capacity, excluding the largest single unit which is nuclear, will be 560 MW.

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[a] All these stations will be withdrawn from service by 1970.

[b] Industry-based plants.

COST OF POWER GENERATION IN EAST PAKISTAN

Cost of power generation in East Pakistan has been unusually high because of several reasons. Until 1962, power in East Pakistan was produced entirely from imported fuels. Since 1962, Kaptai hydroelectric station has been contributing substantially to the power resources of East Pakistan. The cost of imported furnace oil varies from 65 to 85 cents per million Btu, excluding duties and taxes. Coal imported from India and China has been found to be less economical than the imported oil, but it is still being used as fuel for several generating stations in East Pakistan. The result is that the fuel component in the generating cost of these thermal power stations varies from 8 to 12 mills/kWh. The capital cost of the only hydroelectric power station of East Pakistan at Kaptai, having a capacity of 80 MW, has been extremely high—$1 250 per kW installed. It consists of two units of 40 MW each. A third unit is being installed at a cost of about $4 million. This will help to reduce the capital cost per kW installed from $1 250 to $870, but the installation of the third unit will not raise the firm power of the station, which will continue to remain at 44 MW. One of the reasons for the high cost of the Kaptai project was that enormous amount of cultivable land was inundated as a result of the construction of the dam, and heavy compensation had to be paid. This not only raised the cost of the project, but necessitated the loss of good cultivable land. At one time, two small hydroelectric projects having a total capability of 40 MW were also under study, but in view of the high cost of the Kaptai project, these have been suspended.

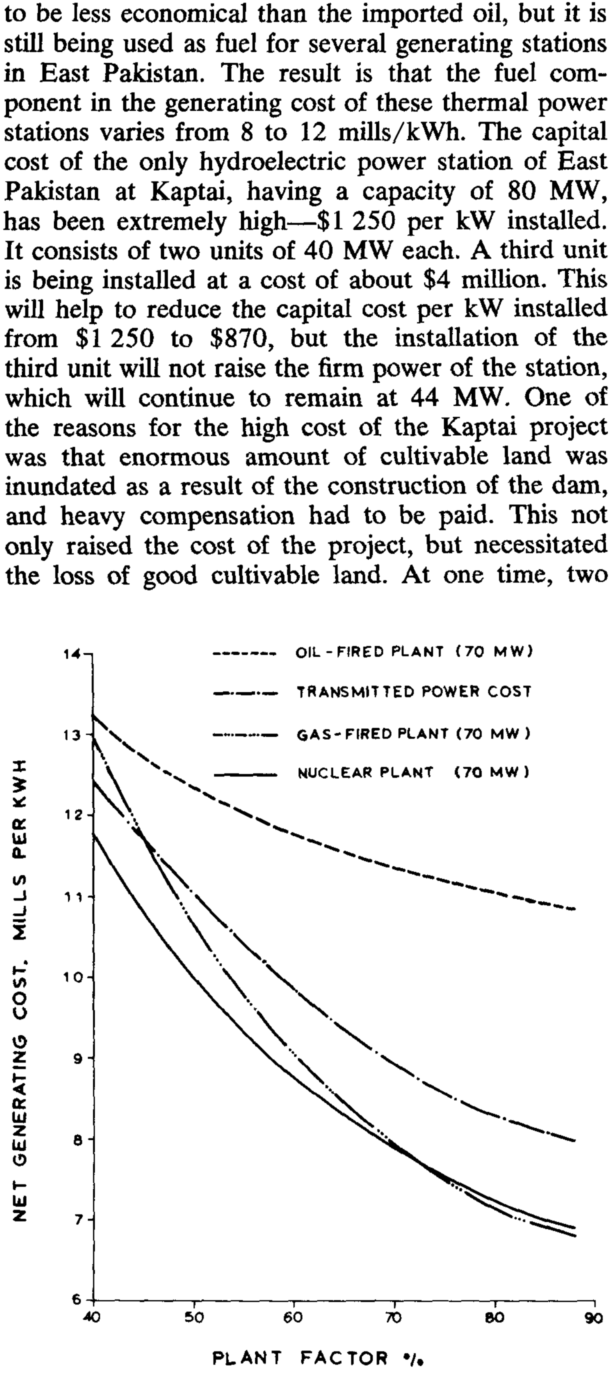

Figure 4. Generating costs v plant factor (4% interest, 30 year plant life)

The situation will be greatly relieved when new gas-fired stations start operation in the eastern zone. The gas price has been tentatively fixed at 27.4 US cents per 1 000 ft^3. The calorific value of the gas is about 1 000 Btu/ft^3, so that the fuel price of gas becomes 27.4 cents per million Btu. Gas in East Pakistan is already being used for cement and fertilizer production and it is proposed to build more fertilizer factories and a petrochemical complex, based on gas, during the Third Five Year Plan. Therefore, the limited amount of gas (equivalent to 45 million tons of coal) that has been discovered in East Pakistan could not all be used for power generation. Present estimates of the gas deposit show that it will be able to meet the requirements of power generation from the new stations that will be built in the eastern zone during the next ten years. In the western zone, since no gas is available, power generation has to be based on partly nuclear fuel and partly conventional fuel, both of which, however, will be imported so far as we can foresee at this stage (Fig. 4).

ROOPPUR NUCLEAR POWER PLANT

Location

The Government of Pakistan in 1963 decided to build a nuclear power plant at Rooppur in the western zone of East Pakistan, at a distance of about 100 miles from Dacca, the provincial capital. An engineering study established that the size of the plant should be 70 MW to be most economic for the size of the grid into which the plant will be introduced. The decision of the Government of Pakistan was based on the recommendations made in the feasibility study reports prepared earlier by Messrs. Internuclear Co. and Messrs. Gibbs and Hill Inc., Consulting Engineers of the USA, and later reviewed by the International Atomic Energy Agency (IAEA). The site at Rooppur was evaluated by a group of experts from the IAEA, Messrs. Bechtel International Corporation, Consulting Engineers of the USA, and the Pakistan Atomic Energy Commission. It is located on the bank of the river Ganges, near the Hardinge Bridge of the Pakistan Eastern Railway. Air, water, road and railway communications already exist to the site. Several industries are expected to be built around the plant site during the Third Five Year Plan.

Present status of the project

The Pakistan Atomic Energy Commission, with the help of IAEA, developed specifications for invitation of bids for the Rooppur Nuclear Power Plant. These specifications were issued in October

1963 and bids have since been received from three US manufacturers of nuclear power plants, namely, Allis-Chalmers, General Electric and Westinghouse. The nuclear reactor will be light water moderated and cooled. Consequently, the plant will be either a boiling water type, or a pressurized water type. These bids are at present being evaluated. The land for building the plant is now being acquired, and preliminary steps have been taken to build a residential colony before the construction of the plant starts. The Rooppur Nuclear Plant is scheduled to start commercial operation in the beginning of 1969.

Major features of the project

The project consists of building (*a*) the nuclear plant, together with all the essential facilities for the purpose of operation, (*b*) a 3½ mile long 132 kV double circuit transmission interconnector from the plant site to the nearest substation of EPWAPDA at Ishurdi, and (*c*) a residential colony for the plant personnel. The cooling water for the plant is most likely to be pumped from the Ganges and the engineering feasibility of doing this is now being studied. Because East Pakistan is frequently visited by severe cyclones and tornadoes, the buildings and structures of the plant will be designed to withstand the pressure of wind having a speed of 150 miles per hour. Because of the high density of population round the plant site, necessary precautions will be taken to ensure that excessive radioactivity is not released to the atmosphere or river.

COST ECONOMICS OF THE ROOPPUR NUCLEAR POWER PLANT

Cost economics of the Rooppur Nuclear Power Plant have been compared with those of an oil-fired plant of the same size built at the same location. If the nuclear plant is not built at Rooppur then only an oil-fired plant will be built instead, as oil is the cheapest of all the fuels in the western zone of East Pakistan at present. Generating costs have been calculated at various plant factors for both the nuclear and the conventional plants (Fig. 5).

The following basic assumptions have been used for the purpose of the cost calculations:

(*a*) Capital cost: Nuclear project, $28.5 million; Oil-fired project, $14.8 million. The nuclear project includes $1.3 million for the cost of the residential colony required to be built for the operating personnel, whereas the oil-fired project includes only $1.0 million for the colony.

(*b*) Plant life: 30 years.

(*c*) Rate of interest on capital for the project: 4%.

(*d*) Loan life: same as plant life (Government of Pakistan borrows money for all Government-owned projects. It is then reloaned usually at 4% for all power projects to the sponsoring agencies. The Rooppur Nuclear Power Plant will be owned by the Government of Pakistan. The Pakistan Atomic Energy Commission is the sponsoring agency for the project).

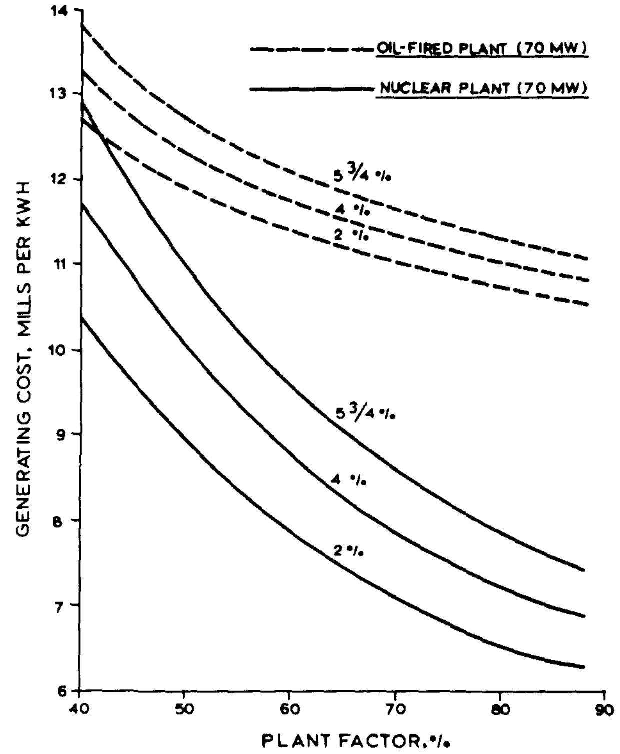

Figure 5. Generating cost *v* plant factor at various rates of interest on foreign exchange component (interest rate on rupee component 4%, plant life 30 years)

(*e*) Interim replacement as a percentage of capital cost: 0.35%.

(*f*) Plant insurance, only nuclear liability insurance for the nuclear plant, as a percentage of the plant capital cost: 0.20% (Government-owned projects in Pakistan do not carry any property insurance).

(*g*) No depreciation reserve will be accumulated to build a replacement plant.

(*h*) Plant factor assumed for the purpose of cost calculations: 40%, 60%, 80%.

(*i*) Oil cost at Rooppur is $33.20 per long ton *excluding* the import duty and other Pakistan Government taxes imposed on oil. The heat rate for the oil-fired plant has been assumed at 11 000 Btu per kWh.

(*j*) The nuclear fuel cost has been worked out as 3.35, 3.17 and 3.06 mills/kWh at 40, 60 and 80% plant factors with the initial core, and 3.10, 2.94 and 2.86 mills/kWh at the respective plant factors with the equilibrium core. It has been assumed that the fuel will be purchased from the US Government and that the USAEC will buy back the reprocessed uranium and credit the net plutonium produced at the rate of $9.50 per gm. Interest rate on the capital required for the fuel has been taken at 4%. The heat rate for the nuclear plant is estimated to be 11 700 Btu per kWh.

(*k*) Operation and maintenance cost for the nuclear plant is estimated to be $261 000 per annum, which includes $30 000 for general administration. Operation and maintenance cost for the oil-fired plant is estimated to be $180 000 per annum.

Results

The generating costs of the nuclear plant with the initial core and the equilibrium core, and of the conventional oil-fired plant as worked out on the basis of the assumptions given above, are indicated in Table 2 for 40, 60 and 80% plant factors in both cases. The generating costs are graphically represented in Fig. 6. It can be seen that nuclear power will be cheaper than oil power under all the operating conditions considered. It should be realised that these values are at this stage only order-of-magnitude estimates. When the process of evaluation of the bids for the project is over, and a fixed price contract is awarded to the Prime Contractor, it will be possible to establish the generating costs for the nuclear plant more accurately. But those accurate values are not likely to be different from the values given in Table 2 by more than 5%. In other words, the competitiveness of the Rooppur plant will not change as long as the present oil price continues to prevail. In fact, calculations show that a 70 MW nuclear plant will be highly competitive with a conventional thermal plant based on coal or oil anywhere in East Pakistan at this stage. Calculations also show that the cost of power generated in the gas-fired plants in the eastern zone and transmitted to the western zone will be higher than the cost of nuclear power by about 0.5 mill/kWh. On the other hand, power from the nuclear plant at high plant factor could replace part of the power to be generated from the gas-fired plants in the eastern zone, as the cost of nuclear fuel will be less than the cost of gas fuel at a plant factor of 60% and above with the initial core and all plant factors above 35% with the equilibrium core of the nuclear plant, as shown graphically in Fig. 7. The fuel com-

Table 2. Generating costs of the Rooppur plant versus a 70 MW oil-fired plant at different plant factors

(Mills/kWh)

		Nuclear plant	
	Oil-fired plant	Initial core	Equilibrium core
80% Plant factor (490 × 10⁶kWh)			
Fixed charges	1.85	3.69	3.69
Operation and maintenance	0.37	0.54	0.54
Fuel	8.78	3.06	2.86
Total	11.00	7.29	7.09
60% Plant factor (369 × 10⁶kWh)			
Fixed charges	2.47	4.90	4.90
Operation and maintenance	0.49	0.71	0.71
Fuel	8.78	3.17	2.94
Total	11.74	8.78	8.55
40% Plant factor (245 × 10⁶kWh)			
Fixed charges	3.70	7.38	7.38
Operation and maintenance	0.74	1.07	1.07
Fuel	8.78	3.35	3.10
Total	13.22	11.80	11.55

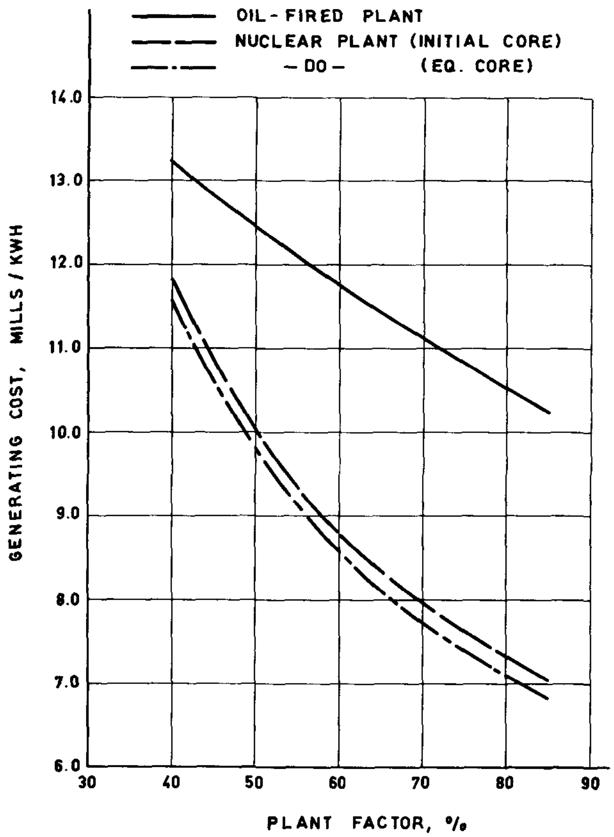

Figure 6. Generating cost of a 70MW oil fired plant v the Rooppur plant at initial and equilibrium core

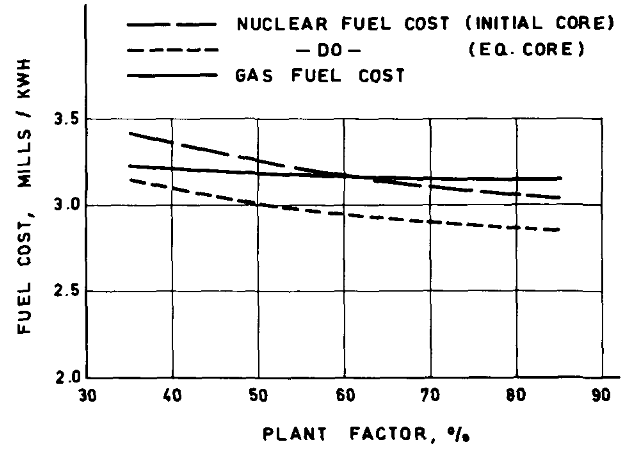

Figure 7. Comparative fuel cost of the Rooppur plant v gas fired plants in the Eastern zone

ponent of the power cost from a gas-fired plant works out to be 3.15 mills/kWh on the basis of 27.4 cents price of gas per 1 000 ft^3, and a heat rate of 11 500 Btu per kWh. At low plant factors of the gas-fired plant, the fuel component of the power cost will be slightly more because of higher value of the heat rate.

THE EFFECT OF INTRODUCING THE ROOPPUR NUCLEAR POWER PLANT INTO THE GRID

It is estimated that the average cost per unit of generation in the combined grid of EPWAPDA in 1970 will be 12 mills/kWh if a conventional oil-fired plant is built at Rooppur instead of a nuclear plant. If the nuclear plant is built, then the average cost of generation in the entire grid will be about 11 mills/kWh. This is based on operating the nuclear plant at 70% plant factor. Therefore, from the economic point of view only, the effect of introducing the nuclear plant into the EPWAPDA grid will be favourable. It envisages, however, that the interconnector between the two zones will be working by that time. Since the total generating capacity of the combined grid is estimated to be 700 MW, the Rooppur plant will contribute about 10% of the total generating capability. Hence, it could very easily operate as a base load station and achieve 70% plant factor in 1970. If, for any reason, the interconnector between the two zones does not materialize by that time, then the Rooppur plant will supply power only to the western zone which, it is estimated, will have a total generating capability of about 215 MW at that time. The Rooppur plant will, in that case, contribute about 33% of the total generating capability of that zone. This will be permissible in an under-developed but fast growing grid area such as that of East Pakistan.

It is difficult to stick to the usual standard rules regarding the addition of new generating units in a rapidly developing grid, the reasons being that firstly the base is low and secondly the rate of growth is very high. The area is far from saturation and mere availability of power will generate its own demand. It is expected that the western zone will develop quickly both in the industrial as well as in the agricultural sectors when all the projects of the Third Five Year Plan are implemented. This will require additional generating capacity immediately after 1970 and in that case the Rooppur plant will be a small percentage of the total generating capability of the western zone. Perhaps the normal approach would have been to install small generating units and wait till the system size becomes large enough to absorb a generating unit of 70 MW without having to violate the usual standard rules regarding the addition of new generating units. That would mean installing too many small units every year in order to keep pace with the rate of increase of power demand which varies from 20 to 30% annually in the western zone, and it becomes completely uneconomical in the context of long-range planning in any developing country. The investment in a plant of slightly larger size than normal in a rapidly expanding grid becomes economical in the long run.

If the Rooppur plant was to supply power to the western zone exclusively, then in 1970 it possibly would not be able to achieve a plant factor of more than 60%. Even under that condition, it would work as a base load station in the western zone grid. The situation will, of course, improve as soon as the proposed interconnector starts working, as the nuclear plant in this case could supply part of the power that would otherwise be generated from oil-fired plants in the eastern zone. As the Kaptai hydroelectric station serves as a base load station in the eastern zone, so the Rooppur plant will serve as a base load station in the western zone. This will make the system stable, as a network analysis conducted by EPWAPDA indicated that if all the base load stations were to be situated in the eastern zone the system could become unstable. In any case, prudence dictates that the entire source of generation of power should not be left to the eastern zone only and thus supply all the power required for the western zone through a transmission interconnector. The operation of the Rooppur plant as a base load station would enable the system to supply power back and forth between the two zones and thus operate the system most economically. The Rooppur Nuclear Plant will introduce diversity in the method of power generation in the EPWAPDA system, and consequently, competition among the sources of power generation. This will help to act as a check on the rising prices of the fossil fuels.

CONCLUSION

The demand for power has been steadily rising in East Pakistan. In fact, it must continue to do so if the people of East Pakistan have to achieve a reasonable standard of living. Looking forward to the next twenty years, we find that our indigenous resources will be extremely inadequate to meet our power requirements. Unless we discover a huge reservoir of some indigenous source of power generation, we will have to depend more and more on imported fuels. It means that we must make a wise selection regarding the bulk source of power supply in East Pakistan on the basis of relative economics. Here we find that because of low fuel cost, nuclear power has a promising future in East Pakistan. Apart from the pure economic competitiveness, there could be numerous indirect benefits from the adoption of nuclear power in a developing country, which may have far-reaching economic implications.

ABSTRACT - RÉSUMÉ - АННОТАЦИЯ - RESUMEN

A/597 Pakistan

Intégration de la centrale nucléaire de Rooppur dans le réseau de l'EPWAPDA

par M. Yusuf

La centrale nucléaire de Rooppur, d'une puissance de 70 MW(e), pour laquelle des soumissions ont été reçues, doit commencer à alimenter le réseau de l'East Pakistan Water and Power Development Authority (EPWAPDA) au commencement de 1969. Le réacteur sera soit à eau bouillante, soit à eau sous pression. Le réseau de l'EPWAPDA est à présent en voie d'extension rapide, et quatre petits réseaux actuellement indépendants doivent lui être incorporés. Il est prévu que le programme de développement actuellement en cours d'exécution au Pakistan oriental fera passer la demande de puissance de 500 MW en 1970; la puissance installée totale envisagée est d'environ 700 MW, dont 215 MW pour la partie ouest et le reste dans la partie est. La centrale de Rooppur doit ainsi fournir 10% de la puissance installée totale et pourrait facilement être exploitée comme centrale de base avec un facteur de charge de 0,7. Même si Rooppur ne devait pas fournir la zone est, sa contribution de 33% à la demande de la zone ouest serait possible compte tenu du développement rapide de cette région industrielle et agricole. On estime que l'augmentation de la puissance disponible fera naître une demande nouvelle.

Le coût du fuel oil importé au Pakistan oriental varie de 65 à 85 cents par million de Btu; le charbon est encore plus cher, et le coût de l'aménagement de la seule centrale hydroélectrique de la région a été extrêmement élevé: 1 250 dollars par kW installé. En conséquence, comme le mémoire le montre en détail, il est estimé que la centrale de Rooppur produira de l'énergie meilleur marché que n'importe quel autre type de centrale classique, même hydraulique. Seules feront exception des centrales brûlant du gaz, installées en certains endroits de la province, mais, si la centrale de Rooppur doit jouer le rôle d'une centrale de base dans le réseau de l'EPWAPDA, le coût marginal de l'énergie produite par elle sera encore moindre.

A/597 Пакистан

Включение атомной электростанции в Руппуре в систему энергоснабжения EPWAPDA

М. Юсуф

Ввод в промышленную эксплуатацию Руппурской атомной электростанции электрической мощностью 70 *Мвт* (заявки на строительство которой уже принимаются) в системе энергоснабжения Управления водных и энергетических ресурсов Восточного Пакистана (EPWAPDA) намечается на начало 1969 года. На электростанции будет установлен либо кипящий реактор, либо реактор с водой под давлением. Система энергоснабжения EPWAPDA находится в настоящее время в стадии организации и быстрого расширения. Четыре небольшие энергетические системы, действующие в настоящее время самостоятельно, планируется объединить в одно целое к 1969 году. Полагают, что к 1970 году эти потребности возрастут до 500 *Мвт* в связи с осуществлением обширной программы разработок в Восточном Пакистане, и планируется, что общая мощность объединенной энергетической системы должна составить к тому времени 700 *Мвт*, из которых 215 *Мвт* в западном районе и остальная часть в восточном районе. Таким образом, Руппурская атомная электростанция будет давать 10% общей мощности энергосистемы, причем станция легко сможет работать с коэффициентом нагрузки 70%. Даже если Руппурская станция не будет обслуживать восточную зону, вклад ее в удовлетворение спроса в западном районе составит 33%, что допустимо для этого быстро развивающегося промышленного и сельскохозяйственного района. Ожидается, что большее количество энергии будет развивать спрос.

Стоимость ввозимого в Восточный Пакистан топлива колеблется от 65 до 85 центов за 1 млн. брит. тепл. единиц (252 000 *ккал*). Стоимость разработки единственного в Восточном Пакистане гидропотенциала исключительно высока — 1250 *долл/квт* установленной мощности. Следовательно, как указывается в данном докладе, стоимость электроэнергии Руппурской атомной электростанции будет ниже стоимости электроэнергии, производимой любой обычной электростанцией, включая гидроэлектростанцию. Исключение составят лишь расположенные в отдельных районах этой провинции электростанции, работающие на природном газе. Однако в энергосистеме EPWAPDA Руппурская атомная электрстанция будет в любом случае электростанцией с базовой нагрузкой, так что для нее стоимость повышенной мощности оценивается ниже.

A/597 Pakistán

Integración de la central nucleoeléctrica de Rooppur en la red de la EPWAPDA

por M. Yusuf

Según los planes previstos, la central nucleoeléctrica de Rooppur de 70 MW(e), para cuya construcción se han solicitado ofertas, comenzará a funcionar regularmente en la red de la East

Pakistan Water and Power Development Authority (EPWAPDA) a principios de 1969. El reactor de la central será del tipo de agua hirviente o de agua a presión. La red de la EPWAPDA se encuentra actualmente en fase de rápida expansión, previéndose que para 1969 se hallarán interconectadas cuatro pequeñas redes que ahora funcionan independientemente. Se estima que el programa presente de desarrollo hará que hacia 1970 la demanda de energía del Pakistán del Este sea de 500 MW, de los cuales 215 MW corresponderán a la zona occidental y el resto a la oriental. Así, pues, la central de Rooppur suministrará un 10% de la energía total generada y podría funcionar perfectamente como una central de carga base con un factor de carga de 70%. Incluso aunque Rooppur no suministre a la zona oriental se podría hacer que contribuyera al 33% de la demanda de la occidental, puesto que se trata de un área de rápido desarrollo industrial y agrícola. Se cree que el simple hecho de disponer de más potencia aumentará el consumo.

El precio del combustible importado en Pakistán del Este varía de 65 a 85 centavos por millón de Btu; el carbón es aún más caro y el coste de instalación de su única central hidroeléctrica ha sido enorme (1250 $/kW). Por todo ello, como demuestra en detalle este trabajo, se estima que la central de Rooppur producirá energía más barata que cualquier central convencional, incluso hidroeléctrica. Se exceptúan las centrales alimentadas por gas en algunos lugares de la provincia, aunque su diferencia con Rooppur sería menor si es que ésta se va a usar realmente como central de carga base en la red de la EPWAPDA.

Integration of nuclear power stations in power networks with special reference to the developing countries

By M. Dayal*

The introduction of nuclear-power stations in existing power networks involves a number of problems relating to feasibility, operational economies as compared to conventional thermal stations and effect on system over-all operation. In this paper some of the more important aspects are dealt with from the special viewpoint of the developing countries. The mathematical formulae presented are evolved on the basis of simplifying assumptions in order to illustrate the principles involved. Only those aspects are dealt with which are of special importance from the system point of view. Other factors entering into the calculations such as site and transmission costs, interest rates, operating life of the station, method of estimating nuclear power costs, etc., have been dealt with elsewhere [1,2] and are not covered in this paper.

Choice of system and size of units

At the present stage of development nuclear-power stations are generally more expensive in capital cost than conventional stations; however, their fuelling costs are lower than for conventional thermal stations in many areas of the world. It is thus clear that the first nuclear stations will be installed in those systems where conventional fuel costs are high due to the distance from the sources of coal or oil. This determines generally the system and region where the installation of a nuclear station is to be considered. While the competitive position varies from country to country and depends on a variety of factors, it can generally be stated that wherever systems have conventional fuel costs in excess of about 30 U.S. cents/million Btu, it is worth examining the introduction of nuclear stations even at present day costs.

Once having chosen a system, the next most important aspect to consider is the capacity of the nuclear station to be installed and the size of the reactor and turbo-generator units. The capacity of the station will depend on the growth in demand and the ability of other sources to meet the demand. On the basis of the station capacity, a site should be chosen based on the availability of adequate cooling water, minimizing distance of power flow, transmission losses, accessibility and population distribution in the neighbourhood [3,4].

So far as the size of units is concerned, several factors enter into the decision and for facilitating discussion these are listed below:

(*a*) The over-all size of the system in terms of connected capacity in which the nuclear station is to be introduced.

(*b*) The extent of emergency relief available from adjacent systems in the event of outages.

(*c*) The size of other units in the system.

(*d*) System stability consequent on loss of largest unit.

(*e*) The ability to transport and handle large-size units for the site in question.

(*f*) Previous experience in the construction and operation of large-size units.

These factors will be examined briefly in turn.

Since the specific cost of plant decreases with increase in size, there is an incentive to go to as high a size of unit as practicable; indeed this is a trend which should be encouraged. However, the size of the total system is important because of the need to cater for outages of individual units. These outages can be of two types, viz., (*a*) planned outages for purposes of maintenance or for refuelling and (*b*) forced outages caused by trips of the turbine generator or the nuclear reactor. The former is a planned affair and the frequency depends on the type of reactor design, as for example, whether refuelling can be done on-load or off-load, the specific heat output of the fuel and the burn-up it can sustain, the amount of stand-by plant provided in the auxiliary system, etc. So far as the forced outages are concerned they depend largely on statistical variations, assuming that the plant has been engineered and operated properly.

In the event of outage of the unit it should be possible to bring up other units to meet the load or meet the requirements by import of emergency power from neighbouring systems if available. This means that if the size of unit is too large, an unnecessarily large reserve would be required which may not be available and which would be uneconomical to provide. In general it may be stated that units of a size greater than about 10% of the system peak-load are not recommended.

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* Department of Atomic Energy.

Forced outage probability

On the question of forced outages, an analysis can be done on the basis of probability theory regarding the chances of a unit failing at the time of peak-load. At other times of the day there will be other generating capacity available in the system which could come on line. Ideally there should always be enough spinning reserve on the system which can immediately be brought up to take the load if the highest size unit goes suddenly off the line. However, in the case of systems which are short of capital (and this applies particularly to the developing countries) it might be justifiable to keep somewhat less spinning reserve on the line at the time of peak-load since the chances of a large unit going off the line at that time may not be great enough to warrant such an investment.

For example, if n is the total number of units in service, p the forced outage probability for each unit, the probability P of m number of machines remaining in service is given by the following expression:

$$P = \frac{n!}{m!\,(n - m)!}\,(p)^{n-m}\,(1 - p)^{m} \text{ .... (1A)}$$

This therefore gives the probability of (n—m) units undergoing a simultaneous outage. The frequency with which failures in excess of the spinning reserve might be permitted can be chosen on the basis of the reliability of service to be offered.

A typical forced outage probability is about once in six months or say 0.005 *. On this basis for a system containing say 25 units, equation (1A) yields the following result:

No. of machines out simultaneously:	Probability
1	once in 8 days
2	once in 126 days
3	once in 2 990 days (8 years)
4	once in 98 510 days (27 years)

To determine the probability of the outage occurring at a time of peak-load, the above probabilities have to be multiplied by the probability of peak-load occurring. In a system where peak-load lasts, say four hours during the full load period of 16 hours a day, the probability of peak-load is 0.25. Thus the probability of one machine being out at the time of peak-load is once in 32 days. Usually there will be other smaller-size units on the system so that the chance that it will be the large-size nuclear (or comparative conventional) unit which will go off the line at peak-load time will be even less. For example, if out of the 25 machines, two are of 150 MW the probability of a 150 MW machine going off the line at peak-load will be once in 32 × 25/2 days, i.e., once in about a year. Nevertheless, a unit-size installed should not be greatly higher than at least some other units that may be available on the system as otherwise it becomes difficult to meet the outage requirements and programme maintenance and overhaul in a satisfactory fashion.

System stability

Apart from considerations of standby and spinning reserve consideration has to be given to system stability in the case of an outage of the largest unit. This will depend on the location of the station with reference to load centres and other generating units, transmission line limitations and the response of the other stations on the system to pick up load. It may happen that this factor limits the size of the unit to an even lower value than that permitted by considerations of reserve capacity.

Transport and handling

This is a practical question. In many cases, particularly in the developing countries, roads, bridges, railway tracks, port and harbour facilities, are not adequate to cope with very large pieces of equipment. For example, the generator stator for a 200 MW unit might weigh about 200 tonnes and have moving dimensions of about 20 ft × 30 ft. If this cannot be transported in one piece to the site in question, it may have to be transported in pieces for assembly at site. In the case of steam turbo-generators such a procedure is usually avoided in the interest of getting high-class finishes and tight tolerances. However site assembly can be considered, but then at the same time the effect of this on construction costs must be examined in view of the need for specialized services at site, staff for such erection, inspection and testing facilities. Similarly in the case of the reactor proper, one has to consider how the major equipment, such as pressure vessel or calandria would be transported and erected at site.

The last point, viz., experience with large-size units, is of some validity. However, in this respect there should not be much apprehension in practice. Staff can very easily be trained to operate and maintain large-size generator sets. Moreover, developments in increasing-size units have been quite rapid and developing countries would usually be taking sizes which have had a fair amount of operating experience in the industrially advanced countries. In addition, high reactor-size can be managed without much difficulty, as almost all operations are automatically controlled.

Comparison of a nuclear station with conventional alternative

After taking these factors into account and deciding on the unit size a comparison may be made of the nuclear station with a conventional alternative. The simplest comparison is between the two stations assuming identical service to the system. In this it is presumed that both stations would

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* This applied until recently to the power system on the west coast of India.

operate at the same plant factor on the system and the cost of power is calculated for each employing the relevant factors, such as interest rate and operating life. From the system point of view the most important assumption in this comparison is that of the plant factor. In order to determine the feasibility of given plant factor operation one has to consider: (*a*) the availability factor of the plant which will constitute an upper limit for the over-all plant factor and (*b*) the system load factors and characteristics of the other stations in the system. A proper analysis of the system will show whether the given plant can operate at the assumed high plant factor without adversely affecting other plant on the system.

The experience of all nuclear-power plants that have been operating confirms that the availability factor for nuclear-power stations will be at least as high as for conventional power stations, if not higher. Several features of nuclear-power stations, in fact, make for higher availability factors such as the absence of ash, coal movement problems, boiler-cleaning problems, relatively low-pressure steam operation and highly automatized control system with built in safety features. The designs of nuclear-power stations also provide for generous safety margins and emergency equipment. For these reasons, an availability factor in excess of 90% can be expected. This therefore does not constitute a limitation on the plant factor.

Operation of a nuclear station in the power network

With regard to the system load factors and characteristics and operation of the station in the system, it is necessary to examine each system on its own. Among the important factors are the system daily load curve pattern, the annual load factor of the system demand, the energy availability from the hydro-stations, the extent of thermal capacity and the minimum load which they have to carry. In a system which has a hydro and thermal capacity, the first principle is to make sure that the available hydro-energy is completely utilized since this provides the cheapest incremental energy cost. For run of the river hydro-plants, base loading could then be necessary. Where the hydro projects are of the storage type, the hydroenergy can be fully utilized even with the hydro capacity taking the upper portion of the daily load curves. For the extreme base load in such systems nuclear-power stations can provide the energy requirement, since this would involve the lowest incremental costs for producing energy in view of the much lower fuelling costs as compared with the thermal stations (this would be the reason for putting the nuclear station in the given system in the first place).

WEST COAST POWER SYSTEM IN INDIA

As an example we may consider the power system in the West Coast region of India into which the Tarapur atomic power station will feed. At present there are two electrical systems in the region viz., the southern or Tata-Koyna-Railway system and the northern or Gujarat system. These two will be interconnected by a 220 kV double circuit transmission line and the Tarapur atomic power station will feed this interconnected system. The maximum demand on the interconnected system is expected to be about 2 000 MW in 1968, when the atomic power station is expected to commence operation [5]. By then it is expected that there will be three conventional thermal sets of a size of 125 MW or more in the system, 4 hydro sets of 75 MW and 11 sets (hydro and thermal) of a size of about 60 MW. In addition 2 × 125–140 MW units are expected to be available on an adjacent system which is also to be linked. The system is fairly extended, covering a distance of more than 500 miles from north to south. Moreover from the Tarapur station, the main load centre to the north is about 200 miles away, while the load centre to the south is about 60 miles distant. Taking these factors into account and using the principles discussed earlier in the paper the unit size at Tarapur has been kept at 200 MW installed (190 MW net). There will be two such reactor units each with associated turbine-generator unit so that the station capacity will be 380 000 kW net.

An examination of the characteristics of the system and scheduling of maintenance on various units has been carried out. This indicates that the capacity that would be under maintenance and use as spinning capacity should be taken as about 400 MW. The installed capacity should therefore be about 2 400 MW as compared to the total installed capacity at present in operation of about 1 400 MW. The system load factors in both systems are very high. In the southern system the daily load factor at present is above 80% and the annual load factor is about 69%. In the northern system, the corresponding figures are 76% and 60%. Daily system demand curves for typical days in 1963 on the southern and northern (Ahmedabad) systems are shown in Figs. 1 and 2. By combining the two curves and scaling up in proportion to the demand, an anticipated typical daily load curve for the year 1968 has been plotted in Fig. 3. By then the total installed hydro capacity in the system will be 996 MW. The energy available in the hydro-system however is only 3 530 million kWh per annum, i.e., the installed capacity can work at an average plant factor of 40%. Since the hydros are all storage schemes, it is possible to make them provide energy for the top portion of the load curve. The nuclear and conventional thermal power-stations can, therefore, be made to take the entire base load of the system, and it is clear that there is no difficulty from the load point of view in operating the nuclear power-station at an annual load factor of 80% or higher. The general sharing of the load that could be programmed normally is shown in Fig. 4. On

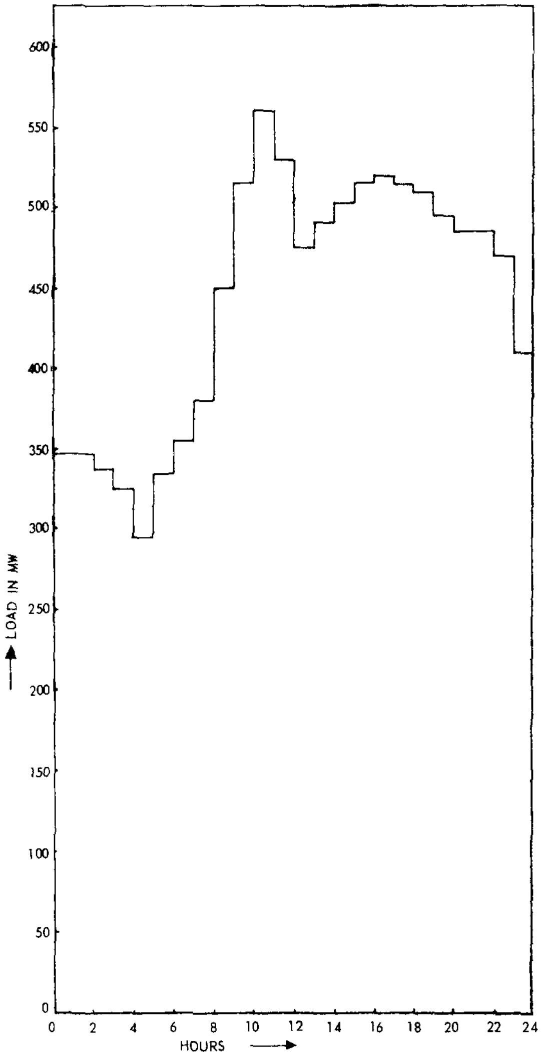

Figure 1. Typical daily load curve of the Tata-Koyna Railway interconnected system (1963). (25.6.63)

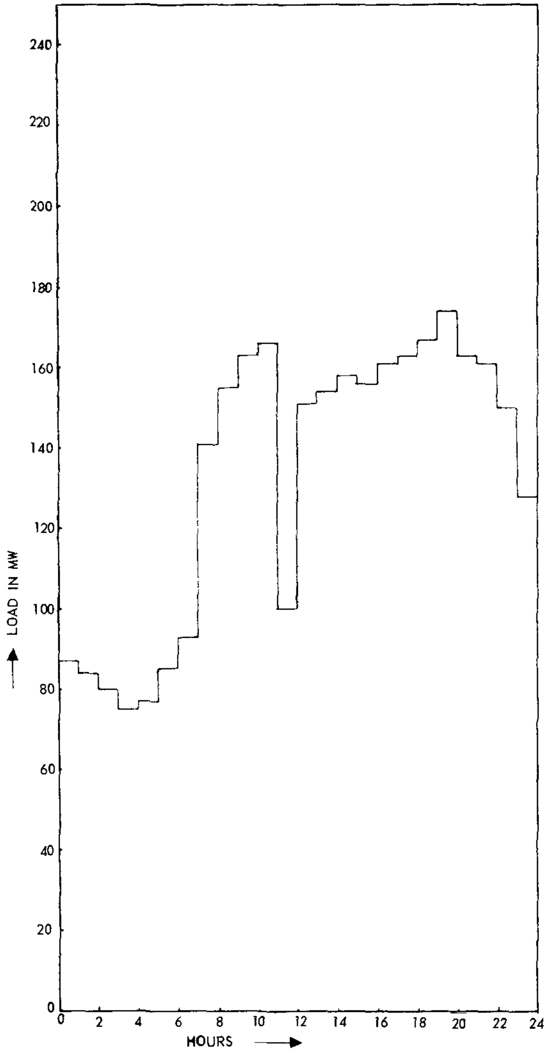

Figure 2. Typical daily load curve of the Ahmedabad, 1963 (30.9.63)

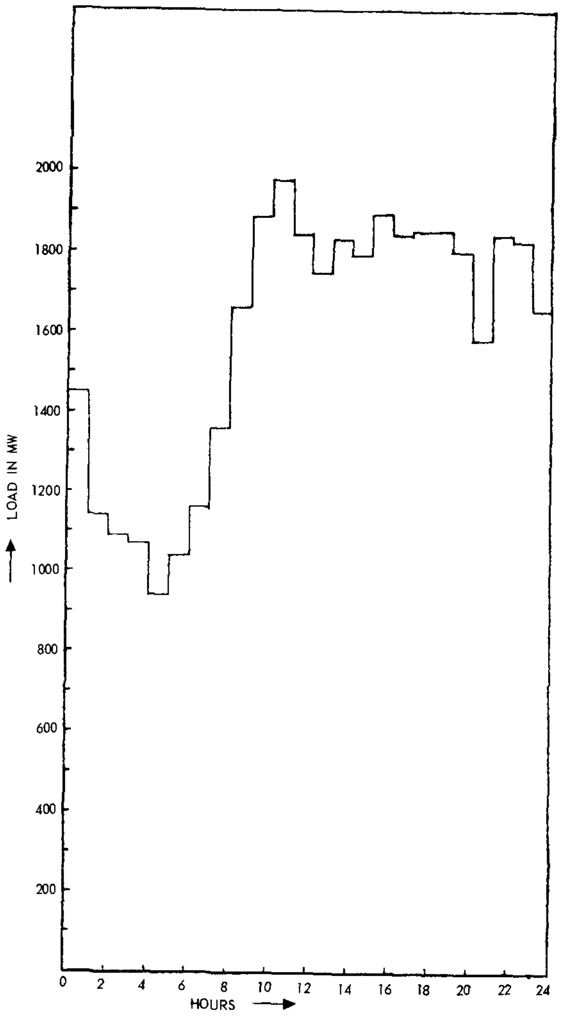

Figure 3. Interconnected Gujarat-Tata-Koyna Railway System: anticipated daily load curve for 1968

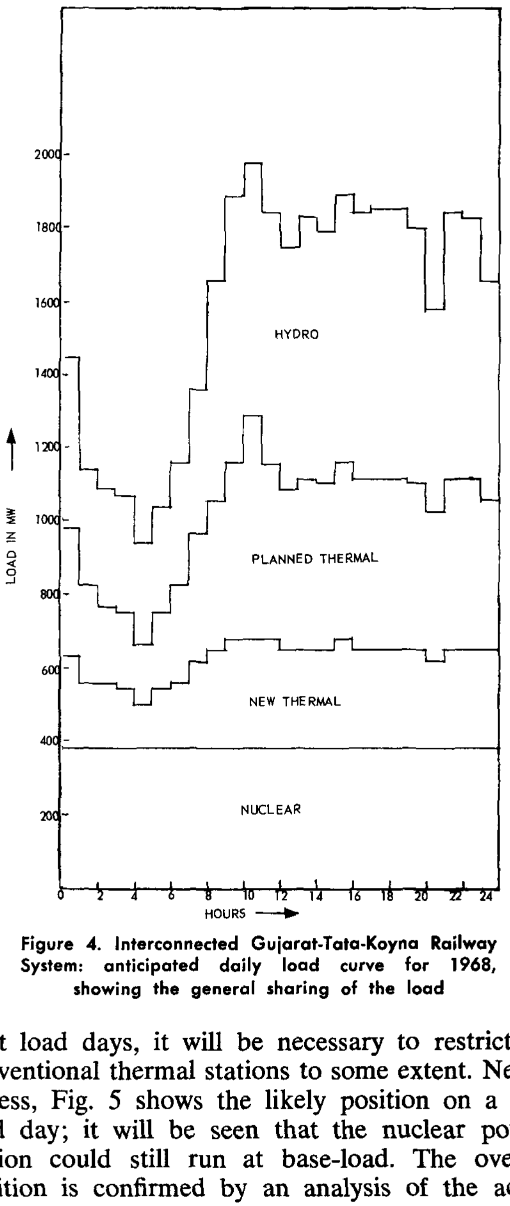

Figure 4. Interconnected Gujarat-Tata-Koyna Railway System: anticipated daily load curve for 1968, showing the general sharing of the load

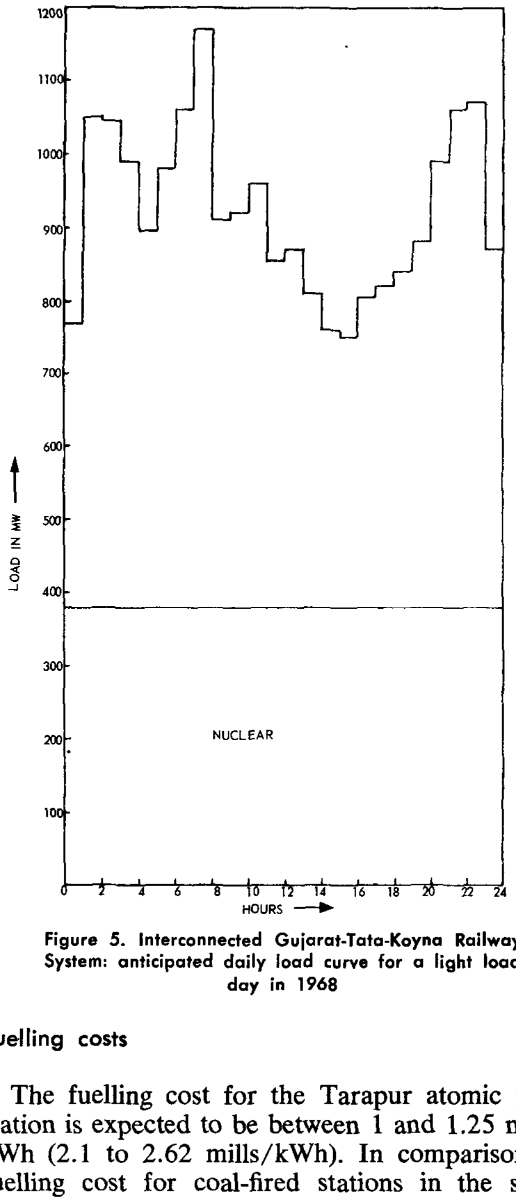

Figure 5. Interconnected Gujarat-Tata-Koyna Railway System: anticipated daily load curve for a light load day in 1968

light load days, it will be necessary to restrict the conventional thermal stations to some extent. Nevertheless, Fig. 5 shows the likely position on a light load day; it will be seen that the nuclear power-station could still run at base-load. The over-all position is confirmed by an analysis of the actual energy requirements of the system on an annual basis, which are expected to amount to over 11 500 million kWh excluding station auxiliaries by 1968 [5]. After utilizing the entire energy available from the hydro-system, even if the nuclear power-station works at 80% load factor, the thermal power-stations, including the capacity installed in addition to that existing or under construction at present, will still be able to work at a high load factor of over 70% operating on the total effective thermal capacity. An anticipated load duration curve for the year is plotted in Fig. 6. In fact, it would be more economical to give an even larger share to the nuclear station and reduce the load factor of the older thermal plants, since the fuelling costs are much lower for the nuclear station as compared to the thermal stations, and it would therefore be more economical to restrict, where necessary, the thermal plants rather than the nuclear station (within technical limits).

Fuelling costs

The fuelling cost for the Tarapur atomic power station is expected to be between 1 and 1.25 nP/net kWh (2.1 to 2.62 mills/kWh). In comparison, the fuelling cost for coal-fired stations in the system will be a minimum of 2.79 nP (5.85 mills) per net kWh. The difference is so great that it is obviously more advantageous to provide for the energy needs by the nuclear power-station rather than the coal-burning power-stations. For example, if there is a question of providing even an additional 2.5×10^8 kWh which is equivalent to only 7.5% plant factor for a station of 380 MW, allocating this to the nuclear station would result in additional fuel costs of about Rs.2.5 million ($525 000) whereas if this were to be allocated to the coal-based stations, the additional costs would be at least Rs.7 million ($1.47 million). Thus the saving to the system in using the nuclear power-station would be more than Rs.4 million ($840 000) per year even for this marginal allocation of energy; the savings will be proportionately greater the higher the amount of energy allocation given to the nuclear as against the conventional thermal stations. The nuclear station fuelling cost is also much less than

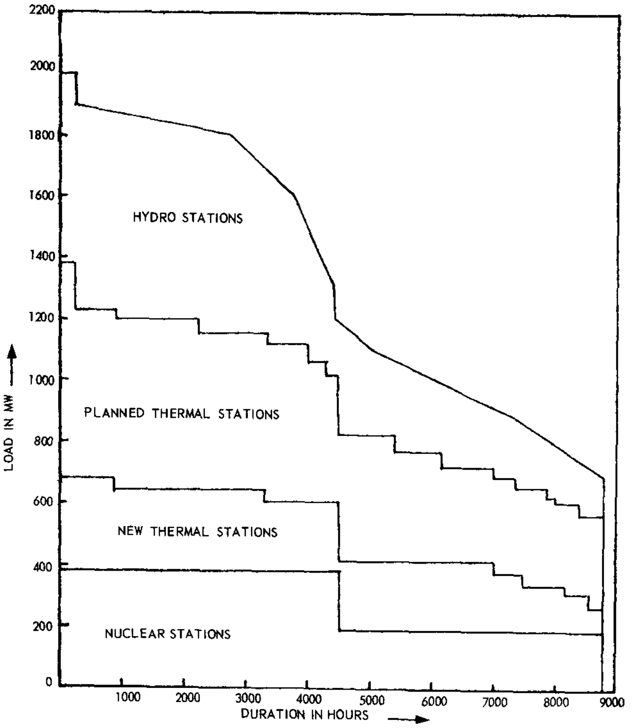

Figure 6. Interconnected Gujarat-Tata-Koyna Railway System: anticipated annual load duration curve for 1968

for oil-fired stations in the area, even if the present duty charged on furnace oil is excluded.

DELHI-PUNJAB-RAJASTHAN SYSTEM

Another nuclear power-station is under construction at Rana Pratap Sagar in Rajasthan. This station will meet the power requirements of the systems of Delhi, Punjab and Rajasthan States, which will be interconnected. Typical present load curves for Punjab and Delhi are shown in Figs. 7 and 8. The present daily load factor in Punjab is 82% and in Delhi 72%. The annual load factors are 75% and 55% respectively [5]. The annual load factor for the combined system is expected to be 65% by 1971, when 400 MW capacity at the nuclear station is expected to be in commercial operation [5]. The main source of hydro power for this region is the Bhakra-Nangal Project in Punjab which has an installed capacity of 1 050 MW and an annual energy availability of 3 460 MW (i.e., an annual plant factor of about 38%). Due to the seasonal variation in the available head caused by the extremely uneven rainfall, the firm power is only 480 MW. A coal-fired thermal-station at Delhi helps to augment this hydropower to some extent but for this coal is being transported over a distance of over 700 miles from the Bengal-Bihar coal-fields. The nearest collieries from which coal could be supplied to the region in the future are about 400 miles away. The fuelling cost for a thermal station in the region based on the cheapest coal available comes to about 2.5 nP/kWh (5.25 mills/kWh). The fuelling cost from an oil fired station in the region would be higher since it is deep inland and oil would have to be transported from the nearest ports (Kandla or Bombay) which are over 550 miles by rail. On the other hand the nuclear power-station, which will be of the heavy-water moderated and cooled type with pressure tubes (CANDU type) using uranium oxide fuel, will have a fuelling cost of about 0.65 nP/kWh (1.36 mills/kWh) at only 75% plant factor. This is because of the relatively low cost of such fuel (about $30/lb of uranium) and the high burn-up available in the heavy water moderated and cooled system (about 10 000 MWd/tonne). The differential in fuelling cost is so great that large over-all savings would result in giving maximum load factor operation to the nuclear as against a conventional thermal station. Figure 9 shows the annual fuel costs to the system from a nuclear as well as a conventional thermal station each of 400 MW net output for varying plant factors.

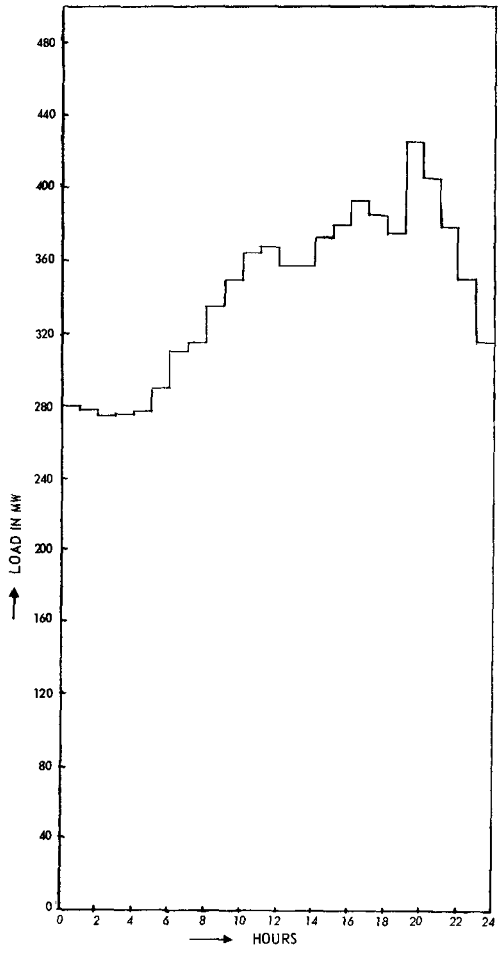

Figure 7. Typical daily load curve of Punjab, 1963 (18.9.63)

Thus it is clear that in this system also, the nuclear station would be able to operate at high load factors. Indeed this will be of double advantage; first, it will result in considerable economies to the system as seen from Fig. 9; secondly, it will provide much

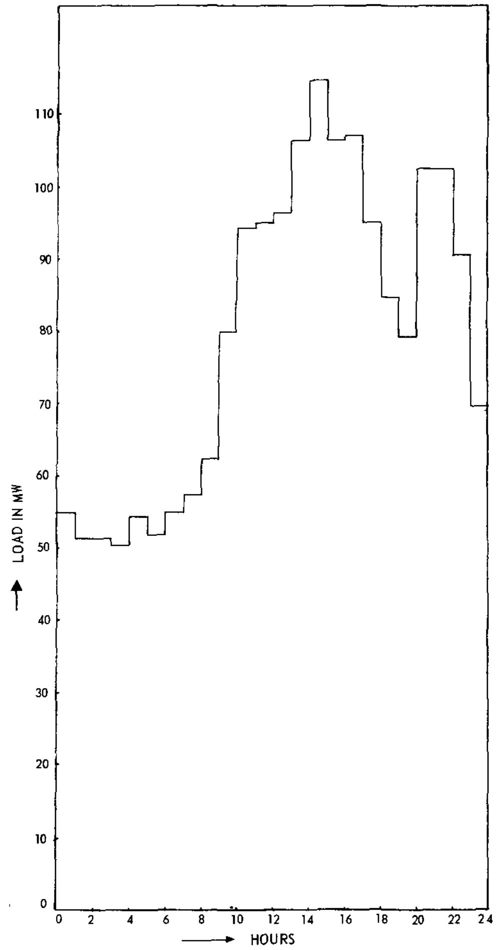

Figure 8. Typical daily load curve for New Delhi, 1963 (18.6.63)

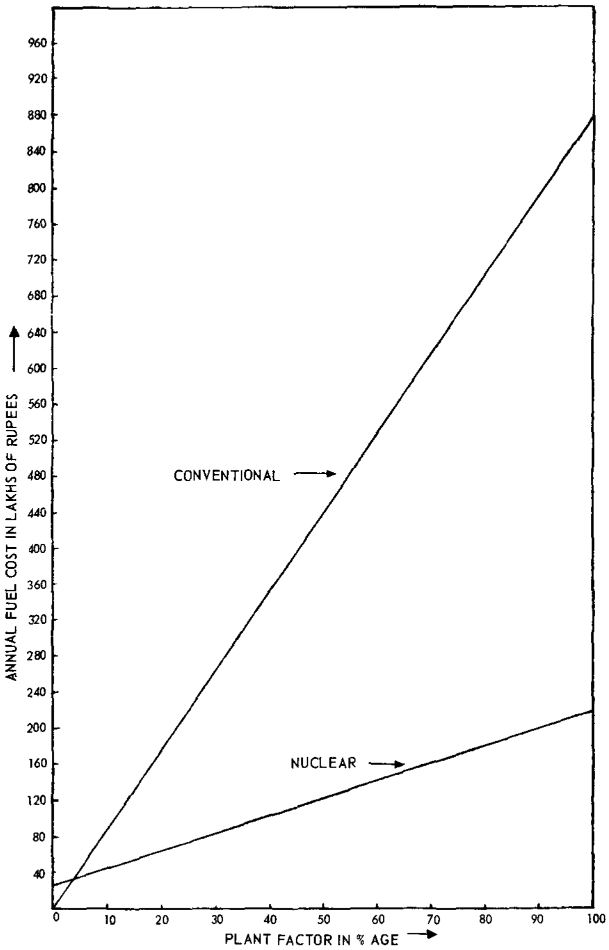

Figure 9. Variation of annual fuel cost with plant factor for 400 MW station

needed backing to the hydro-plants which will be able to regulate themselves more evenly and can therefore provide higher effective firm capacity. These hydro plants will be able to take the loads for the top portion of the demand curve.

MADRAS AND SOUTHERN ZONE SYSTEM

A similar analysis has been carried out in regard to the Madras system into which the Kalpakkam atomic power station which is expected to have a capacity of 400 MW will feed. The present daily and annual load factors are about 74% and 65% [5], respectively; the present installed capacity is 815 MW but effective capacity is only about 600 MW. The power situation at present is however very acute and there is severe repression of demand. Most of the installed capacity is based on storage hydro schemes and the average plant factor is about 46%. By the time the Kalpakkam station comes into operation in 1971, the demand on the Madras system will be over 2 000 MW [5]. Due to the high system load factors and the presence of hydro plants to take the system peaks the nuclear station at Kalpakkam could work at a load factor of 80% or more. Figure 10 shows a typical daily load curve for the system at present. By 1970-71, the Madras system is expected to be interconnected with the neighbouring systems in Andhra Pradesh, Mysore and Kerala forming a south zonal grid with an anticipated peak-load of about 4 500 MW at an annual load factor of about 68% [5]. The neighbouring systems of Mysore and Kerala possess cheap hydro power resources; hydro power however is very seasonal. The proposed 400 MW nuclear station at Kalpakkam in Madras will help to augment this power and the installed capacity of hydro power, which can work only at relatively low plant factors can, largely, take the system peaks. In this system, however, certain hydro stations have to be operated during the irrigation period at base load as in this period water flow has to be maintained for meeting irrigation requirements. Figure 11 shows an anticipated load curve for the entire region for the year 1971 and indicates how the nuclear power station would be able to take the base load without adversely affecting the other stations in the system. Figure 12 shows the expected annual load duration curve for the entire region by 1970-71. The Kalpakkam nuclear station is also expected to be of

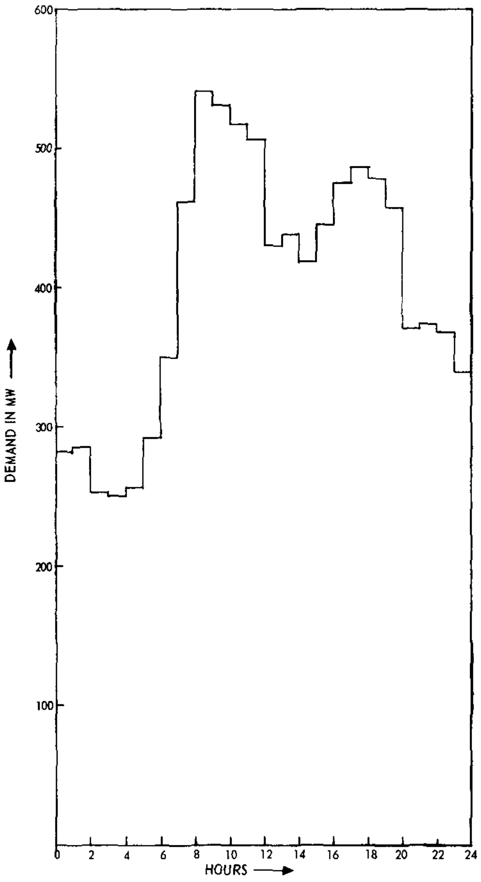

Figure 10. Typical daily load curve of Madras grid, 1963 (12.11.63)

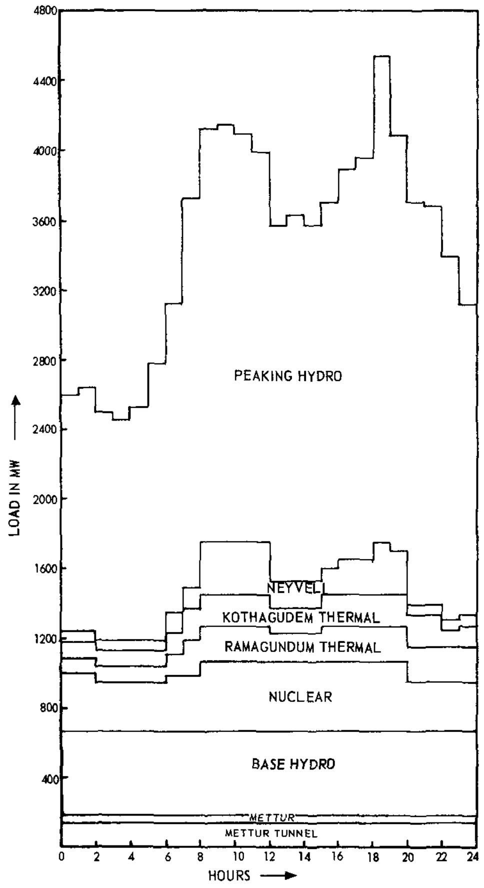

Figure 11. Southern region (Madras, Kerala, Mysore, Andhra Pradesh): anticipated daily load curve for 1971, showing sharing of load

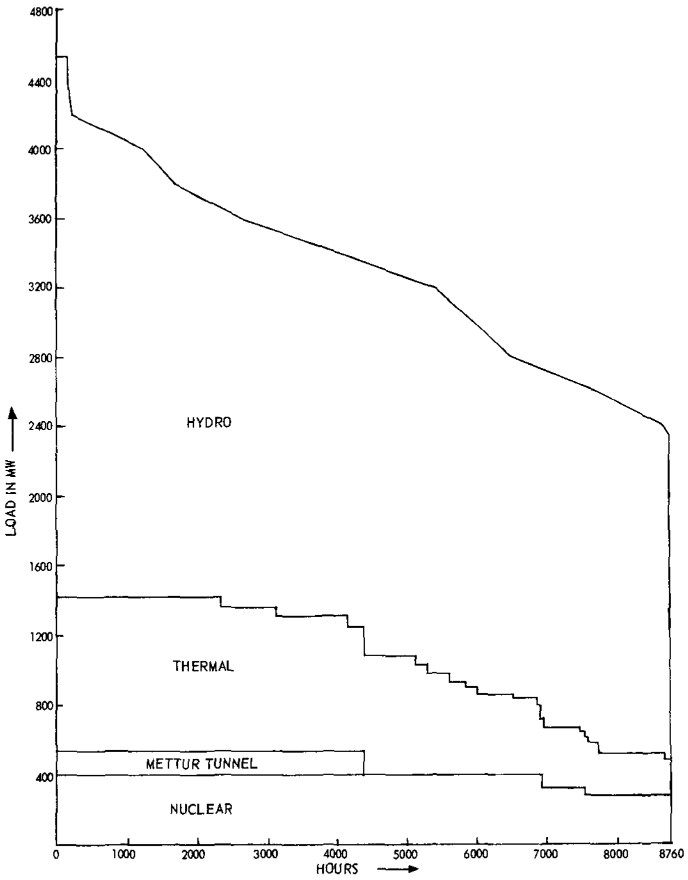

Figure 12. Southern region (Madras, Kerala, Mysore, Andhra Pradesh): anticipated annual load duration curve for 1971, sharing of load

the heavy water moderated type though the exact design has not been chosen. As mentioned earlier, the fuelling cost for such a station will be about 0.65 nP or 1.36 mills/kWh. There is some lignite in Madras State and a power-station based on this is in operation. At the present prices of lignite however, the fuelling cost for such a station would be about 2 nP or 4.2 mills/kWh. In fact the lignite production is not enough to provide for the thermal power needs of the state and a power station based on coal transported over considerable distances from outside the state is also in operation. The addition of similar stations is being considered—their fuelling costs will be even higher; a minimum of 2.68 nP/kWh or 5.42 mills/kWh. This again indicates the desirability of the highest load factor operation for the nuclear power station.

It may be noted in passing that although the peak demand on the integrated system is expected to be about 4 500 MW by 1971, the system is far flung over a very wide area with long transmission distances. There are limitations on the loading of the lines between these stations. The amount of reserve capacity likely to be available by 1971 is also small. Moreover the largest size of unit is only 100 MW of which there are likely to be only two or three machines in the system by 1971. There are also limitations on transport and handling. These considerations, as discussed earlier, tend to limit the size of the unit to a smaller value than what might be considered possible from the point of view of system size alone. The matter is being investigated further for a final decision.

It will be seen that in the systems considered, nuclear stations can be installed to run at high load factors. In fact for comparison purposes, a conservative factor of 75% has been used. The comparative economics have been dealt with in another paper presented at this Conference [6]. It is shown there that nuclear power stations would be economically competitive with conventional stations in the systems considered even at present.

Growth in system and possible future patterns of operation

In this connection, it should be noted that for a given nuclear power station the fuelling costs are likely to go down during its life due to developments in various stages of the fuel cycle, reduction in fuel element fabrication costs and increase in burn-up for new charges. On the other hand for a conventional alternative the fuel costs are if anything likely to go up as the efficiency reduces with life. Moreover, when newer conventional thermal stations are introduced into the system they would have an improved efficiency with the result that the conventional thermal stations already in operation would have higher incremental energy costs and this would tend to make them move upward in the load curve. There is thus no doubt that for the alternative of the nuclear or a conventional station at a given time the load factor of the nuclear station may be considered to be consistently high while that for the conventional thermal station may be reasonably taken as a decreasing amount. Estimates can be made about this on the basis of assumptions regarding efficiency and fuel cost trends, and these can be used to arrive at over-all lifetime costs for a nuclear station against a conventional station built at a given time.

It may be concluded that the simple comparison of a nuclear power-station with a conventional thermal alternative can be made after analysing the system and judging the plant factor at which the two alternatives could operate. For most cases, particularly those in which under-developed countries may be involved, this would be adequate for comparison purposes. In certain cases, life time costs based on changing plant factors and fuel costs can also be estimated to arrive at a final conclusion.

Development of increasing nuclear, thermal and hydro capacity

The problem may arise of contemplating not merely the addition of a given nuclear power-station but of planning, over a reasonably long period, the addition of increasing amounts of hydro, thermal and nuclear capacity in order to meet the needs of system growth in the most economical fashion. This becomes much more complicated but can lend itself to a resolution by following certain general criteria. The basic objective is that the energy and capacity requirements should be met by hydro, conventional-thermal and nuclear stations in such a proportion as would give the lowest total cost to the system. In order to determine this, we may examine a general model. Let C be the additional installed capacity required at a given time; E the total energy required at a given time; then a scheme of additions has to be evolved which will make the fixed charges on C plus the total energy charges on E a minimum. Let this sum be $= R$.

We shall attempt to derive relatively simple mathematical formulae based on certain simplifying assumptions which illustrate the principle of this calculation.

Let the requirements of energy for the system be E

Let the installed capacity required C'

Let the installed capacity available C''

$\therefore$ Additional capacity required $= C' - C'' = C$

Let this be allocated to hydro, thermal and nuclear sources in the ratio $\Big\}\ 1 = K_T = K_N$

Then hydro capacity installed $= \dfrac{1}{1 + K_T + K_N} C$

Then thermal capacity installed $= \dfrac{K_T}{1 + K_T + K_N} C$

Then nuclear capacity installed $= \dfrac{K_N}{1 + K_T + K_N} C$

Let annual fixed costs per unit installed for the new hydro, thermal, and nuclear stations be: F_H, F_T & F_N respectively

Then total annual fixed costs on additional plant

$$= \frac{C}{1 + K_T + K_N}(F_H + F_T K_T + F_N K_N) \text{.... (1B)}$$

Let $E_{H'}$ be the energy generated by the existing hydro plant at a fuel cost of $C_{H'}$ per unit (usually $= 0$ except where royalty or other charges are levied)

$E_{T'}$ be the energy generated by the existing thermal plant at a fuel cost of $C_{T'}$/unit

$E_{N'}$ be the energy generated by the existing nuclear plant at a fuel cost of $C_{N'}$/unit

E_H be the energy generated by the new hydro plant at an average annual utilization of θ_H hours and a fuel cost of C_H/unit

E_T be the energy generated by the new thermal plant at an average annual utilization of θ_T hours and fuel cost of C_T/unit

E_N be the energy generated by the new nuclear plant at an average annual utilization of C_N hours and fuel cost of C_N/unit.

$$\left(\text{PLANT FACTOR} = \frac{\theta}{8760}\right)$$

$$\text{Then } E_H = \frac{C\,\theta_H}{1 + K_T + K_N};\ E_T = \frac{C\,\theta_T K_T}{1 + K_T + K_N};\ E_N = \frac{C\,\theta_N K_N}{1 + K_T + K_N}$$

Let E_L be the total transmission losses, assumed as constant.

$$\begin{aligned}\text{Total fuel cost} &= E_{H'}C_{H'} + E_{T'}C_{T'} + E_{N'}C_{N'} + E_H C_H + E_T C_T + E_N C_N \\ &= E_{H'}C_{H'} + E_{T'}C_{T'} + E_{N'}C_{N'} + \frac{C\,C_H\theta_H}{1 + K_T + K_N} \\ &\quad + \frac{C\,K_T C_T \theta_T}{1 + K_T + K_N} + \frac{C\,K_N C_N \theta_N}{1 + K_T + K_N} \qquad \text{................ (2)}\end{aligned}$$

$$\begin{aligned}\text{Sum of 1 \& 2} = \text{R} &= E_{H'}C_{H'} + E_{T'}C_{T'} + E_{N'}C_{N'} + \frac{C\,\{F_H + C_H\theta_H\}}{1 + K_T + K_N} \\ &\quad + \frac{C\,K_T\,\{F_T + C_T\theta_T\}}{1 + K_T + K_N} + \frac{C\,K_N\,\{F_N + C_N\theta_N\}}{1 + K_T + K_N} \text{........... (3)}\end{aligned}$$

$$\text{ALSO } E_{H'} + E_{T'} + E_{N'} + E_H + E_T + E_N = E + E_L \qquad \text{................ (4)}$$

With (4) as the equation of restraint, a solution can be found for E_H, E_T, E_N, θ_H, θ_N, K_T & K_N for which R is a minimum. The values of K_T & K_N will then give the most economical allocation of the required installed capacity between hydro, thermal and nuclear stations and the values of $\theta_{N'}$ θ_T and θ_N will give the most economical loading of the new plant. The equations can be solved in most cases by an iterative method. It may be pointed out that a considerable simplification is introduced by not taking into account the form of the load duration curve. With the help of such an analysis it is possible to superpose also the likely variations in demand pattern of demand and system load factors, i.e., if we estimate the manner in which C & E are going to vary with time we can solve the equations for minimum cost for a period of time into the future. Similarly it is possible to superpose the likely variations in the capital costs of conventional and nuclear stations as well as the expected changes in efficiency or fuel costs. It will thus be possible to arrive at a tentative programme for the development of the system in terms of nuclear and conventional resources. In arriving at the programme one would however have to bear in mind the physical limitations in the rate of development of the different sources; specifically, hydro-development takes considerable time and this will condition the pattern of growth of the different types of stations in the system. In fact this puts in practice another restraint enabling equations (3) and (4) to be solved in the best manner.

A mathematical treatment of the subject has necessarily to be based on a number of assumptions and the in-put of considerable data which may vary in accuracy. Nevertheless, such a treatment could be of value in pointing out a general guide. It should however be taken as such and be subjected to constant review in order to assess the effect of changes in technology involving changes in costs or other relevant factors. Moreover, in certain cases, as in regard to the power systems of India considered in this paper, certain general conclusions may be arrived at even without going through the mathematical analysis completely. Finally, decisions have to be taken based on judgement.

In Indian conditions, it is found that hydro energy, if available in the region of load demand, provides usually the cheapest source of power and such energy should be developed steadily in accordance with the likely physical growth in harnessing hydro-potential. If the hydro-projects are of the storage type, capacity, installed in a hydroproject, should be designed for low plant factor operation; this provides the most economic way of meeting system peaks since the additional installed cost of units is relatively small. It has been suggested that in general, additional hydro capacity installed now may be designed for about 15% plant factor operation if practicable. The balance of energy requirements other than the energy provided from the hydro can be distributed between thermal and nuclear stations which will therefore be able to operate at reasonably high plant-factors. In this situation it is found that for the regions with high delivered conventional fuel costs, increasing amounts of nuclear power would have to be installed from now on to meet the requirements most economically [6]. Similar considerations may apply to other developing countries as well.

ACKNOWLEDGEMENT

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ABSTRACT - RÉSUMÉ - АННОТАЦИЯ - RESUMEN

A/746 Inde

L'intégration de centrales nucléaires dans les réseaux de distribution, notamment en ce qui concerne les pays en voie de développement

par M. Dayal

L'introduction de centrales nucléaires dans les réseaux soulève de nombreux problèmes techniques et économiques, qui ont des répercussions importantes sur l'économie et le développement des réseaux, ainsi que sur la répartition de la puissance installée hydroélectrique, thermique et nucléaire, pour le présent comme pour l'avenir. Le mémoire discute les différents facteurs dont il faut tenir compte pour déterminer le rôle de l'énergie d'origine nucléaire dans un réseau de distribution: taille du réseau et des unités de production, disponibilité, facteur de charge du réseau, accumulation, frais d'exploitation, etc. Le problème général de l'exploitation de centrales nucléaires dans un réseau de distribution qui comprend des centrales hydroélectriques, thermiques et nucléaires est traité. On examine l'installation de séries de centrales nucléaires et de centrales classiques ainsi que l'économie du réseau dans son ensemble; on étudie les rôles respectifs incombant aux différents types de centrale pour ce qui est de répondre à la charge et aux besoins d'énergie dans les conditions présentes et futures. La possibilité d'appliquer ces méthodes d'étude aux problèmes particuliers des pays en voie de développement est examinée.

Les coûts afférents aux centrales nucléaires et aux centrales classiques en Inde sont étudiés sur le plan du réseau, et l'on compare les coûts de séries de centrales nucléaires et classiques. Trois réseaux particuliers sont l'objet d'un examen détaillé. Ce sont les réseaux régionaux de l'ouest, du nord et du sud. Dans ces régions, des centrales nucléaires représentant une puissance totale de 1,2 million de kilowatts doivent être installées avant 1971. L'étude montre que ces centrales nucléaires, et d'autres à construire plus tard, pourraient assurer la charge de base future dans ces régions et satisfaire aussi une partie des besoins d'énergie avec des facteurs de disponibilité plus bas et que le maximum d'économies pour les réseaux résulterait de l'installation progressive d'une puissance nucléaire croissante. Le mémoire développe et formule des critères qui peuvent être utilisés, surtout par les pays en voie de développement, pour étudier l'introduction et le rôle futur de l'énergie d'origine nucléaire dans les réseaux de distribution.

A/746 Индия

Включение атомных электростанций в общую энергетическую систему с учетом особых условий в развивающихся странах

М. Дайал

При включении атомных электростанций в общие энергетические системы возникает ряд проблем технического и экономического характера, которые оказывают серьезное влияние на экономику и расширение сетей, на распределение мощности гидро-, тепловых и атомных электростанций с учетом современных и будущих условий. В докладе рассматриваются различные факторы, которые необходимо учитывать при определении роли атомной энергии в энергетической системе, например: размеры системы и установок, факторы доступности, коэффициент нагрузки системы, наличие запасов гидроэнергии, стоимость эксплуатации и т. п. Рассматриваются общие проблемы эксплуатации атомных электростанций в энергетической системе, состоящей из гидро-, тепловых и атомных электростанций. Изучена установка каскада из атомных и обычных электростанций и экономика системы в целом; исследована относительная роль электростанций различного типа в удовлетворении потребностей в нагрузке и энергии как в настоящем, так и в будущем. Проверена применимость этих методов при изучении особых проблем, характерных для развивающихся стран.

Изучена стоимость сооружения атомных и обычных электростанций в Индии с точки зрения системы энергоснабжения и проведено сравнение между каскадами обычных и атомных электростанций. Детально рассмотрены три характерные для Индии энергетические системы: система Западного района, Северная система и Южная система. В этих районах к 1971 году общая мощность атомных электростанций должна доставить 1,2 млн. *квт*. Анализ показывает, что эти атомные электростанции и другие, которые должны быть построены к этому времени, могут нести будущую базисную нагрузку в этих районах, а также удовлетворить часть потребностей в электроэнергии при более низких коэффициентах станций и что максимальная экономия для систем может быть достигнута путем подключения непрерывно увеличивающегося количества атомной энергии. В докладе обсуждаются критерии, которые могут быть использованы, особенно в развивающихся странах, при изучении вопроса о включении и будущей роли атомных электростанций в общую энергосистему.

A/746 India

Integración de centrales nucleares en sistemas eléctricos, con especial referencia a los países en vías de desarrollo

por M. Dayal

La integración de centrales nucleares en los sistemas de producción de energía eléctrica suscita una serie de problemas de índole técnica y económica que tienen importantes repercusiones en los aspectos económicos de todo el sistema, en su ampliación y en la distribución de la capacidad hidroeléctrica, térmica y nuclear teniendo en cuenta las condiciones presentes y futuras. En la memoria se examinan los diversos factores, tales como dimensiones de la red y de las centrales, factor de disponibilidad, factor de carga, potencial hidroeléctrico, coste de explotación, etc., que han de tomarse en consideración al decidir la función de la energía nuclear en un sistema de producción de electricidad. Se estudia el problema general que, en un sistema integrado por centrales hidráulicas, térmicas y nucleoeléctricas, plantea la explotación de estas últimas. Se examina la instalación escalonada de centrales nucleares y tradicionales y los aspectos económicos del sistema en su conjunto; se investigan las funciones relativas de los diferentes tipos de central para satisfacer las necesidades de carga y la demanda de energía tanto presentes como futuras. Se estudia, en fin, la posibilidad de aplicar todas estas consideraciones a los problemas particulares de los países en vías de desarrollo.

Desde el punto de vista del sistema en su totalidad, se examina el coste de las centrales nucleares y clásicas en la India y se hacen comparaciones económicas entre series de centrales nucleares y clásicas. Se consideran en detalle tres sistemas concretos de producción de electricidad de la India, que son: el sistema de la región occidental, el de la región septentrional y el de la región meridional, en los que se instalarán de aquí a 1971 centrales nucleoeléctricas que totalizarán 1,2 millones de kilovatios. Los estudios muestran que estas centrales y otras que se construirán posteriormente podrían satisfacer la carga en base de estas regiones y también parte de las necesidades de energía con factores más bajos de utilización, y que el mejor rendimiento económico del sistema se obtendría aumentando progresivamente el número de centrales nucleares. En la memoria se deducen y formulan criterios, aplicables sobre todo a los países en vías de desarrollo, para estudiar la integración y función futura de las centrales nucleares en las redes eléctricas.

La incorporación de la energía nuclear al abastecimiento eléctrico español

por F. Pascual* y J. Molina**

El desarrollo industrial llevado a cabo por nuestro país, especialmente en los últimos años, ha hecho que la producción de energía eléctrica haya experimentado un incremento considerable. Dicha producción, en el período transcurrido entre 1949 y 1963, se ha multiplicado por un factor superior a cuatro ya que ha pasado de 5 742 GWh en el primero de los años citados a 25 750 GWh en 1963. Este incremento corresponde a una duplicación en un período de algo menos de 7 años, lo que representa un incremento anual medio acumulativo, mantenido a lo largo de 14 años, de 10,4%.

Si miramos al futuro encontramos que el Plan de Desarrollo Económico y Social aprobado por el Gobierno, y puesto en marcha el 1° de enero de 1964, prevé, durante su período de vigencia (1964–67), un incremento medio acumulativo de la producción de energía eléctrica de 11,5%.

Para cubrir las necesidades de producción de los años de vigencia del Plan, así como las del período siguiente, que también serán elevadas, como veremos más adelante, será necesario un aprovechamiento al máximo de los recursos energéticos nacionales tanto hidráulicos como de combustibles fósiles. Ahora bien, los recursos nacionales de este tipo son insuficientes, por lo que será necesario recurrir a centrales térmicas que quemen combustibles importados, normalmente fuel-oil producido en nuestras refinerías procedente de crudos importados, o a centrales nucleares, de acuerdo con lo que se considere más conveniente para el país.

En el informe estudiaremos la evolución de la producción de energía eléctrica prevista para el futuro. Partiendo de la situación actual de los medios de generación de energía eléctrica y de los incrementos que pueden esperarse en el futuro como consecuencia del aprovechamiento de los recursos nacionales, estableceremos el momento de incorporación de las centrales nucleares y, finalmente, teniendo en cuenta los problemas que esta incorporación plantea trataremos de establecer un programa de instalación de centrales nucleares hasta 1975, estudiando con más detalle los años 1970 y 1975.

DEMANDA DE ENERGÍA ELÉCTRICA Y DISPONIBILIDADES PARA CUBRIRLA

Situación actual

La potencia total instalada en España en 31 de diciembre de 1963 era de 8 400 MW de los cuales 5 898 MW (70,2%) corresponde a centrales hidráulicas y 2 502 MW (29,8%) a centrales térmicas. De estas últimas, 952 MW corresponden a centrales a bocamina y 1 550 MW a centrales ubicadas en centros de consumo, una parte de las cuales queman combustibles nacionales y otras, más numerosas, combustibles importados, concretamente fuel-oil.

De acuerdo con el criterio actual de explotación del sistema eléctrico español, la explotación de las centrales térmicas está supeditada a la de las hidráulicas. Este hecho, unido a la gran irregularidad de la hidraulicidad de nuestro país, hace que la utilización de las centrales, tanto hidráulicas como térmicas, sea muy variable. La de las primeras está impuesta por las disponibilidades de agua, y la de las segundas por su papel complementario. Así, en el año 1963, hidráulicamente húmedo, de los 25 750 GWh producidos, 21 330 GWh (82,8%) corresponden a centrales hidráulicas y únicamente 4 420 GWh (17,2%) a centrales térmicas que han trabajado, como puede apreciarse, con una utilización media muy baja [1].

A la vista de la situación anterior se comprende que en el futuro ha de variar la estructura del sistema español de producción de energía eléctrica. Por una parte, las centrales térmicas que queman combustibles nacionales han de tener una utilización más elevada y más regular si se desea, como se ha previsto en el Plan de Desarrollo Económico y Social, desarrollar el aprovechamiento de los combustibles nacionales, para lo que es imprescindible que su producción no esté sometida a las fluctuaciones actuales. Por otra, la incorporación de las centrales nucleares que, al menos inicialmente, requieren una elevada utilización, si han de resultar económicas, harán que hayan de seguirse criterios distintos a los actuales para explotar el sistema, como veremos posteriormente.

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Evolución de la generación de energía eléctrica

Hemos señalado anteriormente que la producción total de energía eléctrica en nuestro país alcanzó, en el año 1963, la cifra de 25 750 GWh, lo que representó un incremento del 12,4% con respecto a la del año anterior. A partir de esta cifra se ha determinado la evolución de la producción de energía eléctrica tomando, de acuerdo con las previsiones del Plan de Desarrollo Económico y Social, un incremento anual de 11,5% en el período 1964–1967. Respecto al período 1968–1975 se considera que, una vez alcanzado el consumo previsto para 1967, el ritmo de incremento descenderá hasta un 7,5% para 1975, lo que corresponde a un descenso del incremento de 0,5% al año. La tabla 1 da para cada año la producción y el incremento previsto respecto al anterior, aunque en este estudio vamos a ver con detalle la forma de cubrir estas necesidades de producción solamente en los años 1970 y 1975 a los que nos referiremos en lo que sigue.

Tabla 1. Previsiones de producción de energía eléctrica

Año	Incremento %	Producción prevista GWh
1963		25 750
1964	11,5	28 700
1965	11,5	32 000
1966	11,5	35 700
1967	11,5	39 800
1968	11,0	44 200
1969	10,5	48 800
1970	10,0	53 700
1971	9,5	58 800
1972	9,0	64 100
1973	8,5	69 500
1974	8,0	75 100
1975	7,5	80 700

Ahora bien, además de la demanda de la producción de energía tenemos que tener en cuenta la carga horaria máxima anual que requiere el consumo en cada uno de los dos años, 1970 y 1975, que vamos a considerar. Su cálculo se ha realizado en otro trabajo de los mismos autores [2] considerando la estructura del consumo en dichos años del mismo tipo que la actual. Los valores a que se ha llegado como carga horaria máxima anual han sido de 9 710 MW para el año 1970 y 14 600 MW para el año 1975.

Disponibilidades de energía eléctrica

La generación de energía eléctrica en nuestro país se efectúa, como hemos dicho, mediante centrales hidráulicas y centrales térmicas, dividiendo estas últimas en dos grupos: las que queman carbones nacionales y las que emplean combustibles importados. El criterio que vamos a seguir al establecer las disponibilidades en este trabajo, que es el generalmente admitido en nuestro país, consistirá en continuar poniendo en servicio las centrales hidráulicas que lo permitan económicamente, aprovechar al máximo los combustibles fósiles nacionales y cubrir el déficit, que veremos existe, mediante centrales térmicas que quemen combustible importado o mediante centrales nucleares, seleccionando lo más conveniente de acuerdo con las características de cada una de ellas.

Energía hidroeléctrica

De acuerdo con los programas de construcción de nuevos aprovechamientos hidroeléctricos en nuestro país, se prevé que en 31 de diciembre de 1970 habrá una potencia instalada de 10 900 MW, mientras que cinco años más tarde, es decir, en 31 de diciembre de 1975, se elevará a 12 500 MW, valor que puede considerarse en la actualidad como el límite superior de las posibilidades de aprovechamiento de los recursos hidroeléctricos de nuestro país, especialmente desde el punto de vista económico.

Con el criterio que se han equipado las centrales hidráulicas, es decir, para que puedan funcionar 3 000 horas en un año hidráulicamente medio (50% de probabilidad de presentarse), la potencia instalada podrá generar, en un año así, 32 700 GWh en 1970 y 37 500 GWh en 1975.

Ahora bien, hemos dicho que la hidraulicidad de nuestro país es muy variable, lo que nos obliga a tenerla en cuenta, aunque su influencia en la explotación del sistema vaya disminuyendo a medida que disminuya la proporción de centrales hidráulicas a térmicas, al ir agotándose los recursos hidroeléctricos. En estas condiciones, si el año es hidráulicamente seco, se ha supuesto una utilización anual de 2 500 horas mientras que si fuese húmedo se suponen 3 300 horas, bien entendido que pueden presentarse años con una utilización fuera de este intervalo, pero la probabilidad de que esto ocurra es pequeña.

Tomando las horas de utilización señaladas, la producción de energía, en GWh, en los años considerados sería:

	1970	1975
Año seco :	27 250 GWh	31 250 GWh
Año húmedo :	35 970 GWh	41 250 GWh

Por lo que se refiere a las disponibilidades en potencia se ha estimado que el factor de disponibilidad hidroeléctrica en año seco correspondiente a la hora más cargada del año es 0,5 para el año 1970 y 0,55 para el año 1975, lo que nos da como potencias hidroeléctricas disponibles en la hora de máxima carga anual 5 450 MW y 6 875 MW respectivamente para 1970 y 1975.

Energía térmica con combustibles nacionales

El estudio realizado en el trabajo citado anteriormente, de los mismos autores [2], a partir de los datos de la Comisión de Distribución del Carbón, da como resultado que las disponibilidades máximas de combustibles sólidos nacionales para su utilización en centrales termoeléctricas permitirán generar, en los años 1970 y 1975, 13 400 y 16 700 GWh respectivamente.

Si se considera una utilización anual media de 5 000 horas, las potencias de estas centrales en 31 de diciembre de los años que estudiamos, 1970 y 1975, serán 2 680 y 3 340 MW respectivamente. La utilización media anual supuesta es muy superior a la actual pero se ha considerado la más conveniente, dada la función que estas centrales han de realizar como consecuencia de la variación de los criterios de explotación del sistema eléctrico y del máximo aprovechamiento de los combustibles fósiles nacionales.

En el caso de estas centrales se ha considerado un factor de disponibilidad termoeléctrica correspondiente a la hora más cargada del año de 0,85 en ambos casos, es decir, tanto para 1970 como para 1975. Por consiguiente la potencia termoeléctrica disponible de las centrales que queman combustibles nacionales será de 2 280 MW y 2 840 MW para 1970 y 1975 respectivamente.

Balances de energía y de potencia

Las tablas 2 y 3 nos dan los balances en energía eléctrica y en potencia disponible para los años 1970 y 1975. El déficit en energía eléctrica para un año hidráulicamente medio es de 7 600 y 26 500 GWh respectivamente, mientras que el déficit en potencia disponible es de 1 980 y 4 885 MW. Suponiendo que este déficit se cubre mediante centrales que quemen combustible importado o centrales nucleares, este déficit de potencia disponible requerirá, tomando un factor de disponibilidad de 0,85 para ambos tipos, unas potencias instaladas de 2 330 y 5 745 MW para los años 1970 y 1975 respectivamente.

La utilización de estas potencias, suponiendo que los años 1970 y 1975 fueran hidráulicamente medios, serían de 3 260 y 4 610 horas respectivamente. Ahora bien, como veremos a continuación, en 1970 habrá ya centrales nucleares en explotación con una potencia de 450 MW que, por sus características económicas, será conveniente tengan un gran factor de utilización (del orden de 7 000 horas). Esto hará que el resto de la potencia térmica instalada (1 880 MW) haya de utilizarse únicamente 2 330 horas, cifra todavía superior a la utilización media de las centrales térmicas españolas en 1963 que ha sido de 1 800 horas. En el año 1975, aunque, como veremos, habrá aumentado considerablemente la potencia nuclear instalada, no habrá problema alguno ya que, como hemos visto, la utilización media del conjunto de centrales térmicas con combustible importado y centrales nucleares será de 4 610 horas y, por otra parte, estas últimas podrán explotarse económicamente con utilizaciones inferiores.

Tabla 2. Balance de energía eléctrica

Disponibilidades de energía GWh	Año 1970	Año 1975
Hidroeléctrica	32 700	37 500
Termoeléctrica combustible nacional	13 400	16 700
Total disponibilidades	46 100	54 200
Necesidades	53 700	80 700
Diferencia año medio	7 600	26 500
año seco	13 050	32 750
año húmedo	4 330	22 750

INCORPORACIÓN DE LA ENERGÍA NUCLEAR

En los momentos actuales podemos señalar que España ha tomado la decisión de incorporar la energía nuclear al abastecimiento eléctrico español. Existe un programa, enunciado en diciembre de 1962, a realizar en 10 años, para la construcción de tres centrales nucleares, con una potencia unitaria

Tabla 3. Balance de potencia disponible

Clase de energía	Potencia instalada MW 1970	Potencia instalada MW 1975	Factor de disponibilidad 1970	Factor de disponibilidad 1975	Potencia disponible MW 1970	Potencia disponible MW 1975
Hidroeléctrica	10 900	12 500	0,5	0,55	5 450	6 875
Termoeléctrica combustibles nacionales	2 680	3 340	0,85	0,85	2 280	2 840
Totales	13 580	15 840			7 730	9 715
Carga horaria máxima anual	—	—			9 710	14 600
Diferencias	2 330	5 745	0,85	0,85	1 980	4 885

de 300 MW, la primera de las cuales podrá entrar en explotación a finales de 1969 y las dos restantes defasadas 18 meses aproximadamente. El Gobierno ha dado la autorización provisional para la primera a la Compañía NUCLENOR y otra Compañía (CENUSA) ha presentado solicitudes para las dos restantes. Por otra parte, Unión Eléctrica Madrileña, una de las Compañías que abastecen de energía eléctrica a Madrid, cuenta con la autorización provisional, y está en trámites la concesión de la definitiva, para la construcción de una central del tipo de agua a presión de 150 MW, central que ya ha sido adjudicada a la Compañía americana Westinghouse y se espera esté en explotación a finales de 1967. Esto hará que, como decíamos anteriormente, en 1970 se cuente con una potencia nuclear instalada de 450 MW.

Consideraciones para el establecimiento del programa nuclear

Ahora bien, el establecimiento de este programa nuclear, recogido posteriormente en el Plan de Desarrollo Económico y Social, responde a una situación que se presenta en nuestro país y cuyos puntos fundamentales vamos a analizar a continuación.

Coste del combustible

España es un país con un coste del combustible elevado aunque se presentan diferencias considerables de unas zonas a otras. Si tomamos como base los costes de explotación de las centrales térmicas en el año 1963, encontramos que únicamente en tres centrales que queman carbón, instaladas a bocamina (que representan el 18% de la potencia térmica total instalada), la contribución del coste del combustible al precio del kWh está comprendido entre 0,195 y 0,27 ptas/kWh (3,25 y 4,5 mills/kWh) con unos valores del millón de kcal de 59,50 a 71,50 ptas. (25–30 centavos de $\$/10^6$ Btu), mientras que existen otras (un 17% aproximadamente de la potencia térmica instalada) para las cuales el coste del ciclo del combustible ha sido superior a 0,54 ptas/kWh (9 mills/kWh) con 155 ptas. por millón de kcal (65 centavos de $\$/10^6$ Btu). Si nos referimos a las centrales que queman combustible importado, es decir, a las centrales que queman fuel-oil, encontramos que la participación del combustible al precio del kWh es del orden de 0,36 ptas/kWh (6 mills/kWh) y el valor del millón de kcales de 128 ptas. (54 centavos de $\$/10^6$ Btu). Si no tenemos en cuenta los impuestos sobre el fuel-oil, dichas cifras quedarían reducidas a 0,275 ptas/kWh (4,6 mills/kWh) y 98 ptas/10^6 kcal (42 centavos de $\$/10^6$ Btu). Finalmente, si tomamos las medias ponderadas del conjunto de las centrales térmicas españolas, tanto las que queman combustible nacional como importado, con una potencia de 30 MW o superior, encontramos unos valores de 126 ptas/10^6 kcal (53 centavos de $\$/10^6$ Btu) y una participación del combustible al precio del kWh de 0,426 ptas/kWh (7,1 mills/kWh).

Los datos anteriores indican que, salvo en muy pocos casos (tres únicamente), los combustibles nacionales son caros y lo mismo sucede con el fuel-oil importado. En estas condiciones, en una central térmica moderna que queme fuel-oil instalada en España, la participación del combustible al coste de la energía no será inferior a 0,28–0,30 ptas/kWh (4,6–5 mills/kWh).

Si consideramos que para las primeras centrales nucleares que entren en explotación en nuestro país podemos considerar costes del combustible del orden de 0,075 ptas/kWh (1,25 mills/kWh) para las centrales de uranio natural grafito-gas y 0,134 ptas/kWh (2,23 mills/kWh) para las de uranio enriquecido de agua ligera, se comprende perfectamente que el coste del ciclo de combustible haya sido uno de los factores que se han tenido en cuenta en nuestro país para iniciar la construcción de centrales nucleares ya que, aunque la inversión sea superior, el margen que existe en la diferencia del ciclo del combustible puede compensar, como veremos más adelante, la diferencia en inversión.

Disponibilidades de uranio

Otro factor que se ha tenido en cuenta al establecer el programa nuclear ha sido las disponibilidades de uranio. España cuenta con yacimientos de uranio con unas reservas totales, en este momento, del orden de las 10 000 toneladas de U_3O_8 contenido y con unas brillantes perspectivas [3], cantidad suficiente para iniciar un programa de instalación de centrales nucleares. Por el contrario, hemos visto que la producción de combustibles fósiles en España es insuficiente para cubrir nuestras necesidades y es necesario recurrir a importar crudos de petróleo para la obtención de fuel-oil. Ahora bien, contando con uranio al plantearse el problema de cubrir el déficit energético con centrales que quemen fuel-oil o con centrales nucleares, un punto a considerar es la utilización de los recursos uraníferos españoles con su repercusión en la balanza de pagos.

Si consideramos la situación en el año 1975, supuesto como año hidráulicamente medio, hemos visto que el déficit de energía es de 26 500 GWh; esto representaría la necesidad de importar crudos de petróleo para la obtención de fuel-oil, por un valor de 66,5 millones de $, y esto en el caso más favorable, pues todavía podría suceder que esta cifra se aumentase si en vez de importar solamente crudos de petróleo fuera necesario importar fuel-oil. Por el contrario, si suponemos que el 50% de este déficit de energía se cubre mediante centrales que quemen fuel-oil y el 50% restante mediante centrales nucleares, las necesidades de divisas para cubrir ese déficit se reducen a unos 37 millones de $, suponiendo que, al contar con el uranio español, se gaste en pesetas el 95% del coste del ciclo del combustible de las centrales de uranio natural y el 75% de las correspondientes a las centrales de uranio enriquecido.

Vemos pues que la incorporación de las centrales nucleares al abastecimiento energético español puede representar un ahorro de divisas del orden de los 30 millones de $ para el año 1975, ahorro que será considerablemente mayor en años posteriores, como consecuencia de una mayor utilización de los recursos nacionales.

Coste total de la energía

Ahora bien, a pesar de lo expuesto en los dos puntos anteriores, sería discutible la instalación de centrales nucleares si el coste total de la energía generada en dichas centrales fuese superior a la generada en centrales térmicas clásicas. Los datos que hemos dado al hablar del coste del combustible en relación con el precio del mismo en nuestro país dan una primera indicación de que esta situación es muy poco probable. Si consideramos:

i) un coste del combustible en una central térmica clásica moderna, que queme combustible importado, de 0,276 ptas/kWh (4,6 mills/kWh) de acuerdo con lo indicado,

ii) unos costes del ciclo del combustible para las centrales nucleares, de acuerdo también con lo indicado, de 0,075 ptas/kWh (1,25 mills/kWh) para las de uranio natural grafito-gas, y 0,134 ptas/kWh (2,23 mills/kWh) para las de agua ligera y uranio enriquecido,

iii) unos gastos de mantenimiento de 0,042 ptas/kWh (0,7 mills/kWh) para las centrales de uranio natural, 0,036 ptas/kWh (0,6 mills/kWh) para las de uranio enriquecido y 0,024 ptas/kWh (0,4 mills/kWh) para las térmicas clásicas y

iv) unas cargas fijas de 14% y una potencia unitaria de la central de 300 MW con una utilización de 7 000 horas,

para obtener el mismo coste total de la energía será necesario que la inversión por kW de las centrales de uranio natural grafito-gas, y la de las centrales de agua ligera con uranio enriquecido sea, respectivamente, 9 150 ptas/kW (152,5 $/kW) y 6 510 ptas/kW (108,5 $/kW), superior a la inversión por kW correspondiente a las centrales térmicas clásicas. En la realidad estas diferencias son superiores a las que existen actualmente en ofertas para la construcción de centrales, especialmente por lo que se refiere a las centrales nucleares de agua ligera. Como consecuencia, en las condiciones indicadas, el coste total de la energía producida será inferior en las centrales nucleares que en las centrales térmicas.

En este sentido es interesante señalar un caso concreto: la central de Unión Eléctrica Madrileña, suministrada por Westinghouse para una potencia de 150 MW, tendrá una inversión de unas 12 000 ptas/kW (200 $/kW) con una diferencia del orden de 3 600 ptas/kW (60 $/kW) con relación a una térmica clásica de la misma potencia. Si además en este caso consideramos que la zona que ha de abastecer la central (Madrid) no tiene combustibles fósiles, lo que obligaría a ubicar la central más lejos del centro de consumo, se comprende la decisión de la compañía de recurrir a la solución nuclear.

Aunque en ningún momento hemos considerado la competencia entre las centrales nucleares y las centrales térmicas que quemen combustible nacional, la situación en ese caso sería todavía más favorable para las centrales nucleares excepto comparándolas con centrales a bocamina instaladas en zonas de combustible barato que, como hemos visto, representan un pequeño tanto por ciento de la capacidad total de producción de combustibles.

Problemas que plantea la incorporación de las centrales nucleares

La experiencia actual en la explotación de centrales nucleares indica que la incorporación de éstas a una red eléctrica existente no presenta problemas importantes. Desde el punto de vista eléctrico esta incorporación se realiza perfectamente; sin embargo, vamos a señalar algunas de las cuestiones que, en este u otros aspectos, pueden plantearse y que pueden ser las más importantes para nuestro país.

Utilización y tamaño de la central

Hemos visto anteriormente que para que la central nuclear sea económica es necesario que su utilización sea grande. Por otra parte, esta economía se mejora también al aumentar el tamaño de la central. Por consiguiente, el criterio en la instalación de centrales nucleares será el construirlas del mayor tamaño posible, dentro de las condiciones de la red eléctrica a que han de abastecer, y utilizarlas el mayor número de horas. Esta condición obliga a estudiar la explotación del sistema cuidadosamente con objeto de fijar la capacidad nuclear que éste puede absorber funcionando en base. En el caso de nuestro país se ha establecido como potencia unitaria para las centrales nucleares en la primera fase del programa la de 300 MW, y no se considera existan problemas, como veremos al tratar de la explotación del sistema eléctrico, para que estas primeras centrales puedan funcionar 7 000 horas.

Inversiones

La inversión por kW instalado de una central nuclear es superior a la correspondiente a una central térmica clásica. Esta mayor inversión puede dar lugar a algunos problemas de financiación en países en vías de desarrollo. Sin embargo, en el caso español este problema se ha previsto dentro del conjunto del Plan de Desarrollo Económico y no se considera pueda ser un motivo que retrase la instalación de centrales nucleares.

Tecnología nueva

Las centrales nucleares representan una nueva tecnología que es preciso desarrollar y para la cual es necesario preparar el personal adecuado, tanto por lo que se refiere al proyecto como a la fabricación de equipo, construcción de la central y futura explotación de la misma. El esfuerzo hecho por nuestro país a través, fundamentalmente, de la Junta de Energía Nuclear, hace que en estos momentos se pueda contar con un plantel de personal preparado capaz de abordar dichos problemas. Este esfuerzo, no sólo en la preparación de personal sino también en el desarrollo de técnicas, hace que pueda afirmarse que la participación de la industria española en la construcción de centrales nucleares, así como en el suministro del combustible, podrá ser superior a la correspondiente a las centrales térmicas clásicas.

En la incorporación de las centrales nucleares existe también un factor que es necesario tener en cuenta: el de la seguridad, con todos los problemas técnicos que lleva consigo el reducir a un mínimo las probabilidades de que pueda ocurrir un accidente e incluso, si este ocurre, que las consecuencias del mismo sean mínimas. Por otra parte, será necesario resolver también las cuestiones jurídicas referentes a la responsabilidad civil en caso de que dicho accidente ocurra y afecte a personas o propiedades.

Finalmente, hemos de señalar que la incorporación de las centrales nucleares presentan también otro tipo de problemas nuevos en relación con el combustible quemado, como son el transporte de combustibles irradiados y su tratamiento, el almacenamiento de los residuos radiactivos, etc. Todos estos problemas será necesario considerarlos, y así se ha hecho al establecer el programa nuclear, pero no han de retrasar la realización del mismo.

Consideraciones sobre el tipo de centrales

Iniciado ya el programa nuclear y establecidas las bases para la primera fase del mismo que comprende la construcción de la central de 150 MW, de la que hemos hablado, y de tres centrales de 300 MW, es lógico que al tratar de seleccionar los tipos más convenientes se consideren únicamente las centrales que podemos denominar probadas, es decir, centrales que cuenten con una experiencia, tanto en el proyecto como en la construcción y explotación de las mismas, que permita pueda basarse en ellas, con garantías, el abastecimiento eléctrico del país.

Esto hace que para toda la primera fase del programa se hayan tenido en cuenta únicamente los dos grandes grupos que han alcanzado la madurez técnica y económica, es decir, las centrales alimentadas mediante un reactor moderado por grafito y refrigerado por gas que emplea uranio natural como combustible y las centrales provistas de un reactor moderado y refrigerado por agua ligera con uranio enriquecido como combustible en sus dos versiones de agua a presión y agua en ebullición.

Establecida la competencia entre estos dos tipos, la segunda consideración corresponde a seleccionar entre ellos cuál es el más conveniente para llenar las necesidades del programa por lo que se refiere a las 3 grandes centrales de 300 MW, ya que la de 150 MW, por su potencia, hace que desde el punto de vista económico se hayan considerado únicamente las centrales de agua ligera dentro de las cuales se ha seleccionado, mediante concurso, el tipo de agua a presión. Al contar España con yacimientos de uranio y no poder pensar en instalaciones de difusión gaseosa, es lógico que las preferencias estén dirigidas hacia el empleo de centrales de uranio natural, incluso en el caso de que el coste de la energía resultante fuese ligeramente superior, ya que las ventajas, de todos conocidas, del empleo de dicho combustible, podrían compensar esta pequeña diferencia. Ahora bien, la selección final del tipo más adecuado parece lógico hacerla frente a ofertas concretas que permitan establecer claramente una comparación valorando las ventajas e inconvenientes de cada tipo.

Por lo que se refiere a la segunda parte del programa, es decir, las centrales que hayan de instalarse entre los años 1972 y 1975, es lógico suponer que se considere la competencia de otros tipos, especialmente de aquellos actualmente en desarrollo, que permitan una mayor utilización del combustible. Dichas centrales se espera que alcancen, en el período considerado, unas características económicas comparables con las centrales actuales, pero el hecho de permitir alcanzar unos factores de conversión más elevados y, por consiguiente, un mejor aprovechamiento del combustible, tanto en lo que se refiere al inventario como al consumo, las hará más atractivas.

Dentro de estas centrales, el grupo tecnológicamente más avanzado es el de las centrales moderadas por agua pesada con uranio natural como combustible y con distintos refrigerantes. Dentro de esta línea España trabaja en el desarrollo de un prototipo moderado por agua pesada y refrigerado por un líquido orgánico con una potencia de 30 MW(e) y al que se refiere otro trabajo de esta Conferencia [4]. Si los resultados que se obtengan están de acuerdo con las perspectivas actuales es probable que, al menos, parte de las centrales que se instalen entre 1972 y 1975 sean de este tipo.

EXPLOTACIÓN DEL SISTEMA ELÉCTRICO

Hemos visto ya cómo podría explotarse el sistema eléctrico en el año 1970 si éste fuese hidráulicamente medio partiendo de una potencia instalada nuclear de 450 MW que, de acuerdo con el programa que hemos establecido, será la que corresponda a dicha fecha.

Tabla 4. Explotación del sistema eléctrico español en 1970

	Año medio	Año seco	Año húmedo
Déficit de energía, GWh	7 600	13 050	4 330
Déficit de potencia, MW	2 330	2 330	2 330
i) Centrales nucleares			
Potencia instalada, MW	450	450	450
Utilización horas/año	7 000	7 000	7 000
Energía generada, GWh	3 150	3 150	3 150
ii) Centrales combustible importado			
Potencia instalada, MW	1 880	1 880	1 880
Energía generada, GWh	4 450	9 900	1 180
Utilización horas/año	2 360	5 250	630

Tabla 5. Explotación del sistema eléctrico español en 1975

	Año medio	Año seco	Año húmedo
Déficit de energía, GWh	26 500	32 750	22.750
Déficit de potencia, MW	5 745	5 745	5 745
i) Centrales nucleares			
Potencia instalada, MW	2 250	2 250	2 250
Horas de utilización	7 000	7 000	7 000
Energía generada	15 750	15 750	15 750
ii) Centrales combustible importado			
Potencia instalada	3 495	3 495	3 495
Energía generada	10 750	17 000	7 000
Horas de utilización	3 070	4 860	2 000

La tabla 4 nos da la explotación del sistema en 1970 para los tres casos que hidráulicamente pueden presentarse: año medio, seco o húmedo. Se aprecia que, como en dicho año la potencia hidráulica instalada representa todavía un 68,5% de la total, la hidraulicidad del año tiene una gran influencia sobre la utilización de las centrales que queman combustible importado, ya que se ha seguido el criterio de mantener constante la utilización de las centrales que queman combustible nacional y de las centrales nucleares. En estas condiciones, la utilización de dichas centrales en año húmedo sería únicamente de 630 horas, valor muy bajo que podría incrementarse reduciendo ligeramente la utilización de las térmicas de combustible nacional o de las nucleares, o también, dedicando el sobrante a la exportación.

Por lo que se refiere al año 1975, se ha supuesto en él una potencia nuclear instalada de 2 250 MW fijada con el criterio de que las centrales que queman combustible fósil importado funcionen aproximadamente 3 000 horas en año hidráulicamente medio. Esto representa un incremento de 1 800 MW entre 1970 y 1975 y corresponde a las dos centrales de 300 MW que hemos señalado del primer programa y a 1 200 MW distribuidos en 3–4 centrales para entrar en explotación los años 1973, 1974 y 1975.

La tabla 5 nos da la explotación del sistema en 1975 en las tres condiciones de año medio, seco y húmedo y con los mismos criterios señalados anteriormente. Como en esta fecha la proporción de potencia hidráulica instalada en relación con la total habrá disminuido hasta el 58%, tiene menor influencia la hidraulicidad del año sobre la utilización de las centrales de combustible importado que, incluso en año húmedo, alcanzarían una utilización de 2 000 horas.

El esquema que hemos establecido presenta una variación considerable en relación con la explotación actual y se funda en una mayor contribución de las centrales hidráulicas, con grandes embalses, para cubrir las puntas de los diagramas de carga. En estas condiciones, se comprende que podría incrementarse la utilización de las centrales que queman combustible importado reduciendo su potencia para la misma generación de energía, cubriendo esta diferencia en potencia mediante un sobreequipado de las centrales hidráulicas provistas de grandes embalses. Otra solución sería recurrir a instalaciones de bombeo. Es muy probable que en los años considerados el sistema eléctrico español haya incorporado estas soluciones, mejorándose de esta forma las utilizaciones señaladas en las tablas 4 y 5.

CONCLUSIONES

La demanda de energía eléctrica en nuestro país crece a un ritmo elevado y los recursos nacionales en energía hidráulica y combustibles fósiles son insuficientes para cubrirla. Por tanto, es necesario recurrir a la importación de combustibles o a la instalación de centrales nucleares.

El combustible fósil, tanto nacional como de importación, es caro; por otra parte, España dispone de reservas de uranio y la energía eléctrica de origen nuclear puede competir con la procedente de centrales térmicas para elevadas utilizaciones. Esto ha hecho que se haya establecido un programa de instalación de centrales nucleares para que cubra, al menos, parte de este déficit. Se prevé que en 1970 España contará con una potencia instalada de 450 MW en centrales nucleares, potencia que se elevará a 2 250 MW en 1975.

Se ha establecido el criterio de aprovechar al máximo los recursos hidroeléctricos y los recursos nacionales de combustibles fósiles (las centrales de este tipo funcionarán 5 000 horas al año). Si para las centrales nucleares se establece una utilización de 7 000 horas, las centrales térmicas que queman combustible importado habrán de absorber las variaciones de hidraulicidad.

En condiciones de año húmedo, la utilización de las centrales que queman combustible importado puede ser baja, especialmente, en los primeros años en que la potencia hidroeléctrica representa un elevado porcentaje de la total instalada. Esta utilización se puede mejorar sobreequipando algunas centrales hidráulicas de grandes embalses o mediante centrales de bombeo.

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ABSTRACT - RÉSUMÉ - АННОТАЦИЯ - RESUMEN

A/863 Spain

The incorporation of nuclear energy into the Spanish power network

By F. Pascual and J. Molina

Spain is subjected to a fast rate of increase in electrical energy consumption, which has doubled in the last seven years. The hydroelectric resources, today representing 75 per cent of the total production, have progressively been depleted. Domestic fossil fuels are costly and their production is insufficient to cover the needs of electrical energy production through thermal stations. Imported fuel, generally crude oil, is needed to fill the gap.

Arising from this basic situation, the incorporation of nuclear stations into the Spanish electrical system has been studied, taking especially into account the competition with thermal stations which burn imported fossil fuels. In this paper, the structure of the Spanish electrical network is considered, especially with reference to the size of the nuclear stations and their utilization factor. The programme of installation of nuclear power plants in Spain is indicated, based on the applications submitted by the utilities and the general lines established by the Government, and the necessary investment and the possible participation of Spanish industry are also analysed.

A/863 Espagne

Intégration de l'énergie nucléaire dans le réseau électrique espagnol

par F. Pascual et J. Molina

L'Espagne connaît une augmentation rapide de la consommation d'énergie électrique. Cette dernière a doublé au cours des sept dernières années. On sait que les ressources hydroélectriques, qui représentent en ce moment 75% de la production totale, vont s'épuiser peu à peu. D'autre part, les combustibles fossiles sont chers et leur production insuffisante pour faire face aux besoins de production d'énergie électrique par des centrales thermiques. Il faudrait recourir à un combustible importé, en général du pétrole brut, pour faire face aux besoins.

On a donc étudié l'intégration de centrales nucléaires dans le réseau électrique espagnol, en tenant compte, en particulier, de la compétitivité avec les centrales thermiques qui brûlent du combustible importé. Cette étude tient compte de la structure du système électrique espagnol et, en particulier, de la puissance unitaire des centrales nucléaires et du nombre d'heures d'utilisation de ces centrales.

On indique le programme d'installation de centrales nucléaires en Espagne en fonction des demandes des compagnies électriques et des plans établis par le gouvernement; on analyse les investissements correspondants ainsi que les possibilités de participation de l'industrie espagnole.

A/863 Испания

Включение атомных электростанций в общую энергосистему Испании

Ф. Паскуаль, Х. Молина

В Испании наблюдается быстрый рост потребления электроэнергии. За последние семь лет оно возросло в два раза. Гидроэнергетические ресурсы, за счет которых в настоящее время производится 75% общего количества полученной электроэнергии, постепенно истощаются. Ископаемые виды топлива стоят дорого, и его не хватает для покрытия потребностей в электроэнергии, производимой на тепловых электростанциях. Для удовлетворения потребностей необходимо импортировать топливо, главным образом сырую нефть.

В связи с таким положением был изучен вопрос о включении атомных электростанций в энергетическую систему Испании; при этом особенно учитывалась их конкурентоспособность по сравнению с тепловыми электростанциями, работающими на импортном ископаемом топливе. В данном докладе рассматривается структура энергосистемы Испании, при этом особое внимание уделяется мощности атомных электростанций и коэффициенту их использования. Рассматривается программа строительства атомных электростанций в Испании на основе заявок, представленных предприятиями коммунального энергоснабжения, и в соответствии с общим курсом, установленным правительством. Анализируются также необходимые капитальные вложения и возможное участие испанской промышленности.

Analysis of capital costs for nuclear power plants

By P. H. G. Spray, H. B. Merlin,* L. R. Haywood,** J. L. Olsen and J. O. Holt***

Nuclear power technology has advanced rapidly since the Second Geneva Conference in 1958. In fact, in some parts of the world, nuclear generating stations now set the competitive level for additional base-load generating equipment. There is little doubt that this trend will continue at an accelerating rate; hence more and more utilities will be faced with the problem of evaluating various proposals for new generating units. The choices may include different types of nuclear, fossil-fired or hydroelectric units.

Evaluations are usually based on comparisons of total estimated unit-energy cost (in mills **** per kilowatt-hour) for the various plants. Total unit-energy costs are built up from estimates of three cost components: fixed capital charges, fuelling costs, and operating and maintenance costs. From the viewpoint of the best long-term system economics it is essential that utility planners have available to them detailed knowledge of these cost components, so their evaluation can be made on a known basis acceptable to the utility.

For the Canadian heavy-water reactor, fuelling costs are relatively small and easily calculated. For large units, operating and maintenance costs are an even smaller proportion and can be estimated easily and accurately. Capital charges account for the main component of unit-energy cost, so it is important that these be properly identified for the purposes of comparison.

Much valuable experience has been gained in Canada through construction of the NPD and Douglas Point stations and the cost accounting procedures employed in these projects are being used with full confidence for other later projects.

The purpose of this paper is to outline the system of accounts used in Canada for costing nuclear power plants, and to identify the items included (or not included) in the capital-cost estimates, as illustrated by reference to a typical breakdown of costs for large two-unit stations. In addition the relative distribution is presented of three important categories of cost for the first 200 MW single-unit station in Canada (Douglas Point).

It is hoped that this information will prove of value to those responsible for analysing capital costs of nuclear power plants and for comparing them with other schemes on an equitable basis.

SYSTEMS OF ACCOUNTS

A detailed system of accounts is essential to ensure a complete and accurate estimate. Several ways to break down the accounts can be considered, e.g., grouping according to operating functions, grouping according to physical location of equipment and grouping according to type of work and/or equipment. The system of accounts developed for the Canadian nuclear power projects is divided according to operating functions. The eight major groups are sub-divided systematically so that each subject is generally represented by five digits. For cost accounting, suffixes are allocated to show the type of expense—permanent material, engineering, site labour, inspection and commissioning. In addition to being used for organizing the estimate and later for cost accounting, the system of uniform subject index (USI), as it is known, is used for filing correspondence, numbering drawings and coding equipment. By providing a complete index in all phases of the project, it minimizes the possibility of costs being overlooked and achieves proper correlation of costs with the estimates.

ANALYSIS OF CAPITAL-COST ESTIMATES

Typical estimate breakdowns, in 1963 dollars, for two-unit stations, scheduled for completion one year apart, are shown in Table 1. The items of expense which are included in the estimates are discussed in the following paragraphs.

Site and improvements

This category includes the property, access and station roads, clearing and other improvements to the property, physical and political geographic investigations of the site and any necessary improvements to existing transportation facilities for unloading heavy components. The last cost item may be incurred off-site, e.g., for Douglas Point this consists of a short rail siding on the main rail line,

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**** Unless otherwise stated, all costs in this paper are given in Canadian currency: 1 mill = $ 10^{-3}.

Table 1. Capital-cost estimates for two-unit stations[a]

Item	Investment capital, $$10^3$			
	2 × 200 MW(e)	2 × 250 MW(e)	2 × 300 MW(e)	2 × 500 MW(e)
Site and improvements	850	850	900	900
Buildings and structures	10 980	12 670	13 700	15 830
Reactor boiler and auxiliaries[b]	23 000	24 500	26 860	42 000
Turbine generator and auxiliaries	14 400	17 750	21 000	36 000
Electrical power systems	5 200	6 100	6 750	8 000
Instrumentation and control	5 700	6 200	6 500	6 850
Common processes and services	5 500	6 000	6 200	7 900
Construction plant	2 500	2 500	2 500	2 800
Sub-total	68 130	76 570	84 410	120 280
Heavy water	16 876	18 800	21 700	32 800
Fuel (½ charge)	3 321	3 970	4 570	5 200
Sub-total	88 327	99 340	110 680	158 280
Engineering	8 750	9 850	10 600	11 500
Construction administration	1 340	1 400	1 500	1 700
Commissioning and training	4 000	4 000	4 200	4 200
Purchasing, accounting and inspection	2 500	2 500	2 630	2 900
Sub-total	104 917	117 090	129 610	178 580
Interest during construction	9 130	11 370	13 110	19 260
Contingency	12 200	14 100	15 800	22 200
Total investment capital	126 247	142 560	158 520	220 040

[a] Spares and warranty are included with the appropriate systems.

[b] Excludes D_2O and fuel.

30 km from the station site. The cost of the gantry crane for unloading the equipment is included elsewhere. In general, site costs are independent of the station type.

Buildings and structures

This category includes the structural and civil works for all the buildings required for operation and maintenance of the plant, intake and outfall structures (including installation and removal of the cofferdam), the stack, and all shielding, trims, finishes and linings for these structures. The buildings are essentially functional in design with minimum architectural treatment. Any significant increase in architectural treatment will add directly to the capital costs. The electrical and mechanical costs associated with all these permanent buildings are included with the electrical-systems and common-processes costs respectively. Costs of temporary construction buildings are included in the construction plant category.

Reactor/boiler and auxiliaries

This item includes the equipment required to convert the feedwater into steam and to supply this steam to the turbine stop valve. All auxiliary equipment specifically associated with the reactor/boiler system is included. Equipment and systems common to other processes, e.g., instrumentation, are not included. Only that shielding forming an integral part of the reactor component complex is included under this category. The systems and machines for handling and storing new and spent fuel are included. No facilities are provided on the station for detailed inspection of spent fuel; however, a shipping flask is included so that damaged fuel may be shipped off-site for inspection if necessary. The spent-fuel storage bay in the service building has ample capacity to handle fuel discharged from the station over its operating life, so there is no necessity to provide shipping facilities for off-site storage or processing. Special maintenance and replacement equipment, and tools associated with core component maintenance, e.g., removal and replacement of coolant-tube assemblies, are included in this category, but general maintenance equipment, such as lathes, is included under common processes and services. Items associated with containment, such as dousing systems, are also included here. The reactor/boiler and auxiliary account includes a heavy-water upgrading column.

The detailed engineering of nuclear components is charged to the nuclear engineering account rather than to the cost of the product. Compared to other components the nuclear components include a larger allowance in the price for the development of the manufacturers' new techniques. Examples of such allowances would be those for weld procedures, tube-rolling procedures and machining methods to meet the special requirements of the equipment specifications. Charges incurred in manufacturing and testing the prototypes and in carrying out fundamental studies such as wear and friction of materials however are not included.

Turbine-generator and auxiliaries

This includes the complete turbine-generator and ancillary equipment, the condensing systems and the feedwater system. This portion of the station has cost items similar to those for a fossil-fired station.

Electrical power systems

This includes the main power output system, station service power system and auxiliary systems such as lighting, cable runs and insulating oil systems. The output system includes all equipment in the circuit from the output terminal of the generator to the high-voltage transmission-line bushings including bus duct, transformers, switchgear and switchyard structures. The transmission line is not included in the estimates. All motors are included in the driven equipment costs but cabling up to the motor terminals is included with electrical power systems.

Instrumentation and control

This includes instrumentation and control for all systems and equipment. Factory-mounted instruments on certain equipment such as fuelling machines, diesel generators and cranes are included in the related equipment. Almost one million dollars of the totals in Table 1 for instrumentation and control is associated with equipment or functions common to a fossil-fired station such as communications, annunciation, fire alarms, electrical power systems relaying, turbine-generator and auxiliaries instrumentation. The majority of the costs for the nuclear portion of the plant is associated with monitoring the condition of the coolant in each channel of the reactor. The degree of automation desired in the operation of the station also affects the instrumentation and control costs. In the estimates, certain allowances are made for data handling and station control by computers.

Common processes and services

This includes all water and sewage systems, heating and ventilation, compressed-gas services, cranes, hoists and monorails for material handling, maintenance shops and equipment, waste-management systems and miscellaneous equipment and furnishings for the chemical control laboratory, lunch room, change room, first-aid room and radiation hazards control. Miscellaneous services such as painting and insulating of equipment and piping are also included. An allowance is made for a gantry crane at the rail siding for unloading heavy components.

Construction plant

This category includes all temporary construction buildings and services, their operation and maintenance, the purchasing or renting of construction tools, equipment and services.

Heavy water

The heavy-water inventory is the largest single item of expense for the station. It follows, therefore, that the final capital costs will be quite sensitive to the price paid for it. The price in effect when the Douglas Point project was initiated, \$(US)61.75/kg, has fallen to a current price of \$(US)54.00/kg and will be \$(Can)45.20/kg when the Canadian plant is in production. This last figure, being more representative of the cost for future stations, is the value used in Table 1. Since the unit material cost is high it is also important that the inventory be carefully assessed for each station. The allowances shown in the estimates are sufficient to cover all hold-ups at operating temperatures in the core, pipes, collection systems, heat exchangers, tanks and valves. The allowances also provide for an operation reserve of about 3% of the total inventory.

Although this paper discusses capital costs, it should be pointed out that depreciation methods currently being used in the computation of unit-energy costs for Canadian heavy-water reactors do not allow for any salvage value at the end of the station's useful life. The value of the heavy-water inventory may therefore be considered as a bonus to the owner.

Half fuel charge

The cores for the heavy-water reactors are sized for equilibrium operating conditions. At equilibrium conditions, fuel slugs exist in all stages of irradiation from new fuel to completely irradiated fuel, such that the average condition of fuel in the core is only half-spent. Since the core is at equilibrium conditions at the end of the station life, the unrecoverable half charge of fuel remaining must be amortized over the life of the station rather than charged as an operating expense. In addition to the first fuel charge, it is desirable to purchase an "out-of-core" inventory, equivalent to about 150 days at full power, on which interest charges only are paid. The annual interest payments are assigned to the operations account.

For a two-unit 1 000 MW(e) station, the estimated cost of the first fuel charge and the out-of-core inventory is \$13 500 000. Over the life of the station it is expected that the average unit price of fuel will be reduced by 20% or more.

Engineering

Engineering for a fossil-fired station consists mainly of plant layout and design, equipment selection and liaison during manufacturing, construction and commissioning. At present, engineering for a nuclear station includes such additional functions as: detailed design of special components, unique nuclear application of standard components, reactor physics, safety and stress analyses of components and systems. With the growth of the nuclear industry, nuclear components will become standard to meet the requirements of nuclear reactors, and the detailed design done by the manufacturer will be included in the cost of the equipment.

Simplification of structural and shielding concrete arrangements and the development of standard specifications and practices should result in less engineering effort for second-generation stations, but engineering for the nuclear station may be implicitly higher than that for fossil-fired stations for some time. This is because of the greater complexity of systems, piping and cable runs, especially in the vicinity of the reactor vault, and the higher degree of reliability required of components because of their location in normally inaccessible areas.

Construction administration

This covers the cost of management and supervision of the construction, erection and installation of equipment and plant for the complete project.

Training and commissioning

Training is required to ensure that the supervisory and supporting personnel are capable of operating the nuclear station in accordance with the requirements of the designer and the needs of the system. The cost of training includes all salaries, room and travel expenses of the station staff up to the time when they are sufficiently knowledgeable of the station and station procedures to perform usefully in commissioning or operation of the station. Training is assigned as a capital cost for nuclear generating stations because of special requirements and the lack of experienced personnel. It is expected that, with the growth of nuclear power, training will be absorbed as an operating cost.

The commissioning programme places components, systems and the whole station in operation, and demonstrates that the design specifications have been met. Following the conclusion of the commissioning procedures with a full-power run, the station is turned over for normal operation.

The cost of commissioning includes the costs of planning and preparing the commissioning programme, of the commissioning personnel at site, of field engineering and of all stores and supplies required to operate the station during this period. The operating personnel may in some cases perform commissioning functions, and costs incurred should be included in the commissioning account.

Purchasing, accounting and inspection

This item covers the costs of procurement and supply of all materials and services required for the completion of the plant, the control of costs and the performance of all necessary accounting functions, the inspection of all major or critical equipment before release for shipment, and the inspection of the quality of workmanship and materials on the site.

Interest during construction

This item is included as a component of capital cost to recognize the fact that capital is tied up and unproductive during the construction period. It is a function of the prevailing interest rate, construction time and the expenditure distribution over the construction period. It is assumed here that the interest rate is 5.5%, and that the construction time is 4½ years. The financing is considered to be simultaneous with cash flow.

Contingency allowance

Contingencies are included in estimates to cover changes in design, unexpected difficulties during construction, accidents to structures or equipment, labour troubles and extended deliveries of material and equipment.

In choosing the over-all contingency for the Douglas Point estimate, each group or function was assessed according to the knowledge of requirements for that group or function at the time of the estimate. Initially the allowances varied from 5% on the cost of heavy water to 25% on the cost of certain structures, construction plant, inspection and engineering. Estimates prepared at later stages in construction had material and equipment contingency allowances of 3% on heavy water, 5% on items in process of manufacture, 10% on items in process of purchasing, 15% on items in design, and 20% on other items, together with engineering, inspection and construction administration allowances of 10%. With the construction phase of the Douglas Point project almost complete, it is confidently expected that the total cost will be within the total estimate.

The experience gained in designing and constructing the Douglas Point reactor should reflect in lower contingencies on cost estimates for future heavy-water nuclear stations of similar size. Most of the reduction will be due to improved accuracy and completeness of preliminary designs but some savings will result from construction experience.

Spares

Spares include the "on the shelf" spares normally recommended by the suppliers of conventional equipment, together with spares for the reactor/

Table 2. Estimated capital-cost distribution for Douglas Point

USI group		Item or function	Cost of components and materials (% of total)		Cost of construction and installation (% of total)		Cost of engineering (% of total)	
00000	General	Estimating and scheduling					3.0	
		Physics, stress analysis and safety studies					5.2	
		Other					15.2	
		Sub-total						23.4
10000	Site and improvements	Property	0.5					
		Roads			3.4			
		Site investigation			1.3			
		Other	0.1		1.4			
		Sub-total		0.6		6.1		0.6
20000	Buildings and structures	Reactor and service buildings	4.8				9.7	
		Structural and shielding concrete			18.5			
		Turbine building	2.4				3.9	
		Intake and outfall structures			6.0		0.6	
		Steelwork			2.5			
		Excavation and backfilling			2.5			
		Other	1.0		6.2		4.4	
		Sub-total		8.2		35.7		18.6
30000	Reactor-boiler and auxiliaries	Heavy water, \$(US)54/kg	25.3					
		½ Fuel charge	4.7					
		Non-standard components	21.0				11.8	
		Piping			2.1			
		Other	7.3		7.3		7.9	
		Sub-total		58.3		9.4		19.7
40000	Turbine-generator	Turbine generator	11.3		2.4		1.8	
		Feedwater system	1.4		1.2		1.3	
		Other	1.2		0.8		0.5	
		Sub-total		13.9		4.4		3.6
50000	Electrical systems	Station service	2.5		0.5		1.3	
		Lighting	0.5		0.8			
		Cabling	0.8		5.3		1.8	
		Other	1.8		1.3		3.0	
		Sub-total		5.6		7.9		6.1
60000	Instrumentation and control	Channel instrumentation			1.9		0.9	
		Fuel handling and storage					1.5	
		Other R/B and A instrument	3.9		1.4		2.9	
		Data handling	1.0					
		Other	1.5		1.4		5.1	
		Sub-total		6.4		4.7		10.4
70000	Common processes and services	Water systems	2.5		4.0		3.0	
		Heating and ventilation	1.5		1.7		2.7	
		Waste management	0.7		1.1		0.4	
		Other	2.3		4.1		1.1	
		Sub-total		7.0		10.9		7.2
80000	Construction plant	Initial plant			2.3			
		Expendable equip. or rentals			2.5			
		Other operation and maintenance			16.1			
		Sub-total				20.9		10.4 [a]
		TOTAL		100.0		100.0		100.0

[a] Field engineering.

boiler complex, including a spare fuelling-machine head, spare fuel-site components, valves, pumps, seals, and instruments.

Warranty

The estimates presented in this paper include allowances for warranty services for conventional equipment in accordance with standard commercial practices. While there is no well established history of experience with nuclear generating stations at this date, it is assumed that equivalent warranties will apply to nuclear components and equipment, and that warranties on station performance and operation at least equal to those provided for conventional fossil-fired generating stations will also apply.

CAPITAL-COST DISTRIBUTION FOR DOUGLAS POINT

Three major portions of capital costs are components or material, construction and installation, and engineering. Distribution of these costs for the Douglas Point plant is shown in Table 2, on page 203. From this it is seen that construction and installation charges are primarily associated with civil works, i.e., USI categories 20 000, 70 000 and 80 000. In general, expensive mechanical components have low site labour per unit component cost. Most of the component and material charges are associated with the turbine generator, heavy water, and the nuclear or non-standard components.

The table illustrates the high costs for first-generation plants designed and constructed by a relatively new industry with only a few years of design and construction experience. Considerable savings in construction and installation, engineering and components will be achieved in successive plants, due to development of standards and standard components for reactor requirements together with development of improved construction techniques.

ABSTRACT - RÉSUMÉ - АННОТАЦИЯ - RESUMEN

A/11 *Canada*

Analyse des frais d'établissement des centrales nucléaires

par P. H. G. Spray *et al.*

Le mémoire décrit la comptabilité mise au point par l'Atomic Energy of Canada Limited et la Canadian General Electric Company Limited pour évaluer les charges financières fixes afférentes aux centrales nucléaires équipées de réacteurs refroidis et modérés à l'eau lourde dont la construction est prévue au Canada, et plus particulièrement les frais compris dans les charges indirectes.

La méthode comptable est illustrée par un tableau donnant une ventilation typique des dépenses en capital estimées pour une gamme de centrales à deux unités allant de 2 × 200 MW(e) à 2 × 500 MW(e). Le capital investi est ventilé selon des groupes fonctionnels, les huit principaux étant subdivisés systématiquement.

Le mémoire étudie en détail chacun des groupes, détermine les postes qui y figurent ou n'y figurent pas et signale l'expérience tirée des projets CANDU et NPD pour des projets ultérieurs.

Trois postes importants des dépenses en capital sont l'équipement ou les matériaux, la construction et l'installation, et la technologie; le mémoire contient un tableau de la répartition de ces dépenses par groupe fonctionnel pour la première centrale canadienne à réacteur unique de 200 MW (Douglas Point). Les données du tableau sont brièvement analysées.

Ce mémoire devrait intéresser ceux auxquels il incombe d'analyser les dépenses en capital afférentes aux centrales nucléaires et de les comparer sur une base valable avec les dépenses correspondantes pour d'autres installations.

A/11 **Канада**

Анализ капитальных затрат для атомных электростанций

П. Х. Г. Спрей *et al.*

В данном докладе дается оценка капитальных затрат для типовой атомной электростанции электрической мощностью 200 *Мвт* с тяжеловодным реактором, которая будет строиться в Канаде. Система смет, разработанная компанией «Атомик энерджи оф Канада» и фирмой «Кэнедиэн дженерал электрик компани» применительно к ядерным энергетическим установкам CANDU и NPD, рассматривается с особым упором на статьи, относящиеся к косвенным расходам. Эта оценка включает расходы, обусловленные местными правилами безопасности, необходимостью разработки оборудования и методов, связанных с изготовлением нестандартных узлов, и наймом рабочей силы на месте строительства; рассматриваются также перспективы снижения капитальных затрат для будущих атомных электростанций.

Дается оценка изменений капиталовложений в случае продажи атомной электростанции данного типа и ее сооружения в другой, развитой в промышленном отношении, стране и в стране, вступившей на путь промышленного развития; анализируются объемы капитальных затрат при строительстве такой атомной электростанции за границей и в Канаде. Представлены типичные графики строительства и анализы распределения расходов, показано влияние на капиталовложения иностранной валюты, а также закупок в другой стране и в Канаде. В докладе обсуждаются вопросы влияния национальных принципов архитектуры и строительства, местных проектных условий и местных стоимостей на проектирование и оценку стоимости и приводится список материалов, необходимых для строительства зданий типовой станции, расположенной в Канаде. Дается сравнение стоимости местной рабочей силы для механизированной строительной промышленности Канады и Европы с низкой стоимостью рабочей силы в развивающихся странах.

Показано разделение ответственности между продавцом, покупателем и правительствами при разработке и финансировании программы подготовки специалистов в области использования атомной энергии.

Показано влияние мощности электростанции [в диапазоне от 100 до 500 *Мвт* (эл.)] на некоторые стоимостные составляющие.

Преимущества, предоставляемые какой-то отрасли промышленности в субсидировании изготовления узлов для начальной атомной электростанции, рассматриваются одновременно с указанием опасности оценки стоимости будущих станций на основе стоимостных оценок для начальной электростанции.

Обсуждается желательность разработки общих основных правил при подготовке оценок капитальных затрат, включающих косвенные расходы.

A/11 Canadá

Análisis de los gastos de instalación para centrales nucleares

por P. H. G. Spray *et al.*

Este trabajo esboza el sistema de contabilidad que han puesto a punto la Atomic Energy of Canada Limited y la Canadian General Electric Company Limited para determinar el importe de los gastos fijos de instalación de las centrales nucleares con reactores refrigerados y moderados por agua pesada que se proyecta construir en Canadá y en él se insiste especialmente en el tipo de gastos que se incluyen en las cargas indirectas.

El sistema de contabilidad se aclara mediante una tabla en la que se puede ver un desglose típico de los cálculos aproximados para los gastos de instalación de plantas de dos reactores cuya potencia varía desde 2 × 200 MW(e) a 2 × 500 MW(e). Se desglosan las partidas de la inversión total clasificadas por funciones operativas subdividiendo sistemáticamente los ocho grupos más importantes. Cada grupo desglosado se discute por entero identificando qué partidas están o no están incluidas y se menciona la influencia ejercida sobre los proyectos posteriores por la experiencia adquirida con el CANDU y el NPD.

Tres de las partidas más importantes de los gastos de instalación son: componentes o materiales, construcción e instalación, e ingeniería, y se pone de manifiesto una distribución de estos gastos, en forma tabular, de acuerdo con su grupo funcional, para la primera instalación de 200 MW, con un solo reactor, del Canadá (Douglas Point). Se discuten brevemente estos gastos.

Se espera que quienes tengan que analizar los costes de las centrales nucleares y compararlos con otros sistemas en pie de igualdad encontrarán útil este trabajo.

Integration of nuclear reactors and power networks in the United States: economic and technical aspects

By L. H. Roddis, Jr.* and E. Jones**

With the expansion of power networks and the continuing rapid growth in the use of electricity in the United States, factors governing the selection of a primary energy source for generating stations more and more favor nuclear.

An increase in turbine-generator size, the interconnection of large power systems, the growing size of the load, the trend to economy loading, the computerization of dispatching operations and the automation of plants accentuate the fuel cost advantages nuclear power stations hold over fossil-fuel installations. Additionally, substantial reductions in both fuel and capital costs have been achieved for nuclear reactors scheduled for completion in 1967 and later.

Operating experience with both water and sodium-graphite reactors has demonstrated their ability to meet the demands of electrical network operations on a reliable and consistent basis. Of the 365 reactors constructed under the broad based development programme of the United States Atomic Energy Commission, 11 have been operating as network suppliers in varying degrees for one year or more. Four others reached criticality more recently (Table 1).

While most of the above reactors were originally chosen as experimental or prototype units, they have established parameters for a new generation of nuclear reactors which promise to be economically competitive with fossil-fuel stations in areas where fuel costs exceed 20 cents per million Btu.

FACTORS IN THE SELECTION OF A NEW GENERATING STATION

In determining the characteristics of a proposed generating station five major factors should be studied, namely:

Cost of energy delivered to the customer. This includes:
- Investment required for production facilities
- Investment required for delivery facilities (line and substations)
- Interest rates on borrowed money and investment
- Depreciation
- Taxes and insurance
- Operation and maintenance costs
- Fuel costs
- Position in incremental loading schedule.

Dependability of supply:
- Down time required for fueling, maintenance and forced outages
- Interruption factor in long distance transmission
- Area protection requirements.

Availability of unrestricted power to any system customer:
- Relative location of power plant with respect to the load center
- Capacity, capability and location of existing stations
- Interconnection agreements
- Growth rate.

Quality of service:
- Maintenance of continuity
- Following of load swings.

Acceptability by the public:
- Safety
- Air and water pollution.

These factors will be discussed generally as the purpose of this paper is to develop the inter-relationship of the factors involved in the integration of nuclear reactors and power networks, rather than to provide a definitive explanation of economic evaluations. Delivery costs of energy—both before and after generation—will be equated with production costs of various power plants at alternate locations to obtain the ultimate goal, namely, "the lowest delivered cost of a kilowatt-hour". The system network will be assumed to consist of the primary bus at the load end of the transmission line plus all facilities back to and including the generating station. It is assumed that distribution from the secondary side of the substation in any load center will be equal for all alternatives.

FIXED COSTS VARY

Utility costs are split into two categories, namely, fixed costs and operating costs which in turn have

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Table 1. Nuclear power reactors operating in the United States

Station	Owner	Net KW	Type	Criticality
Santa Susanna [a]	AEC & So. Cal. Edison	6 000	Sodium graphite	25.IV.57
Shippingport . .	AEC & Duquesne Light Co.	60 000	Pressurized water	2.XII.57
Dresden	Commonwealth Edison Co.	200 000	Boiling water	15.X.59
Yankee	Yankee Atomic Elec. Co.	185 000	Pressurized water	19.VIII.60
Saxton [a]	Saxton Nucl. Exp. Corp.	4 200	Pressurized water	13.IV.62
Indian Point. . .	Consolidated Edison Co.	255 000	Pressurized water [c]	2.VIII.62
Hallam	Consumers Public Power	75 000	Sodium graphite	25.VIII.62
Big Rock Point	Consumers Power Co.	72 800	Boiling water	27.IX.62
Humboldt Bay. .	Pacific Gas & Elec. Co.	50 000	Boiling water	18.II.63
Elk River	AEC & Rural Cooperative Pa.	20 000	Boiling water [d]	15.III.63
CVTR	Carolinas-Virginia NPA	17 000	Pressurized D_2O .	28.III.63
Piqua	AEC & City of Piqua	11 400	Organic	10.VI.63
Enrico Fermi [b]. .	PRDC	69 500	Fast breeder sodium	1.VIII.63
Pathfinder	Northern States Power Co.	66 000	Boiling water	25.III.64
Bonus	AEC & Puerto Rico WRA	16 500	Boiling water	10.IV.64

[a] Primarily for research and development.
[b] Has been operating at reduced power level.
[c] Oil superheat: 112 MW.
[d] Coal superheat: 14.8 MW.

several important subdivisions of their own. Fixed costs vary from 10% to 14% of the plant investment (capital expenditures) over the amortized life for investor-owned utilities. Included are: return (approximately 6%) on equity and the large debt structure which must be maintained because of the relatively slow turnover of capital (once in approximately 54 to 60 months); taxes (4% to 6%); depreciation (1% to 3%) and insurance.

While investor-owned utilities generate 76% of the power in the United States, 15% is generated by federally-owned utilities, and 9% by public power agencies. Government utilities enjoy lower fixed costs than investor-owned systems, the range being from 3% to 6% for federally-owned systems and from 6% to 10% for public power systems. Both are favored by tax exemptions and, in addition, federal systems obtain capital at extremely low interest rates.

Plant investment includes all expenditures for site, material, equipment, installation, labor, design, interest on capital during construction and working funds. The total of these costs, divided by the net capacity of the station, provides a comparative cost figure, generally stated as \$/kW, which can be translated into generating costs, mills/kWh, by applying the annual fixed charge rate and the annual plant capacity factor.

For illustrative purposes assume that a 500 MW station cost \$62 500 000 to construct, had fixed charges of 14% and an 80% capacity factor. Capital costs would be \$125/kW and fixed charges assessed to generating costs would be 2.497 mills/kWh.

$$\frac{\$62\,500\,000 \times 14\%}{500\,000\text{ kW} \times 8\,760\text{ hours} \times 80\%}$$

$$= \frac{\$8\,750\,000}{3\,504\,000\,000\text{ kWh}} = \frac{2.497\text{ mills}}{\text{kWh}}$$

If 10% is used as the fixed charge rate in the above example, capital costs charged to generation will be reduced to 1.78 mills/kWh; and if a 6% rate for fixed charges is assumed, the charge is further reduced to 1.04 mills/kWh. This difference in cost of money makes it possible for both public power districts and federally-owned systems to attain lower delivered energy costs than can investor-owned utilities.

Rather drastic reductions in costs recently quoted for nuclear reactors indicate that experience gained in building existing plants will lead to substantial savings in stations scheduled to be completed in the next five years, and that capital costs of nuclear stations eventually will approximate conventional stations. Items which increase nuclear capital costs are the need for containment shells, shielding, instrumentation and other measures to contain radioactivity; and the greater complexity of reactor equipment compared to steam boiler auxiliaries. However, the difference will be kept within reasonable limits by the cost of fuel handling, smoke control, and ash handling equipment in fossil-fuel plants.

Economies of scale exist for all types of generating stations but offer larger opportunities for gain to nuclear units because the latter have a greater proportion of components whose costs are disproportionate to size than conventional stations. Additionally, operating experience indicates that nuclear units will surpass design outputs by a greater margin than their competitors. It is anticipated that cost reductions, resulting from design simplification, standardization of components, and larger sales volume to absorb the manufacturer's overhead will be greater for nuclear than for any other type of station.

OPERATING COSTS

Operating costs depend more on technical and geographical conditions than on type of ownership and, therefore, may be considered similar for investor-owned, federally-owned and public power systems. An exception need be made for the high cost of fuel inventory in large nuclear stations where investor-owned systems would be at a disadvantage because of higher interest rates. Operating costs include: (*a*) operating labor and supplies; (*b*) maintenance labor and materials; and (*c*) fuel, including purchase price, transportation, handling and waste disposal.

Labor costs for existing nuclear stations are higher than for comparable fossil-fuel stations because of larger crews containing a larger number of higher salaried technicians. On the other hand maintenance on nuclear equipment has proved to be less costly than on coal handling equipment and on tubes and other components of high pressure and high temperature boilers. There is sound basis for believing that future nuclear stations will have an advantage in maintenance costs. Niagara Mohawk Power Corporation will have 10–20 fewer employees at its Nine Mile Point Nuclear Station than would be required for an equivalent coal-fired plant.

While insurance costs have been higher for nuclear plants, a recent reduction in rates for commercial reactors indicates that a continuance of safe operating experience may eventually equalize this item. Nuclear owners have the prospect of recovering premium rebates after ten years of operation.

Nuclear power's potential for achieving substantially lower fuel costs is implicit in the compactness of fuel which minimizes problems associated with delivery of fossil fuels and removal of their waste products. One specially equipped truck can move one cubic foot of uranium which contains the energy equivalent of 1 700 000 tons of coal. It requires 2 460 standard railroad cars to haul that amount of coal and 300 cars to take away the ashes. It is equivalent in energy value to 7 200 000 barrels of oil (37 800 tank cars) or 32 000 000 000 cubic feet of natural gas. Only about 0.7 of 1% of this energy is utilized in present so-called "burner" reactors, but even this small percentage of use provides a cost advantage for uranium.

Fossil-fuel costs in any specific area of the United States are determined by the price of the energy most abundantly available locally. Variations are from approximately 10 cents per million Btu in the Texas and Louisiana gas fields to more than 40 cents per million Btu in the north-eastern and western coastal areas where the cost is based on that of imported fuel oil.

Coal is the primary energy source for two-thirds of the electricity generated in the United States and is the fuel with which nuclear power usually is compared. The purchase price of coal has been in a state of flux for more than a year due to changes in methods of transportation induced by the construction of extra high voltage transmission lines and the threat of nuclear power.

Whereas definite parameters exist for determining fossil-fuel costs, more assumptions are involved in computing nuclear fuel costs.

The uncertainty as to whether or not private ownership of nuclear fuel will be authorized, as to whether or not the government will do the reprocessing required and as to what the future price of plutonium produced will be, complicate the predicting of future costs. Estimates based on possible developments in the next ten years are that nuclear fuel costs will range from 1.35 mills/kWh to 2.28 mills/kWh (Table 2).

There are considerations other than fixed charges and operating expenses which must be factored into the "economics" of integrating a new generating unit into a power network. One of the most important, from a cost-of-energy standpoint, is the procedure of incremental loading whereby load is assigned first to the unit in the system which has the lowest incremental cost.

Once a station has been constructed its fixed charges become part of the system's overhead and it can no longer be charged to daily operation as are fuel costs. Fixed charges for the system are retained for a definite period and continue to accrue whether operated or not. Fuel costs are incurred

Table 2. Estimates of nuclear fuel costs

	Decrease or increase	Mills/KWH
Base fuel cycle cost – 1967		
Current price schedules, U_3O_8 at \$8.00/lb	Base	2.09
Pessimistic – 1970		
Private ownership and reprocessing, U_3O_8 at \$6.70/lb	+ 0.19	2.28
No reduction in core fabrication cost		
No increase in core life		
Moderate optimism – 1970		
Private ownership and reprocessing, U_3O_8 at \$6.70/lb	— 0.15	1.88
Reduction in core fabrication cost by 30%		
Increase core life by 25%		
Substantial optimism – 1970		
Private ownership and reprocessing, U_3O_8 at \$5.00/lb	— 0.53	1.56
Reduction in core fabrication cost by 50%		
Increase core life by 25%		
Extreme optimism – 1970		
No private owership or reprocessing, U_3O_8 at \$5.00/lb	— 0.74	1.35
Reduction in core fabrication by 50%		
Increase in core life by 25%		
Converter breeder economy – 1980		
Private ownership and reprocessing, U_3O_8 at \$6.70/lb	— 0.7 to — 0.8	1.3 to 1.4
Reduction in core fabrication by 50%		
Increase in core life by 25%		
Pu value increased to \$14 to \$16 per gram		

Source: L. F. C. Riechle, Ebasco Services, Inc.

only as consumed. (With the exception of carrying charges on fuel inventory which become significant in large nuclear units.)

The use of digital computers and other automation devices has facilitated dispatching operations to the point where output is automatically adjusted by telemetered reports from load centers and interchange points. Even in the largest systems increasing loads can be assigned virtually instantaneously so that the lowest energy cost producer is loaded first. Conversely the highest energy cost unit is unloaded first. The only exceptions involve the maintenance of system stability and an adequate supply of reactive capacity.

It follows that nuclear units, with lower fuel costs, will be among the first loaded and consequently will have a better load factor than commonly assigned in the planning stage. In turn this will improve nuclear's competitive position since longer annual use will reduce fixed charges per kWh.

DEPENDABILITY OF SUPPLY

Dependability of supply has a high dollar value. Lack of continuity in supply encourages customers to seek alternate energy sources and results in revenue losses, since kilowatt-hours have a quality of time as well as volume. When a base unit is inoperative, either on a scheduled or an emergency basis, its normal output must be replaced with that from another unit on the system (usually possessing a higher fuel cost) or by purchase from a neighbor.

Original doubt that nuclear units would be able to meet base load standards because of the time required to refuel have been dissipated. With the experience of several fuel changes it is evident that down time for nuclear causes need not be any longer (over the operating life) than that required for regular boiler inspections, tube repairs and other maintenance of conventional units.

The cyclic nature of electric demand in a system precludes the establishment of parameters which will meet all requirements. Weather, geography, shopping habits, TV programming, air conditioning and heating volume, the power factor of customers' equipment, eating habits and other customer-related activities create situations which place varying values on energy.

However, characteristics of these diverse loads lend themselves to three classifications: daily variations, rapid fluctuations and seasonal variations. Daily variations are caused by factors directly associated with living and working habits of the area (Fig. 1). A low point between 1 and 5 a.m. ends when people begin arising for the day. A very substantial increase with the start of the work day leads to a peak demand between 10 a.m. and noon. A drop in early afternoon is followed by another upsurge which, in turn, begins to taper off with the closing of offices and factories. The decline is steady until the following morning, when the cycle repeats. The duration and time of the peaks vary on various systems due to the relative importance of residential and industrial loads. The afternoon peak frequently is higher than the morning peak during December.

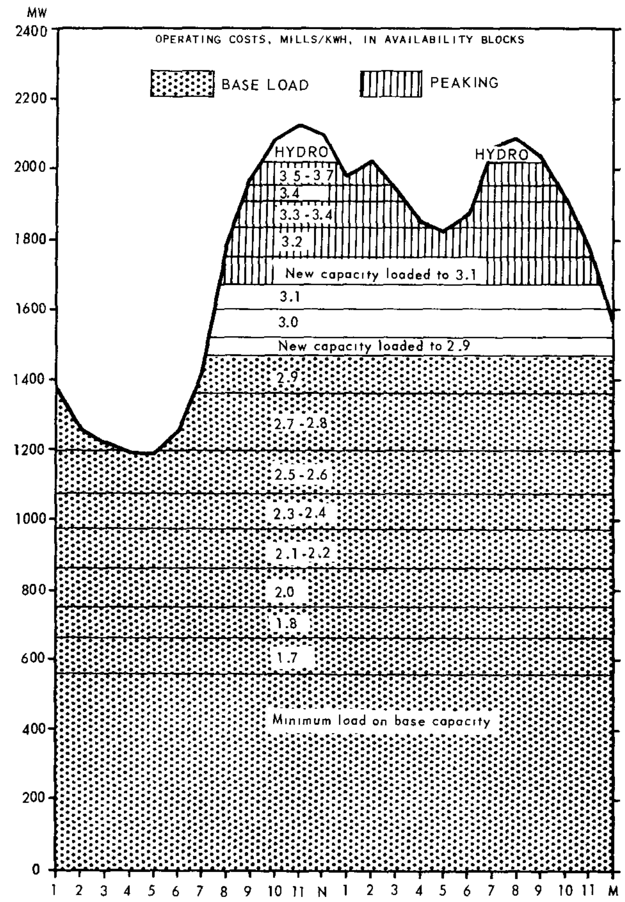

Figure 1. Daily load assigned on incremental cost basis
A large network, which sustains 55% of its maximum load for the full 24 hours of a typical weekday and 65% for 18 hours of the day, assigns this "base load" to stations whose incremental operating costs vary from 1.7 to 2.9 mills/kWh. It utilizes peaking units with costs of 3.1 to 3.7 mills/kWh to carry all but a small fraction of dual peaks

Characteristics of the daily load are vital. On most systems a relatively high demand exists for 40% to 60% of the time. This "base load" generally is assigned to the most efficient units because fuel costs affect net income more directly than fixed charges. For serving this portion of a network's load, nuclear units in sizes of 300 MW and larger, possess an economic advantage over conventional units in a sizeable part of the United States.

Rapid load fluctuations, which may be caused by the off-on characteristics of large industrial loads, by the unpredictable actions of residential customers, or by changes and failures within the network require the maximum in operating flexibility (Fig. 2). Whether the generator serving this portion of the load should be selected for economy in fixed costs or fuel costs depends to a large extent on the recurrence of rapid load swings.

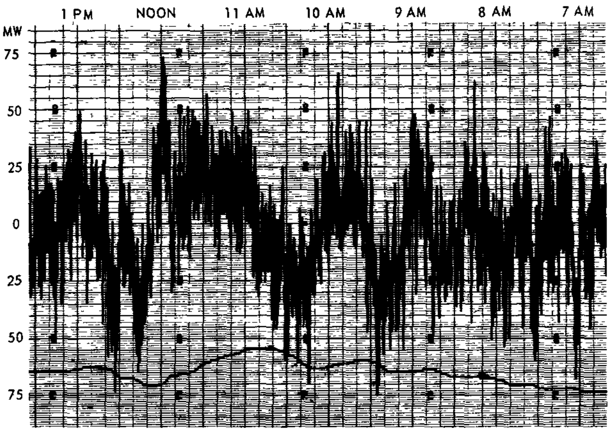

Figure 2. Hourly load fluctuations on a large interconnected system
(Network with 16 993 MW capacity)
Note: system incremental cost (bottom horizontal line) follows the magnitude of the load

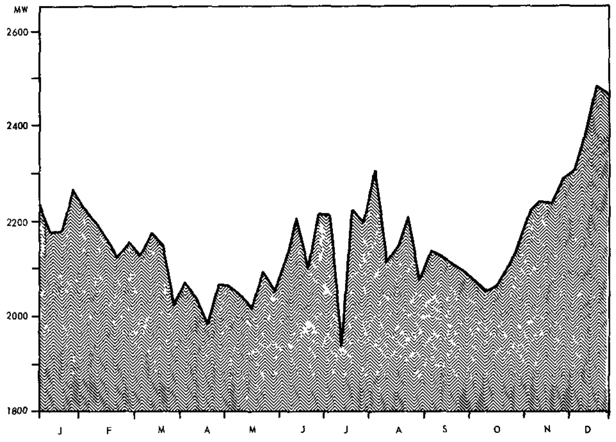

Figure 3. Seasonal variations in load
General public utilities system; weekly peak load
(1 hour integrated)

Here again nuclear has an advantage as proved by the records of operating water and sodium/graphite reactors which have demonstrated a self-regulating ability to handle severe load swings at a level superior to that of steam stations. For example, Shippingport has accepted load swings of up to 24 MW per minute. Dresden has been brought to peak output in 100 minutes after overnight shutdown and in 3½ hours after cold shutdown.

The third category of electricity demand arises from seasonal variations which depend primarily on geography and climate (Fig. 3). They result from lighting and heating loads in the north low-temperature zone and from air conditioning in warmer regions. When the duration is relatively short (40 to 60 days) fixed costs are more important. Otherwise, priority is given to fuel costs.

A variety of energy sources are utilized to supply both the daily and seasonal peaks. It long was customary to retain units which no longer met existing efficiency standards for peaking service. This policy is still followed in many systems. However more and more attention is being given to special peaking units which include gas turbines, diesel engines, pumped storage and hydro. The latter, sometimes referred to as straight or conventional hydro, which depends either on run-of-the-river or large reservoir capacity, has virtually zero fuel costs and low operation and maintenance costs in contrast to high capital costs. Its use for base loading is limited by uncertainty of water supply, and its costs are augmented by above average transmission costs since virtually all sizeable straight hydro locations in the United States are remote from load centers.

Pumped storage is becoming popular for peaking use coincidental with the increase in size of generating units because it extends the operating time of top efficiency units over a longer period of each day. Frequently a low fuel cost unit is capable of generating considerably more electricity than the system can absorb in periods of low demand which generally occur between 10 p.m. and 6 a.m. If the unit's surplus capacity is utilized to pump water into a high reservoir for release later when for a short period demand may exceed the unit's capability, then the economic value of the unit is increased because its period of active use has been extended without any increase in fixed costs (i.e., there will be more kilowatt-hours generated to share the unalterable fixed costs).

Pumped storage facilities have a low capital cost, in the range of \$80 to \$100/kW. Although they may be operated remotely or with a minimum complement of employees, operating costs are high. This stems from the fact that it requires approximately 3 kWh to pump sufficient water to generate 2 kWh. It is possible, even under this handicap, that incremental costs of a pumped storage facility will be lower than those of steam stations during periods of peak demand.

Capital costs of gas turbines are in approximately the same range as pumped storage, but fuel costs are higher than coal-fired units except in gas producing regions. Once somewhat higher than gas, capital costs of diesel generators have decreased within the past year. In addition to the disadvantage of fuel costs in excess of 40¢ per million Btu, they incur high maintenance costs. Both gas and diesel units have excellent load following ability and easily can meet small peaking and emergency demands.

AVAILABILITY OF CAPACITY

The utility systems of the United States are quite proud of their ability to supply electricity in any amount to any customer anywhere. The national gross margin was 27% in 1963. Utilities strive to bring new capacity into operation to meet increasing system demands as they occur. Obviously, when demand is doubling every ten years, it is impossible to add capacity in constant steps but through careful planning and interconnections major networks keep reserve capacity above 12%.

Installation of units larger than any one load center can justify facilitates meeting long-range requirements and in turn has been facilitated by advances in transmission technology. That is, by building EHV lines, utilities are able to distribute the output of large generating units to several load centers. Although theoretically the closer the generator is to the user the more reliable will be the service, from a practical standpoint virtually the same, or higher, continuity standards can be maintained by "looping" of transmission lines into regional networks.

In constructing systems which interconnect load centers with sufficient transmission lines so that they can obtain power from a variety of generating systems, United States utilities have made it possible to efficiently utilize larger generating units than otherwise could be justified. Since these loops and their related interconnections are used to interchange economy power, to meet emergency demands and to provide area protection, their costs need not be charged fully to costs of transmitting power from a new station to the load center. The existence of extensive networks thus facilitates the adding of large nuclear units without adding large costs for transmission facilities.

QUALITY OF ENERGY

One of the most difficult values to assess, but nonetheless important, is the quality of the delivered energy. When an interruption in supply of as little as 20 cycles (⅓ second) can stop a production line and when voltage dips affect motor operation, the question of quality becomes very important to a customer. Nuclear's ability to follow rapid load swings minimizes this problem, and its fast heat-up meets quality standards of the best networks. It is very difficult to give quality a price tag and it can only be evaluated in line with an individual company's reputation for service.

ACCEPTABILITY TO CUSTOMERS

Until recently there was little question about the acceptability of conventional generating stations. They could be located virtually anywhere that other considerations dictated. However, as increased size increased the volume of stack discharges and as the amount of pollutants from other sources in the atmosphere increased, more and more attention has been given to public acceptability.

The dollar value of this factor is directly proportionate to the cost of installing equipment which will reduce the emission of particulates and gases to an acceptable level. Mechanical dust collectors and electronic precipitators are available which will collect up to 99.9% of the particulates in stack gases. They add from $2 to $4 per net kilowatt to the construction cost of a station.

Removal of obnoxious gases by scrubbing and absorbing systems is considered prohibitive in that the equipment adds from $10 to $20 per net kilowatt to construction costs and from $1 to $2 per ton of coal consumed to operating costs, including credit for sale of any usable by-products (S, H_2SO_4, etc.). Costs of converting flue gas components to sulphuric acid at high temperatures have been estimated at $14.50 per net kilowatt in construction costs, partly recoverable from the sale of acid. The latter costs are based on operation of a small prototype; and to date, no large scale installation is planned. Low temperature (wet) process installations that have been made to date do little to correct ground concentration of offensive oxides because the cold effluent holds to ground level.

Variations in air cleaning costs depend to some extent upon the sulphur and ash content of the fuel burned. Since net cost of fuel generally increases in direct proportion to decrease in sulphur and ash content, the power plant designer must weigh costs of removal against the price of better fuel. Experience with washing and other pre-conditioning processes indicate that it is cheaper to remove foreign material in the furnace. This is another statement which must be qualified by stating that transportation charges make it uneconomic to ship high ash coal any great distance.

Another alternative is to propel stack discharges into the upper atmosphere for dispersal over a wider area since criteria as to the acceptability of air pollution is based on the ground level concentration of particulates and gases in the immediate vicinity of the plant. While construction costs of extra high stacks adds only 50 to 60 cents per kW to capital costs and a negligible amount to operating costs, this method becomes less and less acceptable as unit size increases and compounds the waste disposal problems.

Public acceptability of fossil-fuel plants (oil and coal-fired and to a lesser extent gas-fired) has become increasingly difficult to earn in high density population areas as the result of recent reports that long-term, low-level air pollution can contribute to or aggravate certain acute and chronic respiratory diseases. Dust and odor nuisance is also a potential problem, especially with carelessly designed or operated power plants.

From a public relations viewpoint the utility will endeavour to eliminate complaints, either by burning low-sulphur and low-ash content fuel and by installing highly efficient pollutant collectors at plants near load centers, or by placing the station in a remote location. This decision must be based on balancing added construction and operating costs of cleaning equipment against capital and maintenance costs of a transmission line with due consideration for possible variations in fuel costs.

A third alternative would be to select a nuclear plant which does not pollute the air during normal operation. However 80 years of experience with fossil-fuel stations plus an even longer period of living near and with many types of coal and oil burning boilers has conditioned the public to consider conventional units safer.

This is so although there has been no instance of radiation injury to any worker in a central station nuclear power plant and radiation exposure estimated to have been received by the public from operation of nuclear stations has been kept to a very small fraction of that allowed by the Atomic Energy Commission's radiation protection regulations. The only nuclear fatalities which have occurred in the United States were the death of three operators in a severe excursion in a prototype boiling water reactor designed to meet specialized military requirements, two operators in critical experiment facilities used for weapon research and one operator in a chemical processing plant. No fatalities to the general public have occurred.

NUCLEAR BEST FOR OYSTER CREEK

An ideal example of the consideration given to the many factors involved in the selection of a new generating unit for a large network is the Oyster Creek Station of Jersey Central Power & Light Company. Announcement that the station is expected to have energy costs of less than 4 mills per kWh represented a major breakthrough in nuclear power costs. Jersey Central is part of the General Public Utilities Corporation integrated system which has the following generating capacity: 850 MW coal-fired located at or near mine-mouth; 1 800 MW other coal-fired; and 60 MW hydro. In co-operation with neighbouring utilities, it is constructing 330 MW in a pumped storage facility scheduled to have ultimate capacity of 1 300 MW and an 1 800 MW mine-mouth plant. This system is operated on an economy loading basis within the Pennsylvania-New Jersey-Maryland Interconnection which has generation in excess of 17 000 MW.

The Oyster Creek location was selected originally as being most advantageous to the system on the basis of engineering and operating factors. Both fossil-fuel and nuclear plants were studied for this site and compared with costs of a mine-mouth plant approximately 300 miles west of the load centre. Fossil-fuel costs in the coal fields are 17 cents per million Btu compared to 26 cents per million Btu estimated for Oyster Creek. The latter cost was quoted by prospective fuel suppliers after Jersey Central announced it was considering nuclear and was based upon ownership by Jersey Central of a portion of the investment in an integral train and some related facilities. It was 3.5 cents per million Btu below prevailing costs at other stations in the area.

As a result of the lower fuel cost, total costs at the mine-mouth plant were computed to be significantly lower than those for a comparable fossil-fuel plant at Oyster Creek. However, these were partly offset by transmission costs estimated at $3/kW for line losses and $30/kW for line construction (Table 3).

Table 3. Comparative costs of fuels at Oyster Creek
620 MW (electrical) net capacity — 1968 startup

	Fossil fuel		Nuclear—Oyster Creek
	Penna.	Oyster Creek	
Capital costs ($/kW)			
Generation	105	110	110
Transmission	30	3	4
Working capital	2	1	2
Fuel capital	3	4	22
Total ($/kW)	140	118	138
Energy costs (mills/kWh)			
Fixed charges	1.76	1.48	1.75
Fuel costs	1.61	2.31	1.27
Operation and maintenance	0.49	0.39	0.48
Total (mills/kWh)	3.86	4.18	3.50

Note: The above statistics were computed for a dual cycle station. Subsequently a single cycle unit with maximum capability of 640 MW was selected. The latter is expected to increase the economic margin in favor of nuclear. Total energy costs are for the 1974-1978 period of operation. They vary from 3.42 mills/kWh to 3.97 mills/kWh in other periods for the nuclear station.

Basic assumptions: No governmental subsidy of any kind. All investments to be made at interest rates of 4.25% and equity capital at a 10% rate of return.

Nuclear fuel costs: Yellow cake, $6/lb; separative charges, $25/kg; Plutonium, $10/gr until 1970 then $8; processing, $23 500/ton to 1974 then $21 150; turnaround, $7 833 and $7 050/ton.

A load factor of 88% was assigned to the nuclear unit for 15 years after which it decreased to 56%. The western unit started with the same load factor but decreased to 70% in 15 years and to 43% in 30 years. The eastern fossil-fuel unit was assigned a lower load factor because higher fuel costs would reduce its base load use.

Oyster Creek's attainment of lower capital costs than were enjoyed by previously built or committed nuclear plants results from the economies of scale and from improved technology on a dollars per kilowatt basis. Oyster Creek will cost less than one-half that of Dresden, the first major boiling-water reactor placed in commercial operation. Its effective capability will be more than three times as large.

Connecticut Yankee, a 490 MW pressurized water reactor, will have a capacity two and one-half times larger than its predecessor, Yankee, for a $/kW cost approximately 25% less. Yankee's $/kW cost was only one-fifth that of Shippingport, the first pressurized water reactor (Table 4). Shawville No. 4, incorporating the latest technology in steam gener-

Table 4. Capital costs of nuclear stations — United States

	Capacity net MW	Cost $/kW	Start	Type
Piqua	11.4	1 040	1963	Organic
Elk River	20	550	1963	Boiling water
Peach Bottom	40	700	1964	HTGCR
Humboldt Bay	50	400	1963	Boiling water
Shippingport	60	1 220	1957	Pressurized water
Pathfinder	66	350	1964	Boiling water - superheat
Hallam	75	608	1962	Sodium graphite
Yankee	185	220	1960	Pressurized water
Dresden	200	245	1959	Boiling water
Indian Point	255	350	1962	Pressurized water
Bodega Bay	313	212	1966	Boiling water
San Onofre	395	208	1966	Pressurized water
Conn. Yankee	490	174	1967	Pressurized water
Oyster Creek	620	138	1967	Boiling water

Source: Atomic Energy Commission — TID-8531: Adjusted to proved capability.

ation, was placed in operation at approximately the same time as Yankee, the largest pressurized power water reactor then operating. The capacity of the two units was virtually identical. Shawville had a $/kW cost approximately 40% less and its energy charges approximately one-half of Yankee's. The eight-year span between the completion of these stations and the target date for Oyster Creek has narrowed the capital cost between the same size nuclear and fossil-fuel stations to a 16% premium for the former while energy costs have swung full cycle in favor of nuclear.

It is realized that cost comparisons have little meaning without an explanation of background factors. In locations where fuel costs are low, there are limitations on the economic advantage which will accrue from installing costly equipment to improve efficiency. Conversely as fuel costs rise it is beneficial to pay more to obtain a better heat rate.

An example is given by three large stations now under construction (Table 5). Keystone, with two 900 MW units, and Mount Storm with an 1 100 MW net capacity are mine-mouth stations having estimated costs of $93/kW and $98/kW respectively. Their design heat rates are approximately 6% higher than that for Bull Run which will cost $147/kW for a 900 MW station located some distance from the mines.

Whether or not nuclear's apparent breakthrough in costs will be permanent depends as much on actions of competing fuels as on improvements in the state of the nuclear art. Costs of fossil-fuels have been declining under the impetus of competition.

The major portion of reductions in coal prices have come in transportation charges. Integral trains, turn-around barges and pipelines are some of the innovations which have reduced transportation costs as much as $2.10 per ton for some stations. Always in the picture is EHV transmission which for distances of 200 miles or more makes it more economical to transmit electricity by wire than to transport the fuel on land or water.

The unresolved question of total energy supply may, in the long run, play a major part in the issue.

Table 5. Cost of selected fossil-fuel plants

	Capacity MW	Cost $/kw	Heat rate Btu/kWh	Fuel cost ¢/Btu	Start
Nichols [a]	100	141	10 348	18.1 [a]	1960
Seward 5	137	143	11 970	21	1957
Barrett 2	187.5	132	9 847	32	1963
Portland 2	233	129	9 071	30.5	1962
Martin's Creek [a]	312.5	116	11 101	31.6	1954
Armstrong	362	126	9 868	18	1958-59
Brunner's Island [a]	363.3	134	9 648	32.8	1961
Shawville 3-4	368	149	9 451	19	1960
Port Everglades [a]	450.5	104	9 578	32.9 [b]	1961
Breed	500	144	8 550	18.7	1960
Mercer [a]	652.8	175	8 894	18.1	1960
Bull Run	900	147	8 391	21	1965
Mount Storm	1 100	98	8 930	18	1965-66
Keystone	1 800	93	8 900	17	1967

Source: Federal Power Commission, 14th Annual Supplement.

[a] Outdoor construction. [b] Gas-fired. [c] Oil fired.

There is growing belief that gas and oil reserves should be conserved for "superior use." On the other hand, there are indications that coal reserves are far larger than previously thought and may contain more total energy than reserves of fissionable material if the latter is used only in "burner" reactors. On the other hand development of breeding technology should extend the supply of fission fuel indefinitely.

Just as nuclear stations are developing as "good neighbours" suitable for construction in populated load centres, another technological gain—namely, EHV transmission—makes it possible to move coal-burning plants to remote locations. However, it is logical to expect that nuclear power, with its minimal fuel handling problems in contrast to the importing of great volumes of coal and the removal of vast amounts of ashes, along with its cleanliness, may bring back the ideal network condition of locating large generating stations within major load areas.

Nuclear power has met the economic and technical criteria for integration into at least 60% of the power networks in the United States.

Nuclear power has earned top consideration of those planning how best to meet increasing demands for electricity in a country where consumption of energy is governed only by the uses which are found for it, rather than by supply limitations.

ABSTRACT - RÉSUMÉ - АННОТАЦИЯ - RESUMEN

A/216 Etats-Unis d'Amérique

Intégration de réacteurs nucléaires dans les réseaux de distribution aux Etats-Unis: aspects économiques et techniques

par L. H. Roddis Jr. et E. Jones

Les considérations primordiales qui régissent le choix d'une source d'énergie pour une centrale électrique sont les suivantes: i) coût de l'énergie livrée à l'usager; ii) constance de la fourniture de courant; iii) possibilité de répondre sans imposer de limites à la demande de tout abonné du réseau; iv) qualité du service; et v) acceptabilité par le public.

Ces facteurs font l'objet d'un examen d'ordre général; le but du mémoire est en effet de faire ressortir les relations mutuelles entre les facteurs que met en jeu l'intégration de réacteurs de puissance dans des réseaux d'énergie plutôt que d'en définir l'évaluation économique.

Les coûts se répartissent en deux catégories: les frais fixes et les frais d'exploitation. Les premiers comprennent l'intérêt du capital emprunté, les amortissements, les charges fiscales et les assurances; ils varient selon le régime de propriété (secteur public ou secteur privé). Les différences en matière de taux d'intérêt et de charges fiscales sont à l'avantage des réseaux du secteur public à l'échelle régionale ou nationale, qui peuvent produire l'énergie à meilleur compte. Les frais d'exploitations dépendent plus de facteurs d'ordre technique ou géographique que du régime de propriété. Ils comprennent les dépenses de fonctionnement et de combustible; ces dépenses font l'objet d'une étude détaillée dans le mémoire.

Il importe de pouvoir toujours faire face aux variations journalières et saisonnières, ou aux fluctuations brusques de la demande, et les auteurs montrent que les centrales nucléaires peuvent répondre aux besoins de la charge de base, tandis que diverses autres sources d'énergie permettent de satisfaire les demandes de pointe. Les entreprises de distribution s'efforcent d'accroître la puissance installée pour répondre à une demande toujours accrue; grâce à une planification soigneusement établie et à l'interconnexion, les grands réseaux maintiennent une réserve de puissance supérieure à 12%.

La centrale d'Oyster Creek, de la Jersey Central Power and Light Company, fournit un exemple idéal de l'attention accordée aux divers facteurs du choix d'une nouvelle unité de production pour un grand réseau. Le mémoire expose en détail les raisons du choix de l'emplacement et compare les prix des divers combustibles rendus à la centrale, ainsi que les frais fixes et les frais d'exploitation dans certaines autres centrales.

En conclusion, il est logique de prévoir que l'énergie nucléaire, caractérisée par sa "propreté" et une manutention du combustible réduite au minimum, pourrait fournir la solution pour un réseau en permettant d'installer de grosses centrales dans les régions de forte charge.

A/216 США

Экономические и технические аспекты включения атомных электростанций в энергосистемы в Соединенных Штатах

Л. Х. Роддис-младший, Э. Джоунз

Основными факторами, определяющими выбор источника энергии для электростанции, являются следующие: 1) стоимость электроэнергии для потребителей; 2) надежность снабжения электроэнергией; 3) удовлетворение любой потребности потребителей в электроэнергии; 4) качество обслуживания потребителей; 5) приемлемость для населения. Дается общее

рассмотрение этих факторов, поскольку цель настоящего доклада заключается в установлении взаимной зависимости этих факторов при подключении ядерных энергетических реакторов к электросетям, а не в получении определенных объяснений экономических оценок.

Эти расходы можно подразделить на две категории: фиксированные и эксплуатационные расходы. В фиксированные расходы входят процентные отчисления на вложенный капитал, амортизационные отчисления, налоги и страховые платежи, причем эти расходы могут изменяться в зависимости от того, является ли электростанция частной или государственной. Районным энергетическим системам, принадлежащим местным властям, и энергосистемам, принадлежащим федеральным властям, устанавливаются льготные, более низкие ставки отчислений на вложенный капитал и налоговые ставки, что позволяет им снизить стоимость электроэнергии. Эксплуатационные расходы зависят от технических и географических условий в большей степени, чем от принадлежности энергосистемы.

Необходимо иметь возможность изменять снабжение током энергосистемы в зависимости от суточных, сезонных и быстрых колебаний потребности в электроэнергии. Показано, что атомные электростанции могут обеспечивать основную нагрузку, а для удовлетворения потребности в электроэнергии в часы пиковой нагрузки может быть использован ряд других источников энергии. Коммунальные компании стремятся ввести в эксплуатацию новые мощности для обеспечения возрастающих потребностей в электроэнергии путем всестороннего планирования и объединения основных энергосистем для обеспечения резервной мощности не менее 12%.

Идеальным примером анализа многих факторов, связанных с выбором новой электростанции для большой энергосистемы, является электростанция в Ойстер-Крик компании «Джерси сентрал пауэр энд лайт». В этом докладе приводятся подробные причины, определяющие выбор места для строительства станции, и сравниваются издержки на различные виды топлива для этой станции вместе с фиксированными и эксплуатационными расходами для некоторых других электростанций.

В заключение делается вывод, чего логически следует ожидать, что ядерная энергетика, характеризующаяся чистотой и резким снижением объема транспортировки топлива, может создать идеальные условия для размещения крупных электростанций в районах основной нагрузки.

A/216 Estados Unidos de América

Integración de los reactores nucleares en las redes de energía eléctrica en los Estados Unidos: aspectos económicos y técnicos

por L. H. Roddis, Jr. y E. Jones

Cuando se escoge el generador en una central eléctrica se considera en primer lugar: i) precio de la energía entregada al abonado; ii) que el servicio no tenga interrupciones; iii) que no haya que restringir el número ni la potencia de los abonados; iv) que sea un buen servicio, y v) que el público lo acepte. Todo ello se discute aquí en forma general porque el fin de este trabajo es explicar la relación mutua entre los factores implicados en la integración entre reactores nucleares y redes de energía más que dar una evaluación económica definitiva.

Se dividen los costes en dos categorías: costes fijos y costes de operación. Los primeros incluyen intereses de los préstamos, depreciación, impuestos y seguros y varían según quien sea el propietario. Las centrales propiedad de autoridades locales o federales se benefician de menores tipos de interés y menos impuestos. Los costes de operación dependen más de las condiciones técnicas y geográficas. En estos costes se incluyen funcionamiento, entretenimiento y consumo de combustible y se discuten a fondo.

Siempre hay que poder enfrentarse con las variaciones de la demanda, sean diarias, estacionales o súbitas, y puede verse que las centrales nucleares sirven para cubrir las necesidades de cargas base mientras distintas fuentes se ocupen de los picos de demanda. Las empresas se esfuerzan en proporcionar cada vez mayor potencia para hacer frente a las demandas crecientes de los usuarios, y las redes más importantes mantienen su potencia de reserva por encima de 12% mediante planificaciones e interconexiones cuidadosas.

La central de Oyster Creek, de la Jersey Central Power and Light Company, es un ejemplo ideal de cómo se pueden tener en cuenta los muchos factores que intervienen al elegir un nuevo generador para una gran red. En este trabajo se detallan las razones por las que se ha escogido el emplazamiento y se comparan los costes de los diversos combustibles en la central, así como los costes fijos y de operación en otros posibles emplazamientos.

En fin, es lógico suponer que la energía nuclear, que es limpia y produce un mínimo de problemas de manejo de combustible, proporcionará las condiciones de red ideales para situar grandes centrales en las zonas de mayor carga.

Р/316 СССР

Развитие электроэнергетики СССР и атомные электростанции

А. М. Некрасов, Г. С. Зелевинский

ВВЕДЕНИЕ

Успехи научных исследований в области ядерной энергетики и опыт проектирования, строительства и эксплуатации ядерных энергетических установок, накопленный в СССР, США, Англии, Франции и некоторых других странах, привели к тому, что атомные электростанции выходят из области экспериментов и опытных установок и становятся одной из промышленных отраслей энергетики. В силу этого проблемы дальнейшего развития АЭС могут быть целесообразно решены только при учете всех конкретных условий, в которых развивается общая энергетика страны. Необходимо учитывать состояние и перспективы развития энергетики; масштабы и темпы строительства новых электростанций; энергетические ресурсы страны, их запасы, характеристики и размещение по стране.

СОВРЕМЕННОЕ СОСТОЯНИЕ ЭЛЕКТРОЭНЕРГЕТИКИ В СССР

В СССР всегда придавалось первостепенное значение электрификации страны. Советский Союз, получив в наследие от царской России ничтожное энергетическое хозяйство и начав с выработки в 1921 г. всего 0,5 млрд. *квт·ч*, довел выработку электроэнергии в 1940 г. до 48,3 млрд. *квт·ч* и установленную мощность на электростанциях до 11,2 млн. *квт*.

После окончания второй мировой войны развитие энергетики вновь пошло весьма быстрыми темпами, как это видно из табл. 1

Таблица 1

Годы	Выработка электроэнергии, млрд. квт·ч	Установленная мощность, млн. квт	Примечание
1945	43,3	11,1	
1950	91,2	19,6	
1955	170,2	37,2	
1956	191,7	43,5	
1957	209,7	48,4	
1958	235,4	53,6	
1959	265,1	59,3	
1960	292,3	66,7	
1961	327,0	73,9	
1962	369,3	82,4	
1963	411,6	92,4	
1964	455,0	102,4	План
1965	508,0	113,0	План

Таблица показывает, что в течение многих лет ежегодный прирост выработки электроэнергии и установленной мощности на электростанциях устойчиво находится в пределах 10,5—12,5% и удвоение происходило примерно за 6,5 лет, а утроение за 10 лет. За короткий исторический срок СССР добился крупных успехов и уже в 1947 г. занял по выработке электроэнергии первое место в Европе и второе место в мире.

Основой электроэнергетического хозяйства СССР являются тепловые электростанции, удельный вес которых в выработке электроэнергии составляет 82—83%; гидроэлектростанции вырабатывают 18—17%.

Характерной особенностью развития электростанций в последние годы является укрупнение их мощности, что стало необходимым при быстрых темпах развития энергетики. Известно, что в СССР построены самые мощные в мире гидроэлектростанции — Волжская им. В. И. Ленина мощностью 2300 *Мвт*, Волжская имени XXII съезда КПСС мощностью 2530 *Мвт* и Братская на Ангаре, мощность которой в начале 1964 г. достигла 3600 *Мвт*. К началу 1964 г. уже действовали 5 тепловых электростанций, каждая мощностью 1000 *Мвт* и более, и к концу 1965 г. число таких электростанций возрастет до 11, а мощность одной из них превысит 2000 *Мвт*.

Укрупнение мощности тепловых электростанций происходит на основе увеличения единичной мощности турбогенераторов и котлов. Уже в настоящее время широко применяются блоки мощностью по 150 и 200 *Мвт*; в 1963 г. были установлены первые блоки по 300 *Мвт*; начато изготовление блоков по 500 и 800 *Мвт*. Одновременно происходит повышение рабочих параметров пара. Наиболее распространено в настоящее время применение пара с начальными параметрами 130 *ата* 565° С, а блоки 300 *Мвт* построены для работы на 240 *ата* 560° С; применяется промежуточный перегрев пара до 565° С. Одной из характерных особенностей является широкое развитие теплоэлектроцентралей, на которых осуществляется комбинированное производство электроэнергии и тепла в виде пара для технологических нужд промышленных предприятий и в виде горячей воды для отопления зданий и для коммунально-бытовых нужд. Такие теплоэлектроцентрали, дающие значительную экономию топлива, составляют около 30% мощности всех тепловых электростанций. На теплоэлектроцентралях широко применяются турбогенераторы с отборами пара мощностью по 100 *Мвт*, разработаны и в ближайшие годы будут устанавливаться турбогенераторы по 250 *Мвт*.

На электростанциях применяются различные виды топлива. Освоено эффективное сжигание самых разнообразных сортов твердого топлива — антрацитов, каменных и бурых углей всех марок, отходов углеобогащения, торфа, сланцев. Структура топливопотребления электростанциями в 1960 г. была такова (в %): уголь — 65, природный газ — 12, мазут — 9, торф — 7, прочие виды топлива — 7.

В течение последних лет возрастает доля природного газа, мазута и снижается удельный вес угля.

Развитие электроэнергетики СССР на всех этапах характеризуется централизацией энергоснабжения путем создания энергосистем и их крупных объединений, охватывающих значительные территории. Создана крупнейшая объединенная энергосистема, охватывающая большую часть Европейских районов СССР и Урала, суммарной мощностью около 50 млн. *квт*; созданы объединенные энергосистемы районов Северо-Запада, Закавказья, Западной и Восточной Сибири, Средней Азии. Основой объединенных энергосистем является достаточно широкая сеть электропередач напряжением 500 и 880 *кв*; построена и осваивается электропередача постоянного тока напряжением 800 *кв*, соединившая Донбасс и Волгоград; строится первая электропередача переменного тока напряжением 750 *кв* в районе Москвы.

ПЕРСПЕКТИВЫ РАЗВИТИЯ ЭЛЕКТРОЭНЕРГЕТИКИ В СССР

Если рассматривать промышленную программу развития атомной энергетики, то практический интерес представляет перспектива развития энергетики на ближайшие 15—20 лет. Рассмотрение более отдаленных этапов неизбежно принимает отвлеченный характер, поскольку быстрый прогресс науки и техники может открыть новые возможности, которые в настоящее время предусмотреть еще нельзя.

Основные задачи развития всей экономики СССР на период до 1980 г. были установлены в Программе КПСС, принятой в октябре 1961 г.

Опережающее развитие энергетики по-прежнему остается одной из основ экономического развития страны. Если объем всей промышленной продукции за 20 лет с 1960 по 1980 г. должен увеличиться не менее чем в 6 раз, то годовая выработка электроэнергии за этот период должна возрасти в 9—10 раз. Уровень выработки электроэнергии в 1970 г. определен в 900—1000 млрд. *квт·ч.* и в 1980 г.— в 2700—3000 млрд. *квт·ч.* Для обеспечения этих уровней выработки электроэнергии ежегодный ввод мощности на электростанциях должен возрасти к 1970 г. до 18—20 млн. *квт* и к 1980 г.— до 35—40 млн. *квт*.

Такие задачи вполне реальны. Для достижения выработки электроэнергии в 1980 г. 2700—3000 млрд. *квт·ч* необходим средний ежегодный прирост порядка 11%, а такой темп, как показано выше, практически имеет место в СССР в течение многих лет. Непрерывно возрастает ежегодно вводимая в действие мощность на электростанциях, и в настоящее время она составляет уже 10 млн. *квт*. Энергомашиностроительная промышленность не только полностью обеспечивает строящиеся электростанции всем оборудованием, но и экспортирует часть своей продукции в другие страны.

Технический уровень развития электростанций в рассматриваемый период до 1980 г. будет характеризоваться прежде всего дальнейшим их укрупнением. Намечено сооружение крупных гидроэлектростанций мощностью порядка 5000—6000 *Мвт* каждая и начата подготовка к строительству некоторых из них на Енисее и Ангаре. Для новых тепловых электростанций в настоящее время приняты типовые мощности в 1200 и 2400 *Мвт*, начато строительство нескольких электростанций мощностью порядка 3000 *Мвт*, а для одного из районов Сибири проектируется электростанция мощностью 4000 *Мвт*. Одновременно идет повышение единичной мощности агрегатов. В ближайшее пятилетие 1966—1970 гг. основными типами будут энергетические блоки мощностью по 200 и 300 *Мвт*; вслед за этим подготавливается широкий переход на блоки по 500 и 800 *Мвт*, и их удельный вес в общем вводе новой мощности на конденсационных электростанциях в этот период достигнет 90%; начата конструктивная разработка блоков большей мощности и изучаются целесообразные масштабы их применения. Предварительные расчеты показали, что развитие электростанций в рассматриваемый период может быть достаточно экономично решено при применении уже освоенных параметров пара, и еще нет экономических оснований предусматривать в сколько-нибудь значительных размерах применение более высоких параметров пара.

Одновременно намечается самое широкое развитие энергосистем и их объединений вплоть до создания единой энергетической системы Советского Союза, которая объединит Европейские районы и Урал с Сибирью и Средней Азией. Наряду с электропередачами переменного тока 750 *кв* мощностью порядка 2500 *квт* на одну цепь развернуты научные и проектно-конструкторские работы по созданию электропередач постоянного тока 1500 *кв* протяженностью 3000—4000 *км* с возможностью передачи по каждой цепи порядка 6000 *Мвт*. Такие электропередачи будут служить для переброски электроэнергии из районов с дешевыми в районы с более дорогими энергоресурсами.

Таким образом, в техническом отношении программа развития энергетики до 1980 г. опирается на уже освоенные технические решения. Наряду с этим ведутся широкие исследования по изысканию новых более эффективных способов и циклов производства электроэнергии и новых рабочих тел. Успешное разрешение новых научных и технических проблем рассматривается как резерв и будет способствовать более экономичной и быстрой реализации программы развития энергетики.

ЗАДАЧИ АТОМНОЙ ЭНЕРГЕТИКИ И ТРЕБОВАНИЯ К АТОМНЫМ ЭЛЕКТРОСТАНЦИЯМ

Для выполнения намеченной программы развития энергетики потребуются значительные первичные энергетические ресурсы. СССР располагает весьма богатыми собственными энергетическими ресурсами в виде гидроэнергии, угля, нефти, природного газа, торфа, горючих сланцев, размеры которых позволяют решить любую энергетическую задачу. Однако природное размещение энергетических ресурсов по огромной территории страны неравномерно, причем основная часть разведанных к настоящему времени ресурсов, к тому же наиболее дешевых и легко доступных, располагается в восточных районах страны.

В силу этого возникает целесообразность привлечения для районов, не располагающих собственными экономичными энергоресурсами, новых источников энергии и в первую очередь ядерной энергии.

Гидроэнергетические ресурсы СССР значительно превышают ресурсы любой другой страны и размеры технически возможной к использованию гидроэнергии определяются в настоящее время в 2100 млрд. *квт·ч* в год. Однако в Европейских районах СССР находится только около 15% гидроэнергоресурсов страны, а 85% — в Сибири, Средней Азии и на Дальнем Востоке. Использование только наиболее экономичных гидроресурсов, на базе которых могут быть построены крупные ГЭС при стоимости строительства на 1 *квт* установленной мощности на уровне тепловых электростанций и стоимости отпущенной электроэнергии 0,03—0,04 *коп*/*квт·ч*, позволит повысить выработку электроэнергии на гидроэлектростанциях СССР к 1980 г. по крайней мере в 3—4 раза по сравнению с 1965 г. Но при этом гидроэнергоресурсы Европейских районов СССР не только относительно невелики по своим размерам и не смогут играть большой роли в балансе электроснабжения этих районов, но и значительно менее эффективны экономически.

Весьма велики запасы углей в восточных районах, причем не только в малодоступных в настоящее время северных районах, где обнаружены колоссальные запасы углей, но и в обжитых районах. Помимо известного Кузнецкого каменноугольного бассейна в центральной и восточной Сибири, вблизи железных дорог, и в Казахской ССР, а также в некоторых других районах имеются столь крупные месторождения бурых и каменных углей, что там возможно в сравнительно короткие сроки организовать добычу угля в размере нескольких сотен миллионов тонн в год. Причем вся добыча будет организована в открытых карьерах большой производительности при относительно небольших капиталовложениях и низкой стоимости добытого угля. В Европейских районах СССР также имеются запасы углей, но характер их залегания и условия добычи менее благоприятны, требуются большие капиталовложения на строительство глубоких шахт и стоимость добычи углей высока. В ряде Европейских районов СССР имеются значительные запасы торфа и горючих сланцев, применение которых расширяется в меру экономической целесообразности, но которые не будут играть крупной роли в общем топливном балансе.

Быстрые темпы роста добычи нефти и природного газа до настоящего времени обеспечивались главным образом за счет месторождений Европейских районов СССР. Результаты успешных геологических разведок последних лет открывают большие перспективы добычи нефти и газа в Сибири и в Средней Азии.

В настоящем докладе не представляется возможным привести подробные количественные, качественные и экономические характеристики топливных ресурсов СССР. Однако очевидно, что хотя этих ресурсов в целом достаточно для развития экономики страны на длительный период, но в результате неравномерности размещения запасов по территории страны имеются довольно широкие перспективы применения ядерной энергии. Вместе с тем ясно, что для СССР вопрос о развитии АЭС — это в основном вопрос экономический и что СССР располагает достаточным временем для отработки наиболее целесообразных путей развития атомной энергетики и для избежания случайных решений.

Экономичность АЭС определяется в их сопоставлении с тепловыми электростанциями, работающими на обычном топливе. Указанное выше разнообразие условий топливоснабжения предопределяет существенное различие экономических показателей для тепловых электростанций в различных районах страны. В табл. 2 приводятся усредненные экономические показатели, которые могут считаться характерными для обычных тепловых электростанций рассматриваемого периода для четырех укрупненных зон СССР. Приведена себестоимость отпускаемой электроэнергии, в которую включаются: стоимость топлива, остальные эксплуатационные расходы и отчисления на амортизацию оборудования и сооружений. Приведены также расчетные затраты, которые приняты в СССР в качестве комплексного экономического показателя и которые кроме непосредственных расходов, связанных с производством электроэнергии, учитывают размеры капиталовложений для сооружения электростанции, обеспечения добычи топлива и его транспортировки.

Наиболее высокие показатели, как и следовало ожидать, получаются для Европейских районов СССР, и именно в этих районах следует прежде всего размещать АЭС. По мере улучшения своих экономических показателей АЭС смогут получить все большее распространение в этих районах, а затем найти место и в других районах страны.

Таблица 2

Зоны	Себестоимость, коп/квт·ч	Расчетные затраты, коп/квт·ч
Европейские районы	0,40—0,45	0,70—0,75
Урал	0,24—0,28	0,45—0,50
Сибирь	0,17—0,21	0,35—0,40
Средняя Азия и Казахская ССР	0,12—0,15	0,30—0,35

Распространению АЭС и ускорению темпов их строительства будет способствовать привлечение в энергетику в соответствии с заявлением Советского правительства от 21 апреля 1964 г. дополнительных количеств урана, ранее предназначавшихся для оборонных целей.

Современные АЭС еще дороги, и удельная стоимость строительства АЭС как в СССР, так и в других странах значительно выше обычных тепловых электростанций. Но надо учитывать, что АЭС находятся по существу в начальной стадии развития, в то время как тепловые электростанции прошли длительный путь развития и совершенствования. Поэтому прямое сопоставление по современным данным неправомерно. Необходим анализ причин современной высокой стоимости АЭС и возможных путей ее снижения. В СССР и в других странах за последнее десятилетие накоплен значительный опыт проектирования и строительства АЭС с реакторами различных типов, что может служить надежной основой для определения способов и реальных перспектив повышения экономичности АЭС.

Существенное значение для снижения удельной стоимости строительства АЭС имеет увеличение ее мощности. Мощность современных АЭС находится в пределах до 600 *Мвт*, в то время как для обычных тепловых электростанций массовой становится мощность в 1200—2400 *Мвт* и даже более. Расчеты применительно к Белоярской и Нововоронежской АЭС показали, что удвоение мощности АЭС может значительно понизить удельные капиталовложения. Увеличение мощности АЭС должно обязательно основываться на повышении единичной мощности реакторов и турбогенераторов. При увеличении мощности реакторов в 1,5—2 раза весьма существенно снижаются удельные капиталовложения.

Учитывая эти тенденции, на Белоярской и Нововоронежской АЭС начаты работы по строительству новых энергетических блоков с реакторами электрической мощностью до 350—400 *Мвт*. Созданы научные и технические предпосылки для создания реакторов значительно большей мощности, а также для строительства АЭС мощностью 1000 *Мвт* и более и уже ведутся конкретные проектно-конструкторские работы в этих направлениях.

Существенным средством улучшения экономических показателей является повышение рабочих параметров пара энергетического цикла АЭС, что наряду с улучшением к. п. д. АЭС обеспечит возможность повышения единичной мощности турбогенераторов и снижения удельного расхода пара и тем самым дополнительное снижение стоимости строительства. Необходимо переходить к более высоким температурам теплоносителя на выходе из реактора, а также внедрять перегрев пара. Практический опыт работы АЭС с ядерным перегревом пара в СССР и работы по повышению температуры теплоносителя в реакторах других типов позволяют рассчитывать, что в результате будет обеспечена возможность применения на АЭС рабочего пара тех же параметров, что и на современных тепловых электростанциях.

Огневой перегрев пара на АЭС с применением обычного топлива вряд ли может рассматриваться как перспективное направление, поскольку это весьма усложняет компоновку и эксплуатацию АЭС и в то же время не дает существенного экономического эффекта по сравнению с использованием этого топлива на обычных электростанциях.

Резервы снижения стоимости АЭС имеются также в технологических схемах и конструкциях. Построенные и строящиеся АЭС были запроектированы с некоторыми усложнениями в схемах и конструкциях впредь до накопления практического опыта эксплуатации. Опыт проектирования, строительства и эксплуатации показывает, что в дальнейшем можно будет без ущерба для надежности работы и радиационной безопасности существенно упростить защитные строительные конструкции, уменьшить количество дорогих конструкционных материалов, как, например, нержавеющей стали и т. п.

Таковы конкретные направления, которые позволяют в сравнительно небольшой срок существенно снизить стоимость строительства АЭС. Характерно, что эти пути принципиально совпадают с путями совершенствования и удешевления обычных электростанций.

Вместе с тем очевидно, что все эти возможности станут еще более реальными по мере последовательного сооружения целой серии АЭС, что одновременно будет еще одним существенным резервом снижения стоимости строительства за счет серийного производства оборудования вместо изготовления дорогих единичных установок.

Вместе со снижением стоимости строительства будет снижаться и стоимость электроэнергии, вырабатываемой АЭС, поскольку при этом снижается постоянная составляющая стоимости электроэнергии, зависящая от стоимости строительства. Кроме того, и в еще большей степени, снижение стоимости электроэнергии должно и может пойти по пути уменьшения ее топливной составляющей. Значительную долю стоимости топлива на АЭС составляет стоимость не только самого ядерного горючего, но и изготовления конструкций тепловыделяющих элементов. Помимо больших возможностей усовершенствования и удешевления конструкционных материалов снижение стоимости будет происходить тем быстрее, чем большие масштабы будет принимать строительство АЭС и соответственно более массовым и серийным станет изготовление топливных сборок. Существенные возможности удешевления электроэнергии содержатся также в увеличении глубины выгорания ядерного горючего. Опыт показывает, что практически могут быть достигнуты большие глубины выгорания, чем первоначально предполагавшиеся.

Одновременно с улучшением экономичских показателей АЭС необходимо техническое их совершенствование, имея в виду, что АЭС, как и всякая другая электростанция, должна обеспечивать бесперебойное электроснабжение потребителей и надежно работать при всех возможных эксплуатационных режимах. Следует стремиться к тому, чтобы реакторная установка в пределах своей проектной мощности допускала резкие сбросы нагрузки на любом этапе кампании активной зоны с немедленной готовностью к повторному подъему мощности и быстрый набор мощности, чтобы пуск из холодного состояния не требовал большего времени, чем на современных крупных электрических блоках, работающих на обычном топливе. Желательно, чтобы конструкция реактора позволяла производить перегрузку активной зоны без необходимости длительной остановки реактора со снятием давления и расхолаживанием. Необходимо упрощать технологические схемы, уменьшать количество вспомогательных агрегатов, различных аппаратов и арматуры. Весьма важно, чтобы совершенствование АЭС производилось без ущерба для обеспечения полной радиационной безопасности эксплуатационного персонала АЭС, а также населения, фауны и флоры района. Работы, которые проводятся во всех перечисленных направлениях, а также имеющийся опыт показывают, что эти условия могут быть обеспечены.

Кардинальное значение имеет вопрос о типах энергетических реакторов, которые должны быть приняты за основу как для первого этапа доведения АЭС до требуемого уровня экономичности, так и для последующей программы широкого их строительства. При решении этой задачи следует учитывать, что действительно перспективной атомная энергетика может стать только при условии обеспечения АЭС самой широкой топливной базой. Такой базой не может стать применение на АЭС только изотопа U^{235}, что явилось бы совершенно неразумным использованием ценного природного урана, содержащего в себе огромные потенциальные энергетические возможности. При больших масштабах и темпах развития всей энергетики АЭС могут внести существенный вклад в топливно-энергетический баланс и на достаточно длительный период только при условии использования в качестве топлива всего природного урана. Эту задачу не могут решить современные энергетические реакторы, работающие на тепловых нейтронах, поэтому настоятельно необходимым становится освоение и внедрение реакторов-размножителей.

Таковы задачи атомной энергетики и требования к атомным электростанциям, вытекающие из конкретных условий развития всей электроэнергетики Советского Союза.

ABSTRACT - RÉSUMÉ - АННОТАЦИЯ - RESUMEN

A/316 USSR

Development of electric power in the USSR and atomic power plants

By A. M. Nekrasov and G. S. Zelevinsky

Present power development in the USSR is characterized by a rapid growth of power capacity arising from the construction of large hydroelectric and thermal power stations, incorporating large units, and from the integration of separate power networks into larger power complexes.

The availability of practically unlimited resources of coal, oil, gas and hydroelectric power in the USSR makes it appropriate at the present time to build only prototype atomic power plants with

various reactor systems in order to accumulate experience in design, construction and operation of such plants.

The enormous scale of power development provided for in the USSR programme, and the unequal distribution of power-demanding regions and energy sources, will, however, make it necessary in the future to build a number of large atomic power stations, mainly in those districts where resources of fuel and hydroelectric power are limited.

The paper discusses the necessary conditions for the integration of atomic plants into the power networks of the USSR, and the main requirements that these plants will have to meet in order that their extensive introduction into the networks is economically justifiable.

A/316 URSS

Développement de l'énergie électrique en URSS et centrales nucléaires

par A. M. Nekrasov et G. S. Zelevinsky

Le développement actuel de la production énergétique en URSS se caractérise par un rapide accroissement des puissances installées, dû à la création de grandes centrales hydroélectriques et thermiques avec des groupes à puissance unitaire élevée, et à la réunion de différents réseaux en de très gros complexes énergétiques.

L'existence en URSS de réserves énormes de charbon, de pétrole et de gaz, et de ressources hydrauliques, lui permet pendant un certain temps de se limiter à la construction de centrales nucléaires prototypes avec différents types de réacteurs en vue d'accumuler de l'expérience dans l'étude, la construction et l'exploitation de ces centrales.

Le développement à grande échelle de l'énergétique, prévu dans le programme du Parti communiste, et la répartition inégale des régions de consommation d'énergie électrique ainsi que des sources énergétiques, exigeront à l'avenir la construction d'une série de grosses centrales atomiques, surtout dans les régions manquant de réserves de combustibles et de ressources hydrauliques.

Le mémoire expose certaines conditions nécessaires à l'introduction de centrales nucléaires dans le réseau énergétique de l'URSS, et les principales exigences auxquelles doivent satisfaire les centrales pour que leur large introduction dans les réseaux énergétiques soit économiquement rentable.

A/316 URSS

Desarrollo de la energética eléctrica en la URSS y centrales nucleares

por A. M. Nekrasov y G. S. Zelevinsky

El desarrollo energético actual de la URSS se caracteriza por el rápido aumento de las potencias instaladas mediante la entrada en funcionamiento de potentes centrales termo e hidroeléctricas con unidades de gran potencia, y también por la unificación de diversos sistemas en complejos energéticos muy potentes.

La existencia en la URSS de reservas prácticamente ilimitadas de carbón, petróleo, gas y de recursos hidráulicos permite limitarse, durante un cierto período de tiempo, a la construcción de centrales experimentales con distintos tipos de reactores, a fin de ir acumulando experiencia en el proyecto, construcción y explotación de dichas centrales nucleoeléctricas.

El enorme desarrollo energético previsto en el programa del Partido Comunista de la URSS y la irregularidad de la distribución de las zonas de consumo de energía eléctrica y de los yacimientos de recursos energéticos requerirán, en el futuro, la construcción de una serie de grandes centrales nucleares, principalmente en las zonas que no disponen de reservas de combustible suficientes, ni de recursos hidraúlicos.

En la memoria se consideran algunas premisas para la introducción de centrales nucleares en los sistemas energéticos de la URSS y los requisitos fundamentales que tendrán que cumplir dichas centrales para que esté justificada económicamente una amplia introducción de las mismas en estos sistemas.

Studies of the frequency and power regulation of a power system containing nuclear and water power stations

By D. Jungnell and T. Spanne*

The regulation properties of different types of nuclear power stations have been thorougly studied by many authors. However, the conditions when the nuclear power stations are connected to a power system have normally not been considered. As the share of nuclear power in the power systems grows, it will be increasingly important that the nuclear power stations are able to take a considerable part of the frequency control of the power system. Therefore it is important to study the suitability of using nuclear power stations for frequency regulation and their co-operation with water power stations.

The factors mentioned above are dependent on the properties of the nuclear power stations and the power system, for which reason no general rules can be given. However, as the procedure of investigating the frequency regulation is independent of the power system, a study of a special power system can be of general interest, and will therefore be described in this paper.

Description of the Swedish power system

At present 95% of the electrical energy production in Sweden consists of hydro power. The total installed hydro power connected to the network in 1963 was about 8 600 MW and the thermal power was about 2 100 MW. The total electrical consumption this year was somewhat more than 40×10^9 kWh. During the 1970s most water falls will be harnessed and nuclear power will mainly be used to cover the additional power demand. The hydro power stations are very suitable for frequency regulation. However, to get an accurate frequency control, the power of the frequency regulating stations must be a considerable part of the power of the system. Most of the hydro power stations are very small and there are only seven stations with a power above 200 MW. This number will not increase much because most of the big water falls are already harnessed. It is therefore desirable that the nuclear power stations will be able to take part in the automatic frequency control in the future.

Experimental investigations of the Swedish network by frequency analysis have been made [1]. They indicated that the transfer function from power to frequency during times with high loads could be written with good approximation.

$$f/P_n = G_n = \frac{1}{R_n(1 + T_n s)} \tag{1}$$

The first term in the denominator represents the frequency rigidity of the power system. The total kinetic energy of the system per MW generating capacity is equal to $\frac{1}{2}R_nT_n$. Studies made on later occasions prove that the changes of the characteristic properties of the network are so small that this formula is still approximately valid. For the present and the future network one can approximately write $R_n = 2.0$, $T_n = 7.5$ seconds. The low value of the frequency rigidity means that the self-regulating effect of the network is very small. The power change for a frequency change of 1 Hz will be only 4%.

A power system is always subject to rather large slow load changes during the day and the night. Smaller random load changes caused by connecting and disconnecting loads and generators are superposed on the slow larger changes. In the Swedish network the rapid load fluctuations are normally lower than 1% of the total load. The load consumers can demand that the frequency variations caused by these load variations are kept within very small limits. During normal operation the frequency is therefore kept within ± 0.1 Hz in the Swedish network according to international practice. With this condition the frequency variations will not give any inconvenience even to the most frequency-sensitive consumers.

The frequency control of the power system

In the Swedish power system only electrically operated turbine governors are used in the frequency regulating power stations, which has influenced the method applied for frequency control [2]. The electrical regulator is in many respects superior to the mechanical regulator used in many countries. Thus the permanent and temporary statism can easily be adjusted and adopted to the conditions of the power system. All the stations which take

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* Swedish State Power Board, Stockholm.

part in the frequency regulation can be given a weak permanent feedback. Therefore the frequency regulation is carried out in such a way that a small permanent statism down to 0.4% is introduced in a great number of larger stations so that the regulation work will be suitably distributed at the same time as the frequency error will be small. Normally the frequency regulation is chosen so that the permanent change in power production will be somewhat over 50% of the total power at a frequency change of 1 Hz, being equivalent to a permanent statism of less than 4% calculated on the total power of the system. A load change as large as 2% of the total power will then give a stationary frequency change of only about 0.04 Hz, hence an adequate margin from the permissible change. The self-regulation of the network is then less than 10% of the total contribution to the power adjustment.

The following transfer function between servomotor piston displacement and frequency is valid for an electrically operated turbine governor with a temporary feedback [3]. The notations are defined in the end of the report.

$$\eta/f = \frac{G_1}{1 - G_1\,(G_2 + G_3)} \qquad (2)$$

where $G_1 = -\frac{1}{\tau s}$; $G_2 = \delta$; $G_3 = \delta_t \frac{T_t \cdot s}{1 + T_t \cdot s}$

The transfer function from frequency to power at the water power stations also contains the inertia of the water as well as the relation between the servomotor piston displacement and the turbine power [3-4]. The transfer function from frequency to turbine power in the nuclear power stations can be determined from the differential equations of the reactor, turbine, and control systems as described in the following paragraph. It is assumed that all frequency regulating nuclear power stations are similar and that the same is true of the regulating water power stations. The system can then be represented according to Fig. 1.

The dynamic model of nuclear power stations containing reactors with heavy water moderator and coolant

The Swedish work within the nuclear power field has hitherto mainly been concentrated on pressure vessel, heavy-water-moderated reactors with pressurized and boiling heavy-water as coolant. In the studies reported in this paper it has therefore been assumed that the nuclear power stations are of these types. A simplified description is shown in Figs. 2 and 3. The fuel elements consist of rods of uranium oxide canned in Zircaloy and put into a tube. The coolant first flows into the moderator and then to the fuel element tubes. It has been necessary to give a fairly detailed description of the nuclear power stations.

For lack of space the equations describing the nuclear power reactors cannot be given here in detail but some comments will be made. We can also refer to a report of the Swedish State Power Board containing a detailed description of the equations.

At the rather slow and small transient deviations from steady state which will occur when nuclear power stations take part in the automatic frequency regulation, and as the reactor core will not be studied in detail but only the influence of the reactor on the rest of the system, it will be sufficient to write the kinetic equations of the reactor in one neutron energy group model and point geometry. The delayed neutrons are represented by four groups, where the most short-lived emitters are put together in one group and the most long-lived ones, which are of only little yield, in another group. Reactivity changes caused by changes of fuel temperature, void, moderator temperature, xenon poisoning and position of control rods are considered.

For the pressurized water reactor with steam generator according to Fig. 2 thermodynamic equations of point model have been used for this study. These equations are similar to those normally used for pressurized reactors [5].

For the boiling heavy water reactor with natural circulation according to Fig. 3 linearized equations of point model are used. The equations are based on many assumptions which cannot be related here for lack of space. Similar models for boiling reactors have been described in great detail in literature [6-9]. The pressure drops are dealt with in the same way as in ref. [10]. The relation between relative void, steam quality and pressure in the boiling channels is based on data given by Martinelli-Nelson [11].

The turbine uses saturated steam and the turbine system is designed according to Fig. 4. Throttle regulation is assumed and the valve characteristic is chosen linear within the range of interest. For the feed water heaters according to Fig. 4, equations are written in point model with one equation for each heater. The transport lag in the feed water pipelines is approximated with complete mixing of the water in the pipe. In the pressurized water reactor case the transport lag in the feed water pipelines is so large that three equations for successive mixing have been chosen to represent the time delay from the feed water heater to the steam generator [12-13].

The following principle has been chosen for the control system of the nuclear power stations. The frequency change is assumed to influence only the turbine valve. A permanent but no temporary feedback from the piston displacement is assumed according to equation (2) with $G_3 = 0$. The reactor power is adjusted to the turbine power by a continuously acting control system consisting of an integrating stabilizing circuit for the neutron flux according to the equation

$$\delta k_c = -K_1\,(\phi - \phi_r) \qquad (3)$$

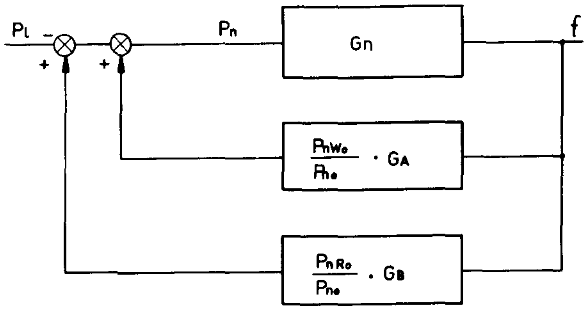


Figure 1. Block diagram of a power system with frequency regulating water and nuclear power stations

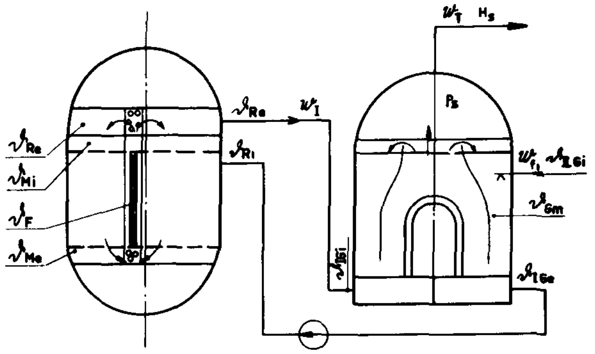


Figure 2. Simplified diagram of the pressurized water reactor plant

When a combined regulation of the outlet temperature of the reactor and the pressure of the steam generator is used in the pressurized water reactor the reference value ϕ_r is formed in the following way

$$\phi_r = K_2 w_{mT} - K_3 \cdot \theta_{mRe} - K_4 \cdot p_{ms} - \int (K_5 \cdot \theta_{mRe} + K_6 \cdot p_{ms}) \mathrm{d}t \qquad (4)$$

For the pressurized water reactor investigations are also made when only the outlet temperature of the reactor is regulated ($K_2 = K_6 = 0$) and when only the pressure of the steam generator is regulated ($K_3 = K_5 = 0$). For the boiling reactor a regulation of the pressure of the reactor ($K_3 = K_5 = 0$) is used. For describing the primary elements for measuring temperature, pressure and flow simple time constants have been used.

For the control of the feed water flow the following simplified equation has been used

$$w_f + T_f w_f = K_7 (w_T - w_f) + K_8 \int (w_T - w_f) \mathrm{d}t \qquad (5)$$

Summary of studies performed

With the dynamic model developed a power system containing water and nuclear power stations can be investigated by different methods, e.g., by step disturbances or by frequency analysis.

A great number of studies have been carried out where the disturbances were step load changes. Only some characteristic studies can be shown here for lack of space. Some introductory studies of the regulation properties of water power stations were carried out by using detailed equations. It could be shown that the temporary feedback, which reduces the tendency to oscillations but has only little influence on the magnitude of the first swing, could be neglected without any great error in this study; this can also be done with the inertia of the water.

The results of positive step changes of 2% of the total load, shown in Figs. 5-8, will give a good idea of the behaviour at the greatest conceivable fast load disturbance. Comparison has been made between cases with only water power, only nuclear power and half of each as regulating power and with different values of this power. The behaviour by using either boiling or pressurized water reactors with different control systems or self-regulation of the reactor has been studied. The control systems used at the investigations have been roughly opti-

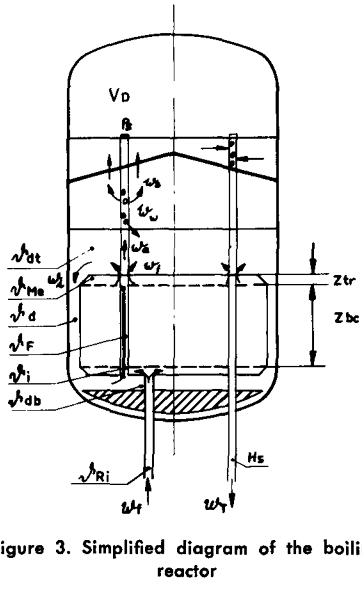


Figure 3. Simplified diagram of the boiling reactor

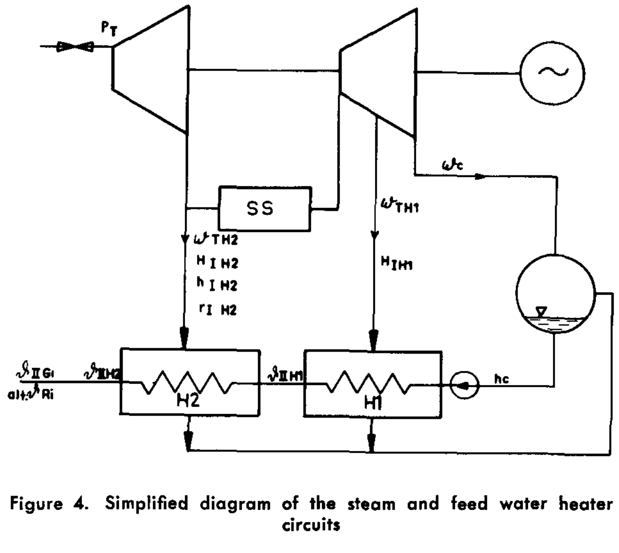


Figure 4. Simplified diagram of the steam and feed water heater circuits

$\tau_R = \tau_W = 0.5$ SEC $\delta_R = \delta_W = 0.5$ %
SELF-REGULATING REACTORS

$\tau_R = \tau_W = 0.5$ SEC $\delta_R = \delta_W = 0.5$ %
REACTORS WITH PRESSURE CONTROL

THE POWER OF THE FREQUENCY REGULATING STATIONS 15 % OF THE NETWORK POWER

$\tau_R = \tau_W = 0.5$ SEC $\delta_R = \delta_W = 0.5$ %
REACTORS WITH PRESSURE CONTROL

$\tau_R = \tau_W = 0.5$ SEC $\delta_R = \delta_W = 1.0$ %
REACTORS WITH PRESSURE CONTROL

THE POWER OF THE FREQUENCY REGULATING STATIONS 30 % OF THE NETWORK POWER

1. $P_{RTO} = 0$ %
2. $P_{RTO} = 50$ %
3. $P_{RTO} = 100$ %

} OF THE POWER OF THE FREQUENCY REGULATING STATIONS

Figure 5. Frequency and power changes by a step change of +2% in load in a system containing frequency regulating water power and boiling reactor power stations

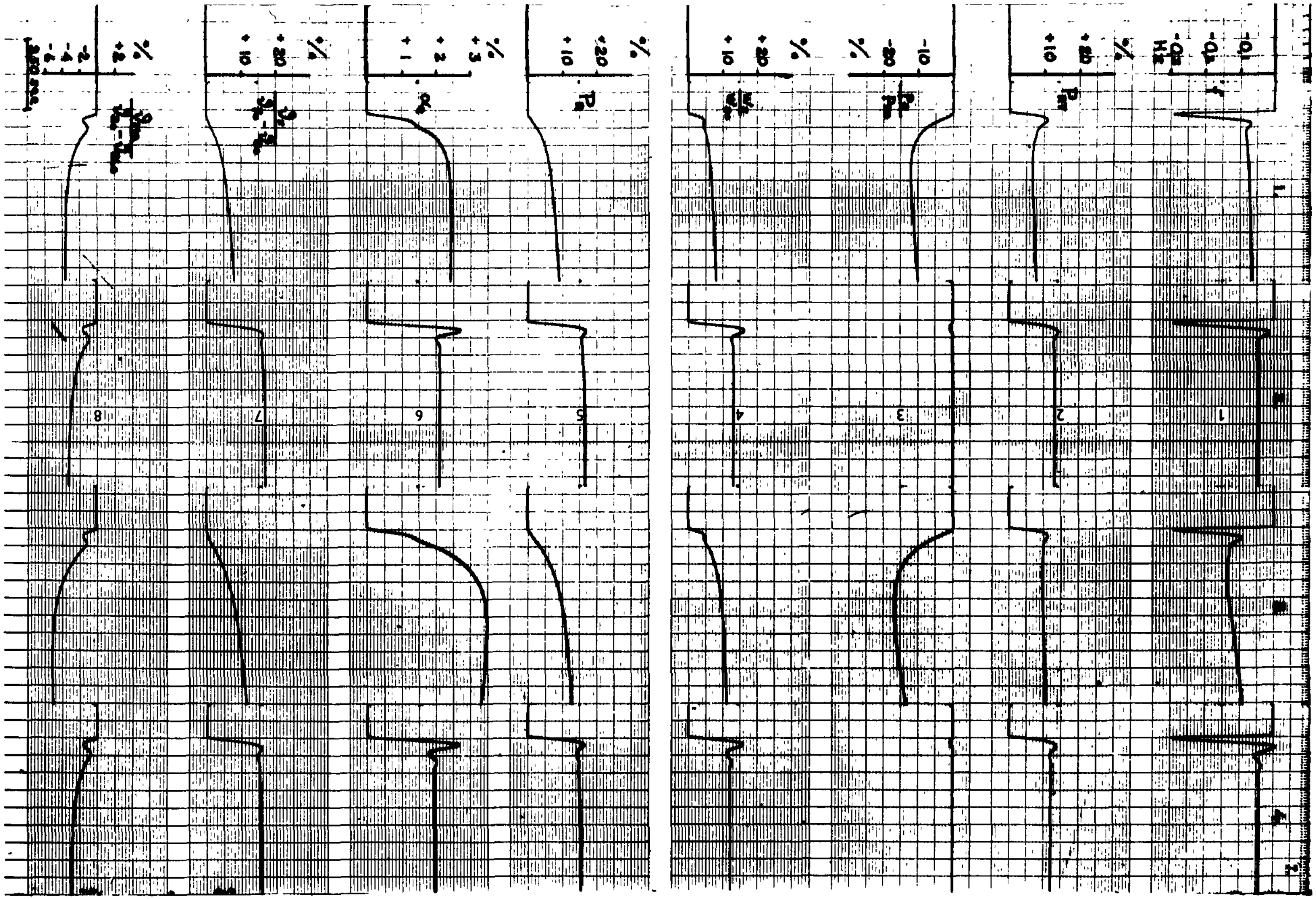
τ_R = 2 SEC τ_W = 0.5 SEC $\delta_R = \delta_W$ = 0.5 %	τ_R = 2 SEC τ_W = 0.5 SEC $\delta_R = \delta_W$=0.5 %	τ_R = 0,5 SEC τ_W = 0.5 SEC $\delta_R = \delta_W$ = 0.5 %	τ_R = 0.5 SEC τ_W = 0.5 SEC $\delta_R=\delta_W$=1.0 %
SELF-REGULATING REACTORS	REACTORS WITH CONTROL OF THE OUTLET TEMPERATURE		

THE POWER OF THE FREQUENCY REGULATING STATIONS 30 % OF THE NETWORK POWER

1. P_{RTO} = 0 %
2. P_{RTO} = 50 %
3. P_{RTO} = 100 %

} OF THE POWER OF THE FREQUENCY REGULATING STATIONS

Figure 6. Frequency and power changes by a step change of +2% ***in load in a system containing frequency regulating*** **water power and pressurized reactor power stations**



THE POWER OF THE FREQUENCY REGULATING STATIONS 15 % OF THE NETWORK POWER

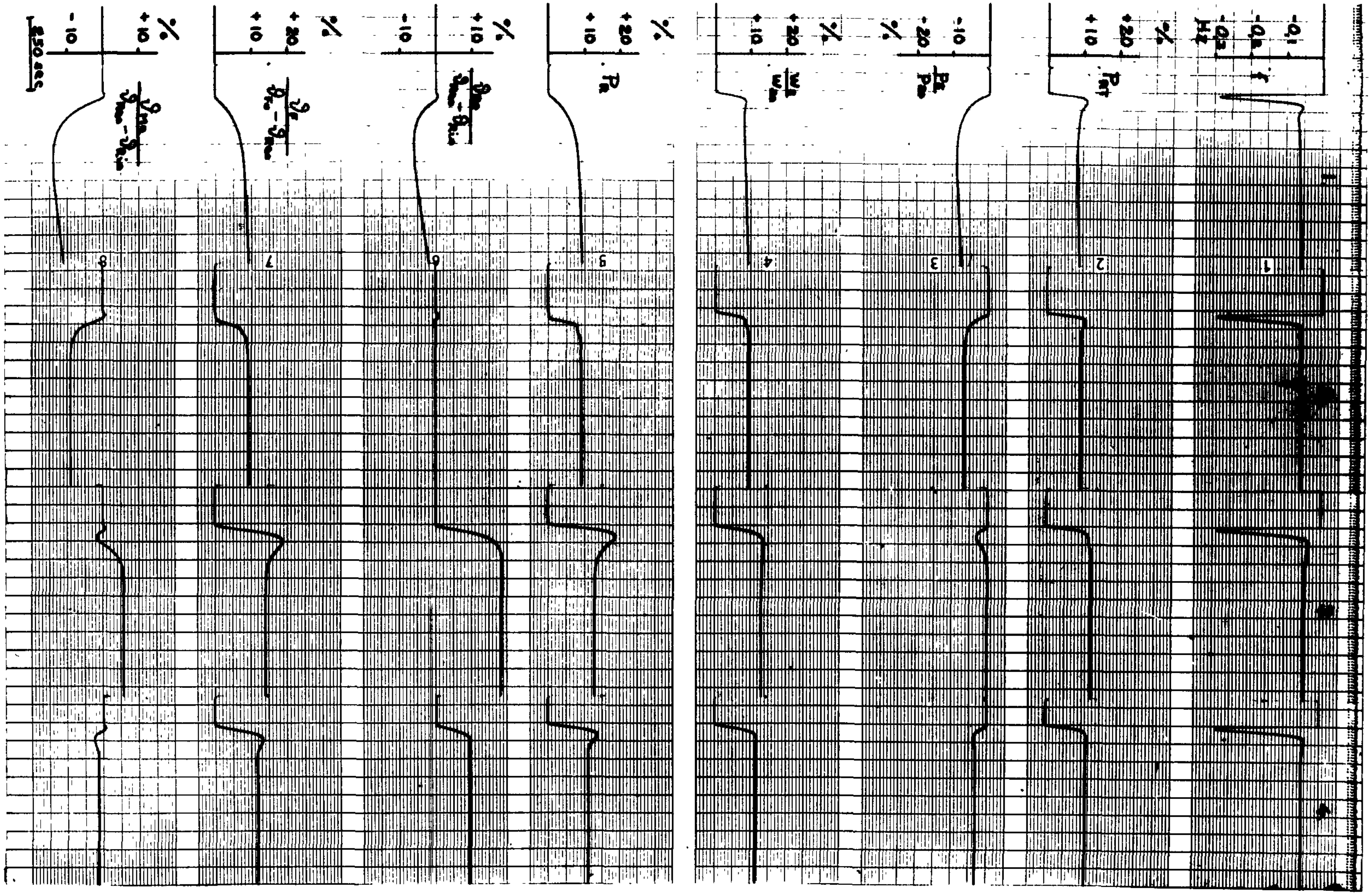
1. SELF-REGULATING REACTORS
2. REACTORS WITH PRESSURE CONTROL

} P_{RTO} = 50 % OF THE POWER OF THE FREQUENCY REGULATING STATIONS

3. SELF-REGULATING REACTORS
4. REACTORS WITH PRESSURE CONTROL

} P_{RTO} = 100 % OF THE POWER OF THE FREQUENCY REGULATING STATIONS

Figure 7. Various transients in frequency regulating boiling water reactor stations by a step change of +2% in load



THE POWER OF THE FREQUENCY REGULATING STATIONS 15 % OF THE NETWORK POWER, $P_{RTO} = P_{WTO} = 50$ % OF THE POWER OF THE FREQUENCY REGULATING STATIONS

1. SELF-REGULATING REACTORS
2. REACTORPLANTS WITH CONTROL OF REACTOR OUTLET TEMPERATURE (Alt. A)
3. REACTORPLANTS WITH CONTROL OF STEAM GENERATOR PRESSURE (Alt. B)
4. REACTORPLANTS WITH COMBINED CONTROL OF REACTOR OUTLET TEMPERATURE AND STEAM GENERATOR PRESSURE (Alt. C)

Figure 8. Various transients in frequency regulating pressurized reactor power stations by a step change of +2% in load

mized during some introductory tests. The permanent statism and the characteristic time of the turbine valve have been varied (Figs. 5 and 6). Many of the parameters of the nuclear plants have been registered; Figs. 7 and 8 are shown as examples.

Discussion

To obtain a comparison between water and nuclear power stations as frequency regulating stations, a number of studies were made with the same data of the turbine regulators for the two types of stations. If the nuclear power stations are equipped with a suitable control system for the reactor one will in this case get about the same frequency regulation whether the regulation is carried out by only nuclear, only water or a combination of nuclear and water power stations (Figs. 5 and 6).

At a load change of 2% of the total power and a regulating power of 15 or 30% a frequency deviation greater than 0.1 Hz will only be obtained during a time of about 30 or 15 seconds respectively. One of the reasons for this insignificant difference between nuclear and water power stations is, that the former stations are equipped with such large steam drums that the pressure before the turbine valves will change very slightly after a disturbance; at the same time a change in the production of steam will occur immediately, which will adjust the reactor power.

For the first transient frequency deviation it does not matter if the reactors are equipped with power control or not. However, it is important for the stationary frequency deviation and for the distribution of the load between water and nuclear power stations that the reactor power is regulated in a suitable way. Nuclear stations with boiling reactors having constant pressure regulation are very good in this respect.

When using pressurized water reactors the frequency regulation will be as good as in the case mentioned above if the pressure of the steam generator is regulated. At a load increase the outlet temperature of the reactor will increase, however, and if this increase cannot be allowed one has to regulate the temperature instead. In this case the regulation will not be much better than that obtained when using a self regulated reactor. If the pressurized water reactor is to be used for frequency regulation it has to be designed so as to allow pressure regulation.

As can be seen from Figs. 5 and 6, a self regulated reactor cannot be accepted if the nuclear stations alone carry out the frequency regulation, since the stationary frequency deviation will be too great. If water and nuclear power stations regulate in cooperation and if the water power stations can endure the overload, the frequency regulation would be acceptable as the latter station would take a comparatively greater power.

An important factor which has to be considered when choosing the data of the control system is that owing to the thermal strain, the power of the steam turbine is not allowed to change too rapidly. The demands are particularly severe for the high pressure turbines which should normally not be exposed to more rapid load changes than 4% per minute, but which on special occasions can endure about 10% per minute. Turbines for more moderate pressures, which will be used in these types of nuclear power stations, can endure higher load changes, instantaneously 10% and greater changes at a rate of normally 10% per minute and maximum 20% per minute. As can be seen from Figs. 5 and 6, the maximum change is about 15% in half a minute in the most unfavourable case whether the nuclear power stations regulate alone or together with water power stations and whether the power of the regulating stations is 15 or 30% of the total power. Thus the regulation is too rapid in this case and cannot be allowed. The initial rate of the turbine power change is particularly influenced by the characteristic time of the turbine valve. If one chooses a greater value of this parameter in the nuclear than the water power stations, one will get greater frequency variations when the nuclear power stations take the whole or a part of the frequency regulation than when only water power stations do this. When water and nuclear power stations work together the former will take a greater part of the regulation during the transient. In the case shown in Fig. 6, with a characteristic time of 2 seconds for the steam turbine regulators and 0.5 seconds for the water turbine regulators, the load change of the steam turbines will be 12% per minute. A shorter characteristic time than 2 seconds could therefore be allowed.

In order to be equivalent to water power stations the nuclear power stations in the case mentioned above should be able to endure a load change of about 30% per minute. If, for example the permanent statism and the characteristic time of the turbine regulator are chosen 50% greater than in the case shown in Fig. 5, and if the regulating nuclear power is also increased by 50%, one should get the same frequency regulation as in Fig. 5 at the same time as the total power change at the steam turbines would be somewhat less than 10% and the load change rate about 20% per minute, which are acceptable values. This gives a measure of the difference in regulating efficiency between water power stations and nuclear power stations equipped with pressure vessel heavy water reactors when used for frequency regulation.

A problem which is important not at the rapid load changes around the equilibrium state but at the slow larger load changes during day and night is the xenon poisoning. One has to supervise and adjust the power production by connecting and disconnecting stations at great load changes so that each individual station does not get such a high remaining load decrease that the xenon poisoning will be too large and the station will be shut off.

However, the same procedure has to be used in a network with only water power stations for frequency regulation as it is desirable to operate all the stations as near as possible to the optimum efficiency. Therefore there is no important difference in the supervision requirements in these cases.

Summary

Studies of frequency regulation by nuclear power stations containing heavy water reactors in cooperation with water power stations have been carried out on an analogue computer. For this reason a dynamic model of the total power system containing nuclear and water power stations with their control systems is developed.

The studies show that it is always possible to design a control system for the nuclear power stations studied so that these stations will be suitable for frequency regulation and that they will cooperate well with frequency regulating water power stations. However, owing to limitations caused by the thermal strain of the steam turbines the valve characteristic time of the nuclear stations cannot be made as low as that of the water power stations for which reason one has to use a greater frequency regulating nuclear power to get an equivalent frequency control. The types of nuclear power stations studied in this paper should have about 50% greater regulating power in order to be equivalent to water power stations.

SYMBOLS

Constant parameters

G = transfer function
K = control coefficient
R = frequency rigidity of the unregulated network
T = time constant, time delay
δ = statism of regulator
τ = characteristic time of regulator

Variables

The following symbols denote without index "0" deviations from corresponding steady state values; these are indicated with the same symbol using index "0". The symbols f, P, η and ϕ represent changes divided by their steady state values.

f = frequency of power system
P = power
p = pressure
t = time
w = total mass flow
α = void fraction
η = piston displacement of main servomotor
θ = average temperature
ϕ = mean neutron flux in the fuel
δk = reactivity

Indices

c = control
e = outlet, spec. outlet of channels in reactor
F = fuel
f = feed water
M = Moderator
m = measuring unit, primary element
n = network
0 = steady state
R = reactor, nuclear power station
r = reference, set point
s = at saturation, spec. saturated steam from boiling channels in reactor and steam generating zone in steam generator
T = turbine
t = temporary feedback
W = water power (station)

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ABSTRACT - RÉSUMÉ - АННОТАЦИЯ - RESUMEN

A/606 Suède

Etudes sur la régulation de fréquence et de puissance d'un réseau de distribution électrique comprenant des centrales nucléaires et des centrales hydrauliques

par D. Jungnell et T. Spanne

Au fur et à mesure que la part de l'énergie d'origine nucléaire augmente dans un réseau de distribution électrique, les centrales nucléaires joueront un rôle plus important dans le contrôle de la fréquence de ce réseau. En raison de la précision requise en matière de contrôle de fréquence, des exigences spéciales seront imposées aux centrales nucléaires assumant ce rôle.

Pour cette raison, le mémoire étudie dans quelle mesure il est convenable d'utiliser des centrales à réacteurs à eau lourde sous pression ou bouillante en même temps que des centrales hydrauliques pour la régulation de la fréquence sur le réseau suédois. A l'heure actuelle, ce réseau assure une puissance

totale de 8 000 MW. Les variations rapides de la charge ne dépassent pas en général 1%. Dans les centrales de régulation de fréquence, on utilise des régulateurs électriques dont le statisme permanent peut être aussi bas que 0,4%. La régulation de fréquence est généralement choisie de telle sorte que le changement permanent de production d'énergie électrique ne dépasse guère 50% de la puissance totale pour une variation de fréquence de 1 Hz.

Des études sur la régulation de fréquence par des centrales nucléaires couplées avec des centrales hydro-électriques ont été effectuées à l'aide d'un calculateur analogique, et l'on met au point pour cela un modèle dynamique du réseau. Les centrales nucléaires assurant la régulation de fréquence et les autres centrales de régulation de fréquence sont considérées comme étant deux éléments distincts, et le reste du réseau est représenté par une fonction de transfert empirique simplifiée entre puissance et fréquence. Etant donné que l'action compensatrice apportée par la contribution du reste du réseau au contrôle de la fréquence est faible par rapport à la contribution des centrales régulatrices de fréquence, la précision de ce modèle du reste du réseau peut être considérée comme suffisante. On admet que les réacteurs des centrales nucléaires régulatrices de fréquence sont du type à eau lourde bouillante ou sous pression. Pour ces centrales on utilise un modèle analogique détaillé, comprenant des modèles partiels du réacteur avec les appareillages de contrôle et les turbines à vapeur avec vannes et régulateurs, de manière à pouvoir étudier les variations transitoires de la puissance, de la pression et de la température dans les différentes parties du système du réacteur.

On a étudié les conditions de puissance réglée et non réglée du réacteur pour différentes valeurs du statisme des régulateurs des turbines. On a étudié aussi différents principes de régulation pour l'ajustement de la puissance du réacteur à la charge ainsi que l'influence des variations transitoires sur le réacteur et ses principaux éléments. Il a été procédé à une comparaison entre les centrales nucléaires et les centrales hydrauliques utilisées pour la régulation de fréquence. La coopération entre ces centrales lors de différentes perturbations de la charge a été l'objet d'un examen particulier.

Les études montrent qu'il est toujours possible d'imaginer un système de contrôle pour les réacteurs des centrales nucléaires pour que celles-ci conviennent pour la régulation de fréquence et coopèrent bien avec les centrales hydro-électriques régulatrices de fréquence. Cependant, compte tenu des limitations imposées par les contraintes thermiques dans les turbines à vapeur, la régulation de l'admission ne peut être aussi rapide dans les centrales nucléaires que dans les centrales hydrauliques. Il faut donc une puissance installée nucléaire plus grande pour avoir une régulation de fréquence équivalente. Les centrales nucléaires étudiées dans le mémoire doivent avoir une puissance supérieure de 50% environ à celle des centrales hydro-électriques pour donner une régulation de fréquence équivalente.

A/606 Швеция

Изучение проблемы стабилизирования частоты и мощности электроэнергетической системы, включающей атомные и гидроэлектростанции

Д. Юнгнелл, Т. Спанне

В связи с ростом роли ядерной энергетики в электроэнергетической системе она будет играть все более важную роль в стабилизировании частоты. Ввиду точности, необходимой для стабилизирования частоты, особые требования будут предъявляться к стабилизирующей частоте атомных электростанций.

Поэтому в настоящем докладе рассматривается вопрос о целесообразности использования в электроэнергетической системе Швеции энергетических реакторов с водой под давлением и кипящих тяжеловодных реакторов вместе с гидроэлектростанциями для стабилизирования частоты. В настоящее время общая мощность электроэнергетической системы Швеции составляет около 8600 *Мвт*. Быстрые изменения нагрузки обычно не превышают 1%. На станциях, поддерживающих заданную частоту, используются электрические регуляторы с постоянным статизмом не более 0,4%. Как правило, стабилизирование частоты выбирается таким образом, чтобы постоянное изменение в вырабатываемой электроэнергии составило лишь немногим больше 50% общей мощности при изменении частоты на 1 *гц*.

Изучение стабилизации частоты путем использования атомных электростанций в сочетании с гидроэлектрическими станциями будет проведено при помощи аналоговой вычислительной машины. Для этого была разработана динамическая модель электроэнергетической системы. Атомные электростанции, регулирующие частоту, и другие стабилизирующие частоту станции рассматриваются как две отдельные части, тогда как оставшаяся часть электроэнергетической системы представлена упрощенной эмпирической переходной функцией между мощностью и частотой. Поскольку компенсирующий вклад остальной части электроэнергетической системы в стабилизирование частоты невелик по сравнению с вкладом станций, стабилизирующих частоту, то точность этой модели остальной части электроэнергетической системы может считаться достаточной. Принимается, что на регулирующих частоту атомных электростанциях используются такие типы реакторов, как кипящий реактор и реактор с тяжелой водой под давлением. Для этих атомных электростанций используется подробная аналоговая модель, включающая блочные модели реактора с системой управления и паровые турбины с клапанами и системой управления, позволяющая изучить переходные режимы мощности, давления и температуры в различных частях реакторной системы.

Изучены также условия как регулируемой, так и нерегулируемой мощности реактора при различных значениях статизма турбинных регуляторов. Исследованы различные принципы регулирования для согласования мощности реактора с нагрузкой, а также влияние переходных режимов на реактор и его основные узлы. Проведено сравнение между атомными и гидроэлектростанциями, используемыми для стабилизирования частоты, и будет особо рассмотрено взаимодействие между этими станциями при различных изменениях нагрузки.

Исследования показали, что всегда имеется возможность создать такую систему регулирования для изучаемых атомных электростанций, чтобы эти станции можно было использовать для регулирования частоты и чтобы они могли работать одновременно со стабилизирующими частоту гидроэлектростанциями. Однако вследствие ограничений, обусловливаемых термическими напряжениями в паровых турбинах, характеристическое время клапанов на атомных электростанциях нельзя сделать таким же малым, как на гидроэлектростанциях, из-за чего пришлось бы для такой же стабилизации частоты подключать станцию большей мощности. Изученные в настоящем докладе типы атомных электростанций требуют примерно на 50% большей мощности для стабилизации частоты, чем гидроэлектростанции.

A/606 Suecia

Estudios sobre la regulación de frecuencia y energía en un sistema generador constituido por centrales nucleares e hidráulicas

por D. Jungnell y T. Spanne

En un sistema de energía eléctrica la proporción de energía nuclear crece y como consecuencia tendrá un papel más importante en el control de frecuencia de este sistema. A causa de la precisión requerida en el control de frecuencia será necesario exigir condiciones especiales a las centrales nucleares que regulen la frecuencia.

Por esta razón, en esta memoria se estudia la conveniencia de emplear centrales con reactores de agua pesada en ebullición y bajo presión en unión de centrales hidráulicas para la regulación de frecuencia en la red eléctrica sueca, que, actualmente, tiene una potencia total instalada de unos 8 600 MW. Las variaciones rápidas de carga no superan normalmente el 1%. En las centrales reguladoras de frecuencia se emplean reguladores eléctricos con un estatismo permanente inferior al 0.4 %. Normalmente se elige la regulación de frecuencia de manera que la variación permanente en la producción de energía sea un poco mayor del 50 % de la energía total si el cambio de frecuencia es de 1 Hz.

Se han realizado en un computador analógico estudios de regulación de frecuencia mediante las centrales nucleares en combinación con centrales hidráulicas, para lo cual se desarrolló un modelo dinámico del sistema generador. Las centrales nucleares reguladoras de frecuencia y el resto de las centrales que efectúan el mismo papel se tratan como dos partes separadas, mientras que las restantes del sistema eléctrico se representan por una función de transferencia, empírica y simplificada, entre energía y frecuencia. Como el resto de la red contribuye muy poco a compensar el control de frecuencia en comparación con las centrales de regulación de frecuencia, se considera suficiente la precisión del modelo del resto de la red. Se supone que los reactores de las centrales nucleares reguladoras son de los tipos de agua pesada a presión y ebullición. Para estas centrales se emplea un modelo analógico detallado, incluyendo modelos puntuales del reactor con sistema de control y de las turbinas de vapor con válvulas y sistema de control, de modo que puedan estudiarse en las diferentes partes del reactor los estados transitorios de potencia, presión y temperaturas.

Se estudian las condiciones de la potencia del reactor, tanto regulada como sin regular, para diferentes valores del estatismo de los reguladores de la turbina. Se investigan distintos principios de regulación para ajustar la potencia del reactor a la carga, así como la influencia de los estados transitorios en el reactor y los componentes principales. Se efectúa una comparación entre las centrales nucleares y las hidráulicas empleadas para regulación de frecuencia y se considera, especialmente, la cooperación entre estos dos tipos de centrales para diferentes perturbaciones de carga.

Este estudio demuestra que siempre se puede proyectar un sistema de control para las centrales nucleares de modo que sirvan para regular la frecuencia y que de ese modo colaboren adecuadamente con las centrales reguladoras de frecuencia hidráulicas. Sin embargo, no se pueden conseguir con una central nuclear tiempos muertos de las válvulas tan pequeños como los de una central hidráulica a causa de las limitaciones térmicas de las turbinas de vapor, por lo que se necesita mayor potencia reguladora nuclear para obtener el mismo resultado. Los tipos de centrales que se estudian en este trabajo habrían de tener como un 50 % más de capacidad de regulación para poderlas considerar equivalentes a las centrales hidráulicas.

Analysis of the technical and economical aspects of the inclusion of a nuclear power station in electric networks of various sizes for self-producers or national distribution

By S. Pittori,* C. Del Tredici,* D. Dini,* G. Mussari,** L. Orsoni,** L. Biondi** and A. Vaudo**

"Nuclear power is on the threshold of economic competitiveness." This is the view of a number of reports over the last few years beginning with that of USAEC in December 1962 and taking us up to the most recent estimates of plant manufacturers. Specifications accompanying nuclear power stations offered for sale by the latter include unit-cost estimates which are already competitive, assuming a utilization factor of between 7 000 and 8 000 hours yearly. The fact remains, however, that the criteria for judging a given nuclear plant to be competitive cannot be sought exclusively in a mere comparison with a thermoelectric station of comparable power rating and for identical load factors, but demands that, taken over the entire life of the plant, the total of fixed and operating costs of the entire electric system of which it forms part shall be lower than that for any alternative method of production including that of the conventional thermal plants. The final problem facing a self-producer company or a state generating board accordingly reduces to that of covering future power requirements in a manner that shall be technologically and economically the most sound, whether the solution be to have thermoelectric units, nuclear units or a mixture of the two. Nuclear energy, therefore, must demonstrate its competitiveness in the framework of a "programme" [50-51].

The purpose of this paper, therefore, is to put forward a method of comparing from a technological and economical standpoint the alternative plants — hydroelectric, thermoelectric and nuclear — proposed as a means of supplying the power needs of an expanding network. Using the method proposed here it will be possible to frame a programme and, concomitantly, evaluate the economics of its major features (overall costs of the alternative solutions, the different formulae for combining nuclear and thermoelectric production, load factors of each generating unit, transmission losses and utilisation of hydroelectric potential).

Outline of methodology

The present paper is based on a methodology that follows practice evolved in other countries, in particular the United States, in the matter of the technical planning of electric systems. Of the various possible methods, the one adopted here is close to those that, although under different names, set out to analyse the technical and economic characteristics of a power station construction programme. Such analyses proceed by reproducing all network load and demand conditions, assuming the feeding of such generating stations into the grid, and simulating their co-ordinated operation. Experience shows that once the system is perfected, the analysis of its economic rate and of the technical efficiency of the different solutions that may be tried out can be performed rapidly, calling for a relatively small number of machine hours on a high-speed computer. The findings are always very numerous and require careful interpretation [49].

A more detailed description of the phases over which the planning method may be deployed, by means of simulation techniques, has been explained in a previous CNEN report [53]. The present paper, nevertheless, follows a line that departs somewhat from the above mentioned report by introducing a certain number of simplifications.

STUDY OF A NUCLEAR PLANT PROGRAMME

Introduction

Following from the above described aims, this part of the paper consists of an example of a programming operation for a relatively simple electrical system. We shall here consider a mixed hydro/thermoelectric system of the kind likely to be found in an industrial self-producer group or in a developing country.

The following need to be known: (*a*) the installed power suitable for the system in question, adequate to cover the possible future load-growths; (*b*) whether consideration should be given to including nuclear power stations among those envisaged in the programme. If so, what is the most economic proportion for nuclear production?; (*c*) the appro-

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priate scheduling of starting operation date of future units; (*d*) total capital cost and annual operating expenses for the entire system, for each alternative under consideration; (*e*) the role of the different generating units in the system, the load factor of each, the incremental costs of the energy produced and the transmission losses; (*f*) the determination of the programme of new stations likely to possess the best technical and economic characteristics.

Accordingly, the methodology which has been described in a CNEN report [53] will be followed. This methodology is summarized in Fig. 1. For the calculation performed in the present report, the following simplifications have been adopted.

Outline of simplifications adopted

The characteristics of power stations existing in year zero — the beginning of the programme — have been exactly represented in a computation code; the curves showing specific consumptions, efficiencies and incremental consumptions for each of the hydroelectric and thermoelectric plants in the system will be found in the figures that follow.

As far as the forecasting load is concerned, only one growth-load trend is assumed as known, and probable deviations will not be computed. As regards the choice of the alternatives, the number of the latter has been restricted to three. In order to arrive at their determination, certain criteria for a first approximation have been followed. These have been assembled and described in a report CNEN-Montecatini, already available [54]. That part of the methodology relating to the scheduling of operation starting date of the new generating plants has been handled on probabilistic principles, as described in a previous CNEN report [55]. In computing the net available power it has been assumed that no forced outage occurs during days of peak load. For the distribution of the load among the plants, a code has been developed to simulate a co-ordinated operation of the entire system of hydroelectric, thermoelectric and electronuclear plant supplying the grid, hour by hour, for all characteristic days of the years envisaged by the programme. The operational principles of the computation code appears in a EURATOM report already published [52].

With the foregoing provisions established there now follows, as an example, a trial planning for an imaginary electric system, though one having characteristics very close to those of one sector of the Italian grid. The method set forth here, however, may be applied to any system, whether in the hands of concerns, self-producer companies or public generating and distribution boards. The main point of the example below is to put forward a method of appraising the economics of bringing into the generating system one or more electronuclear plants with a view to testing the ability of the latter to compete under operational conditions.

Example of planning

Phase 1 — Reproduction of plant characteristics

The assumption is made of a hypothetical system, but one possessing characteristics very similar to those of a known existing system. In the year of the start of the programme, the system is taken as composed of 6 thermoelectric units for a generating capacity of 534 MW(e), 13 reservoir hydroelectric plants providing 342 MW(e) peak availability, distributed between two equivalent generating stations respectively, of 158 and 184 MW(e) rating, and 5 equivalent run-of-river plants, for a total installed capacity of 250 MW(e).

Briefly, the network (see Fig. 2) is constituted by the following plants: T_1 (1 × 60 MW inst.); T_2 (2 × 177 MW inst.); T_3, T_4 and T_5 (1 × 64 MW inst.). We have for the equivalent hydroelectric reservoir plants: I_1 (Pelton 2 × 55 + Francis 2 × 55 MVA); I_2 (Pelton 5 × 20 + 2 × 30 + Francis 2 × 25 MVA). In Figs. 3 to 6 are given, by way of example, the characteristics of some hydro and thermoelectric units in the system. The system is presented as a closed loop consisting of 220 kV transmission lines. In the region served by the network in question, the water regime is assumed as being seasonal, beginning in late October and continuing until the summer droughts of the following year. The storage is assumed as beginning to fill in the winter months, completing the process in February/March, when the peak flowrates on the year normally occur. The water regime year is divided into three distinct periods: Period N-F: November to February inclusive; Period M-M: March to May inclusive; Period J-O: June to October inclusive. For more details concerning either the characteristic days and the water availability in the reservoir and run-of-river plants, during the different periods of the year, see Ref. [52].

Phase 2 — Forecasting load

The year has also been divided into the same periods N-F, M-M and J-O for the purpose of load evaluation. Three days typical of the year and one of each period have been taken into consideration. The daily load curves for year zero (year of the start of the programme) are taken as in Fig. 7. Load growth forecasts have been computed over a five-year period with an assumed expansion rate of 7% per year. Accordingly, peak annual loads appear as in Fig. 8. The load curves for the three days characteristic of the year five, are given in Fig. 9.

Phase 3 — Selecting construction alternatives

By way of determining, as a preliminary step, the total power need for the five years of the programme and in order to establish what proportion between nuclear production and total power needs shall be accepted as a first approximation — sufficiently close, that is, to the optimum solution — a

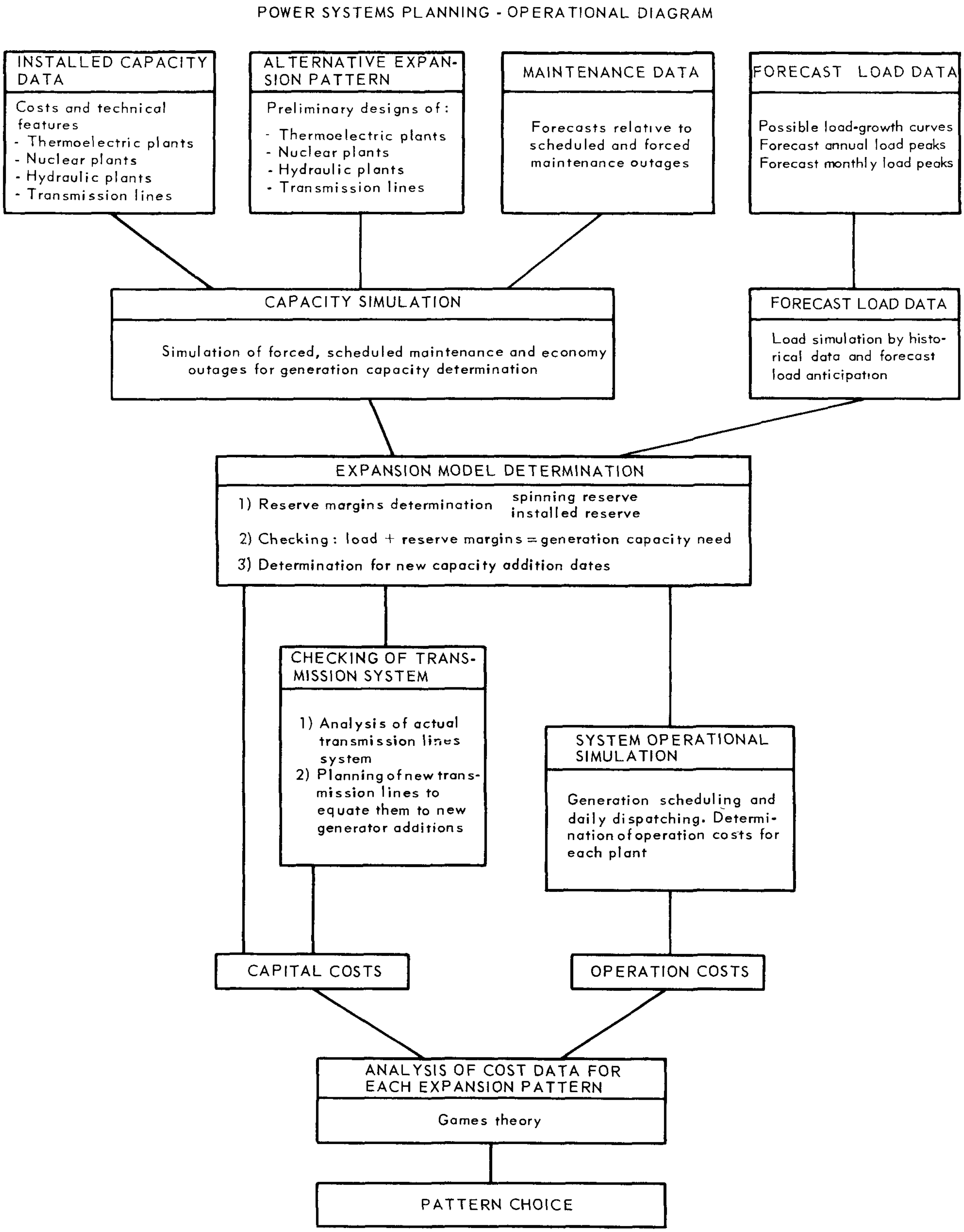

Figure 1. Power systems planning — operational diagram

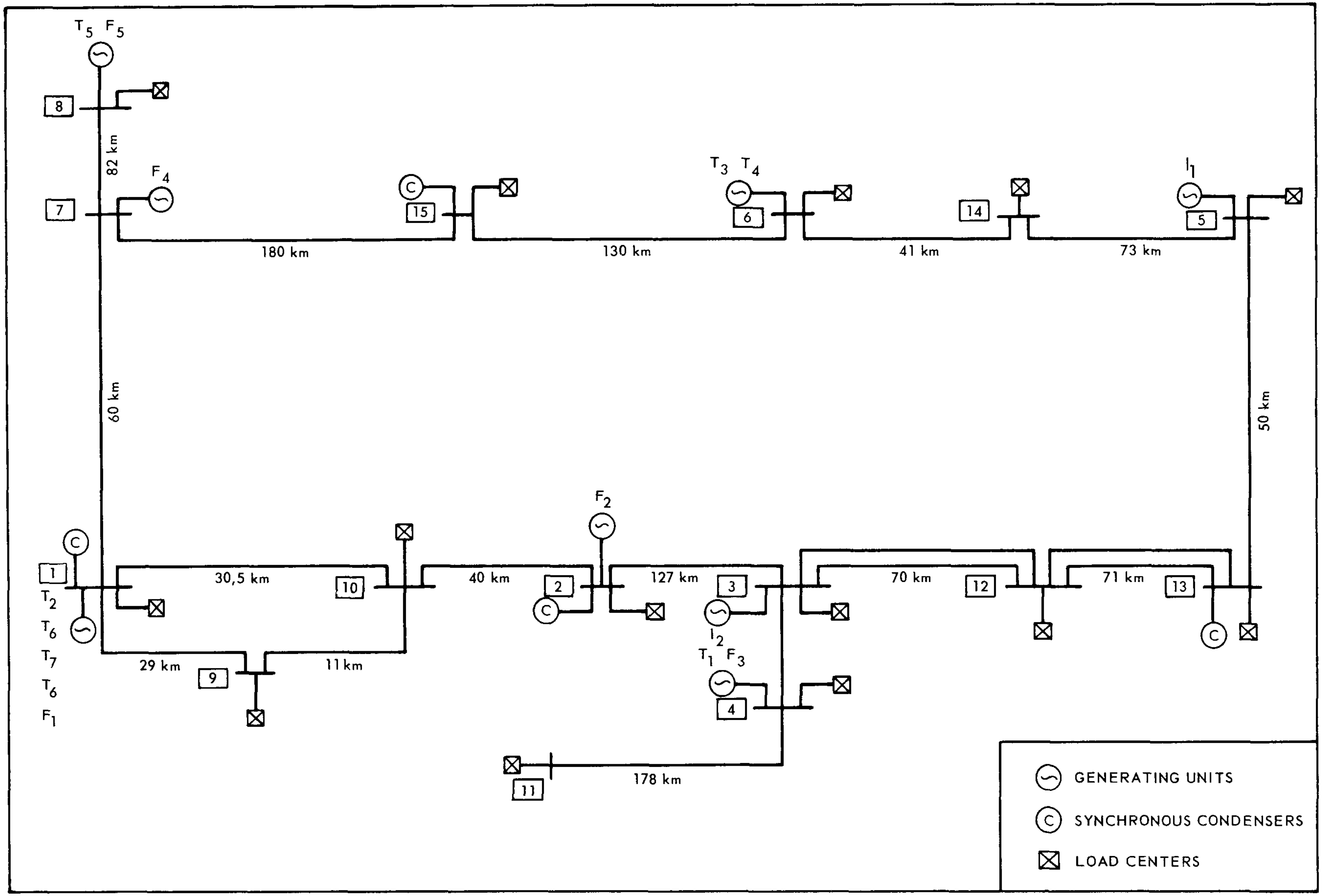

Figure 2. General scheme and features of the grid

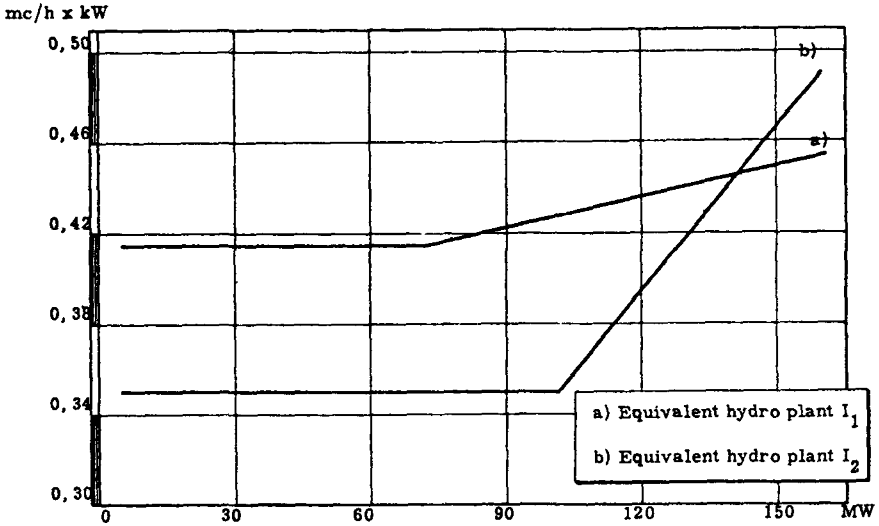

Figure 3. Incremental water rate characteristics of the equivalent hydro plants

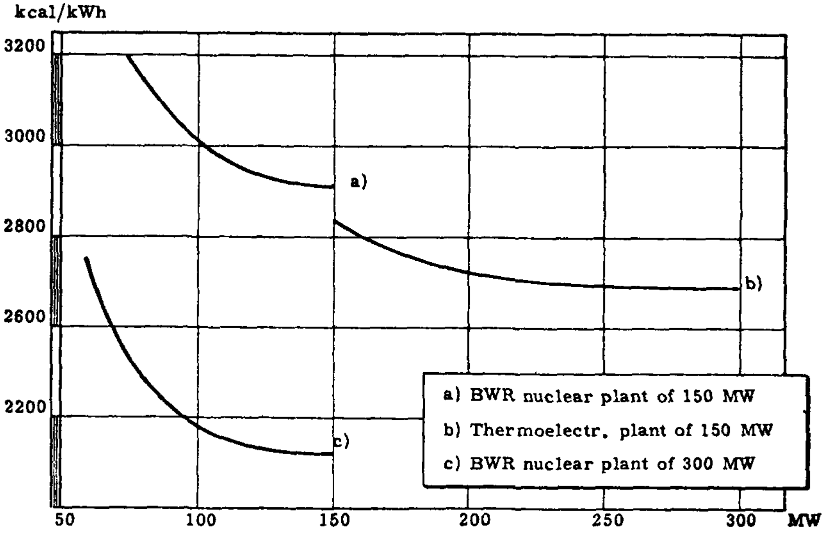

Figure 4. Heat rate characteristics of the thermoelectric and nuclear plants

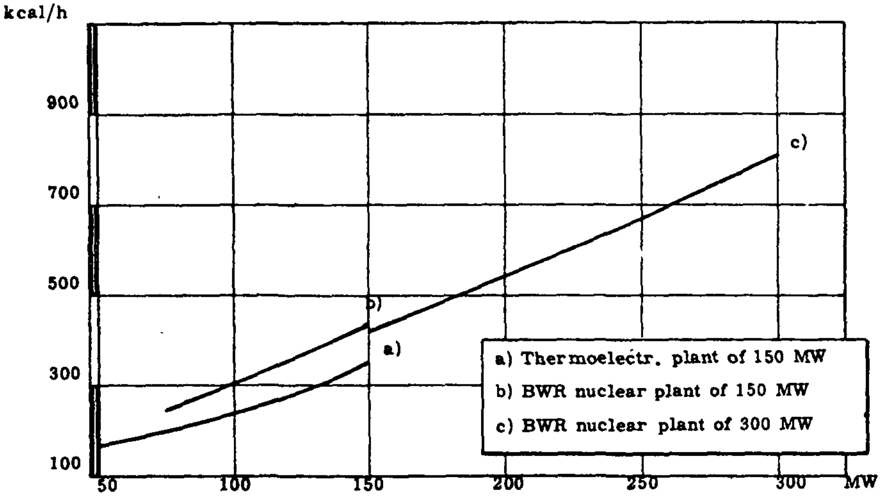

Figure 5. Input/output curves of the thermoelectric and nuclear plants

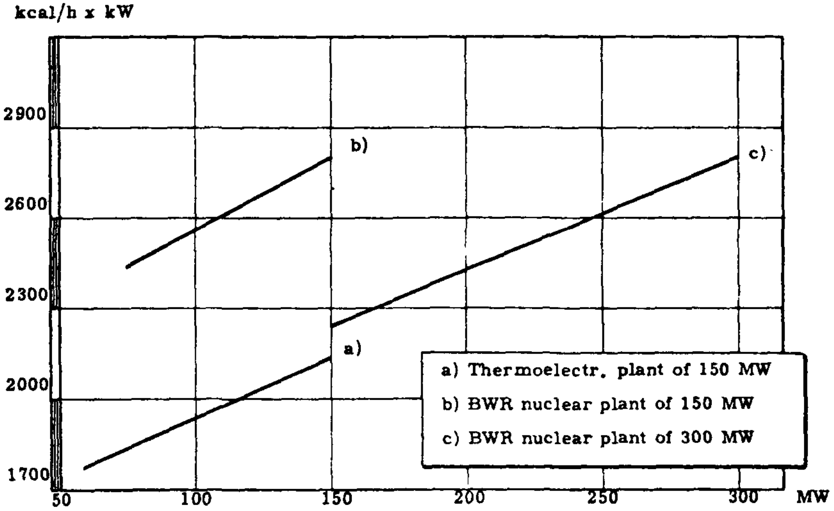

Figure 6. Incremental fuel rate curves of the thermoelectric and nuclear plants

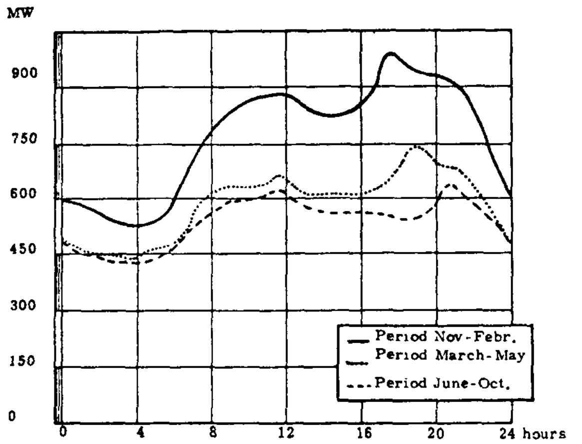

Figure 7. Load curves for the characteristic days of the year (zero year)

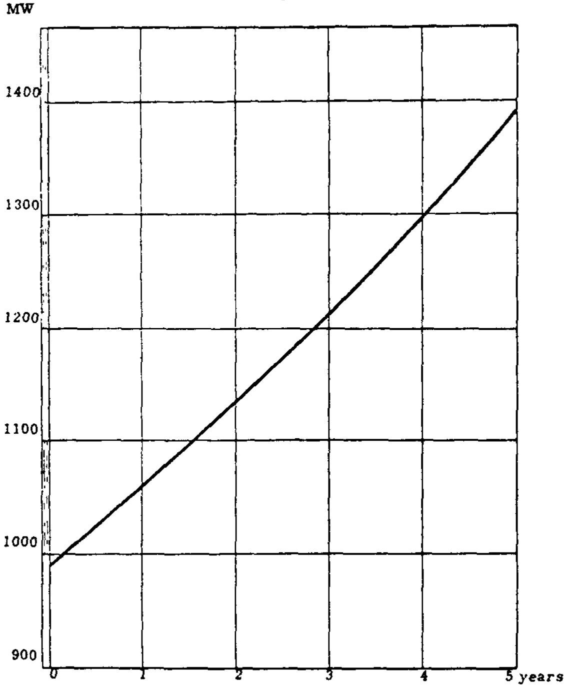

Figure 8. Trend of annual peak loads. Annual increment 7%

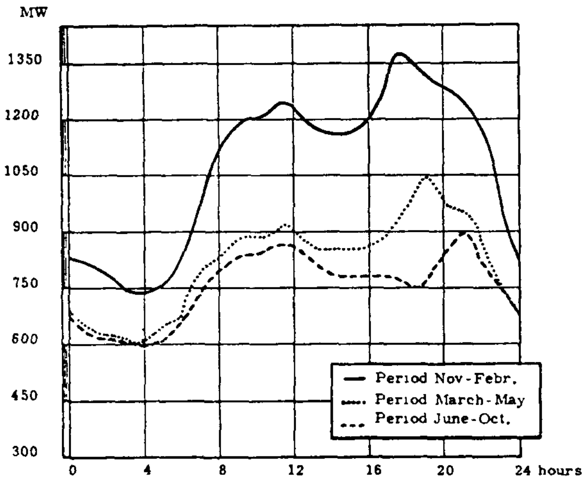

Figure 9. Load curves for the characteristic days of the year (fifth year)

preliminary calculation has been made following the methodology described in Ref. [54]. From this procedure, still as a first approximation, the total power need is shown to be around 450 MW(e). The most appropriate solution should be:

Alternative 1 — Construction of one BWR nuclear generating station of 300 MW(e) rating and having the specifications set forth in Figs. 4, 5 and 6 together with one thermoelectric plant of 150 MW(e) rating and having the specifications given in the same figures. Nevertheless, the following alternatives may be considered.

Alternative 2 — Construction of one 150 MW(e) nuclear power station with specifications as in Figs. 4, 5 and 6 together with two thermoelectric plants identical to that in Alternative 1. Lastly the comparison alternative:

Alternative 3 — Construction of three thermoelectric stations of 150 MW(e) rating of identical specifications to those proposed in the foregoing alternatives.

Phase 4 — Schedule of the starting operation date of the new plants

Risk indices have been computed as described in a CNEN report already published [55]. Calculation results are shown in Tables 1 and 2. Figures 10 and 11 reproduce (broken line) the loss-of-load probability of the system, expressed as a number of days per annum. On the assumption that the loss-of-load probability does not represent a figure in excess of 3 days/10 years during the year 5 of the programme, the rate at which new stations would be inserted has been computed (Figs. 10 and 11).

Phase 5 — Simulating coordinated operation of system

Coordinated operation of the system under consideration has been simulated for each of the three alternatives under the programme. For each characteristic day of the programme year and for each alternative solution, computed (Bendix G-20) output sheets have been obtained. On these output sheets figure the following items for each generating station in the system: the operating power at different hours of the days characteristic of the years covered by the programme, and the daily operating costs for the system as a whole. Since the simulation procedure described here is purely for the purpose of example, only those results pertaining to the last year of the programme are given. Similar calculations are to be understood as being carried out for the intermediate years. The results are also set forth in Figs. 12, 13 and 14.

Results

The numerical computation, conducted by way of example, of the proposed methodology in application, considers the three possible alternatives, each of them confined within a five-year period.

Table 1

Capacity outage (MW)	Probability of outage	Zero year: Time per unit	Zero year: Loss-of-load probability	First year: Time per unit	First year: Loss-of-load probability
0	0.8858420	0		0	
65	0.0633136	0		0	
125	0.0022134	0		0	
140	0.0361568	0		0	
190	0.000030	0		0.19	0.00000570
205	0.0029512	0		0.22	0.00064926
250	0.0000001	0.19			
270	0.000090	0.21	0.0000189	0.33	0.0000297
280	0.0003689	0.23	0.0000848	0.34	0.00012543
330	0.0000008	0.33	0.00000026	0.42	0.00000034
345	0.000030	0.35	0.0000105	0.45	0.0000135
390	0.000000				
410	0.0000006	0.48	0.00000029	0.67	0.0000004
470	0.000000				
535	0.000000				
			0.000011475 × 365 =		0.00082433 × 365 =
			0.0418 day/year		0.301 day/year

Table 2

Years	Peak load (MW)	Alternative 1: Capacity (MW)	Alternative 1: Reserve (MW)	Alternative 1: Loss-of-load probability (days/year)	Alternative 1: New units (MW)	Alternative 2: Capacity (MW)	Alternative 2: Reserve (MW)	Alternative 2: Loss-of-load probability (days/year)	Alternative 2: New units (MW)
0	410	635	225	0.0418		635	225	0.0418	
1	490	635	145	0.3018	+ 150	635	145	0.3018	+ 150
		785	295	0.0253		785	295	0.0253	
2	550	785	235	0.111		785	235	0.111	
		785	150	0.459	+ 300	785	150	0.459	+ 150
3	635	1 085	450	0.0067		935	300	0.0163	
4	720	1 085	365	0.106		935	215	0.215	
5	810	1 085	275	0.89		935	125	2.742	+ 150
						1 085	275	0.137	

Alternative 1 — Construction of one 150 MWe conventional plant and one 300 MW nuclear plant;

Alternative 2 — Construction of two 150 MWe conventional plants and one 150 MW nuclear plant;

Alternative 3 — Construction of three 150 MWe conventional plants.

The corrected economic evaluation of a development programme should be carried out, as pointed out at the beginning of the paper, over an approximately long period of time, computing overall costs involved in the programme for each year, and computing the present worth of all expenses for a determinate reference year. In the interests of brevity, the example given here confines each programme within a period of five years and performs the economic evaluation only in year five.

Assuming a conventional fuel cost of 1 lire/10^3 kcal and, for nuclear fuel of 0.75 lire/10^3 kcal, the overall production costs calculable by means of simulating operation come to, for the respective alternatives (Fig. 15):

Alternative 1: 11 500 million/lire per year;

Alternative 2: 12 115 million/lire per year;

Alternative 3: 12 330 million/lire per year.

Now, taking the installation cost of a conventional thermoelectric unit of 150 MW rating as lire 70 000/kW, and those of a nuclear unit station of 150 MW and 300 MW rating as lire 150 000/kW and lire 130 000/kW respectively, the overall installation cost for the three possible programmes comes to:

Alternative 1: $150 \times 10^3 \times 70 \times 10^3 + 300 \times 10^3 \times 130 \times 10^3 = 49.5$ billion lire;

Alternative 2: $2 \times 150 \times 10^3 \times 70 \times 10^3 + 50 \times 10^3 \times 150 \times 10^3 = 43.5$ billion lire;

Alternative 3: $3 \times 150 \times 10^3 \times 70 \times 10^3 = 31.5$ billion lire.

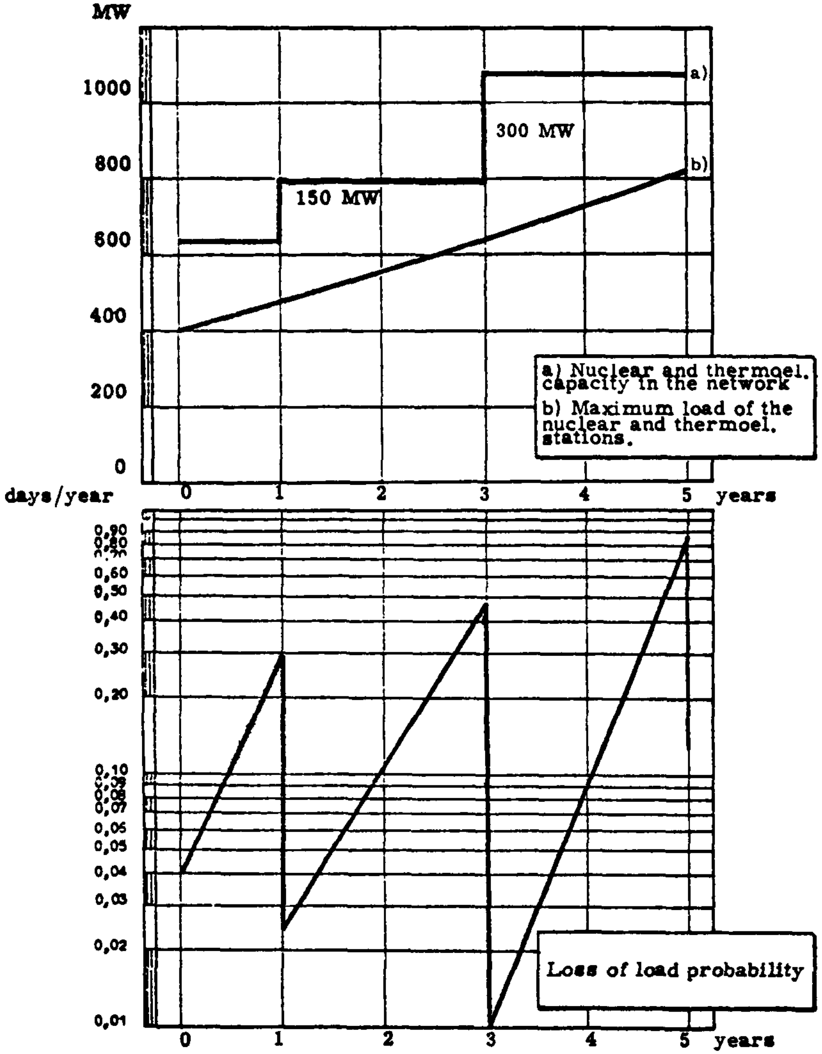

Figure 10. Alternative 1 — Loss of load probability and schedule of initial operation dates

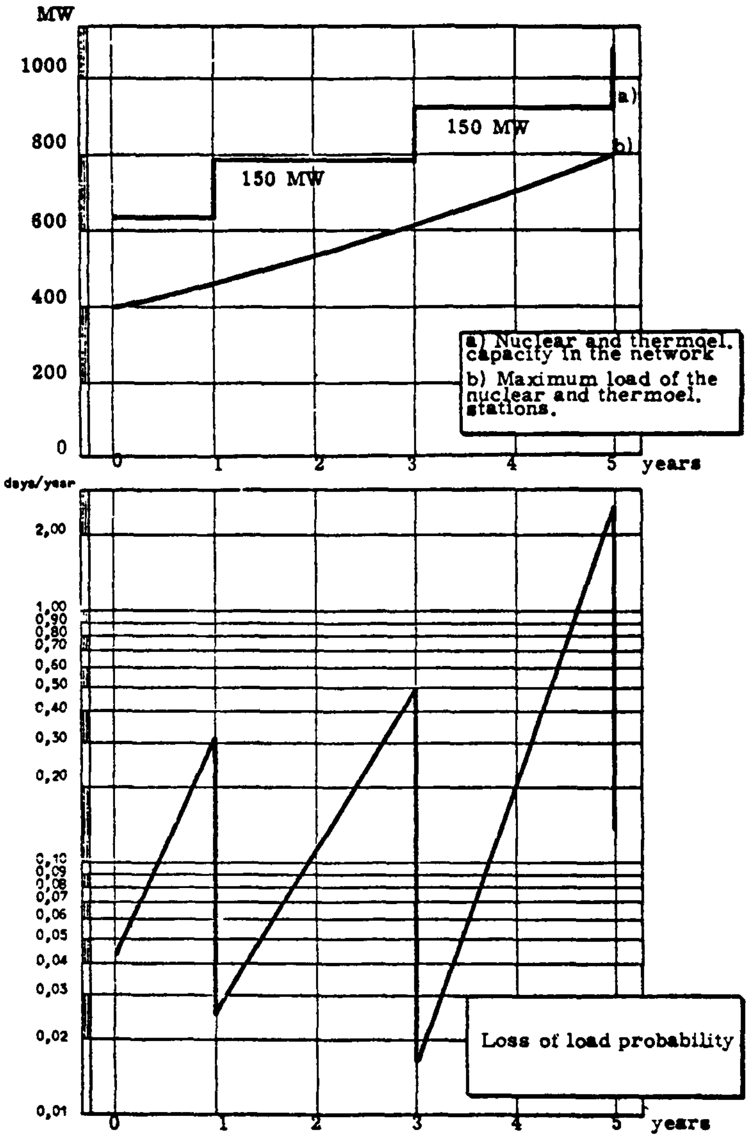

Figure 11. Alternatives 2 and 3 — Loss of load probability and schedule of initial operation dates

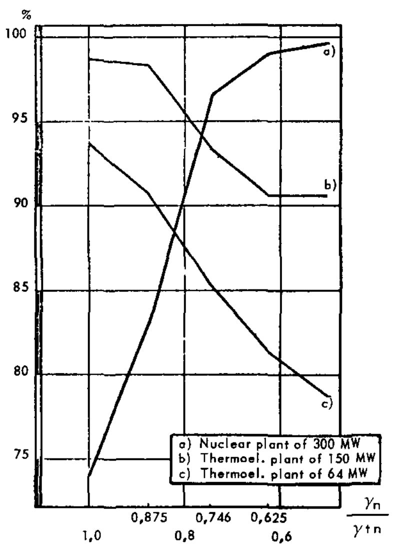

Figure 12. Alternative 1 — Annual service factors of some plants of the system

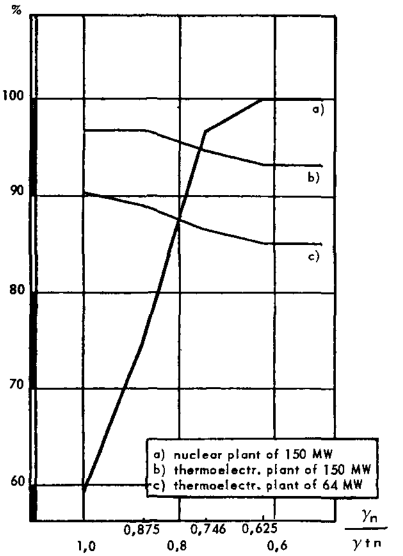

Figure 13. Alternative 2 — Annual service factors of some plants of the system

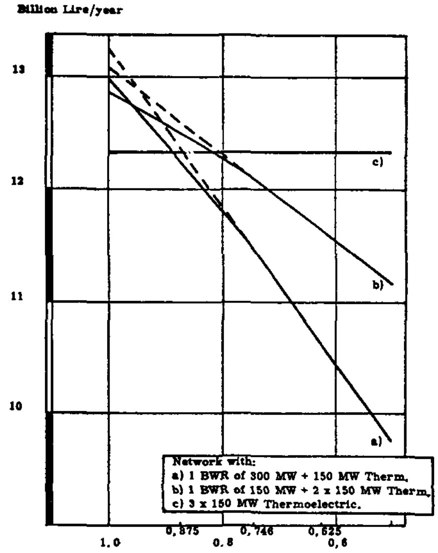

Figure 14. Annual system operating cost

Writing A to represent the yearly cost due to construction of plant existing prior to year zero, and assuming an amortization interest rate of 14%, we have a capital cost in year 5, for each of the three possible programmes, as follows:

Alternative 1:
$A + 14\%\ 49\,500 = A + 6\,930$ million lire/year
Alternative 2:
$A + 14\%\ 43\,500 = A + 6\,090$ million lire/year
Alternative 3:
$A + 14\%\ 31\,500 = A + 4\,410$ million lire/year

The overall costs (installation plus fuel) in year 5 are therefore:

Alternative 1: $A + 18\,430$ million lire/year
Alternative 2: $A + 18\,205$ million lire/year
Alternative 3: $A + 16\,740$ million lire/year

It is clear, therefore, that, with the fuel and installation costs here contemplated, Alternative 3 (installation of thermoelectric station only) is to be preferred in absolute terms. It is worth noting, however, that Alternative 2 being more advantageous than Alternative 1, should it nevertheless be wished, for reasons other than those of a strictly economic nature, to construct a nuclear generating station, it would be better to plan a 150 MW rating in preference to a 300 MW plant. The above situation would be changed where nuclear costs were lower. Let it be assumed, for instance, that with conventional thermoelectric costs remaining stable, the costs of nuclear fuel comes down from lire $0.75/10^3$ kcal to lire $0.70/10^3$ kcal, and that the capital cost for:

a nuclear plant (300 MW) = lire 120 000 kW;
a nuclear plant (150 MW) = lire 140 000 kW;
a conventional plant (150 MW) = lire 70 000 kW.

In the above case, Alternative 3 (thermoelectric stations) is still to be preferred, in absolute terms, but the order between Alternative 2 and 3 is now reversed, the installation of 300 MW nuclear plant being more economical than that of a 150 MW nuclear plant. In view of the uncertainty of current costs, it was thought appropriate to compute the operational costs of the system for different cost figures per nuclear calorie (see again Fig. 14). Accordingly, Figs. 15 and 16 have been compiled

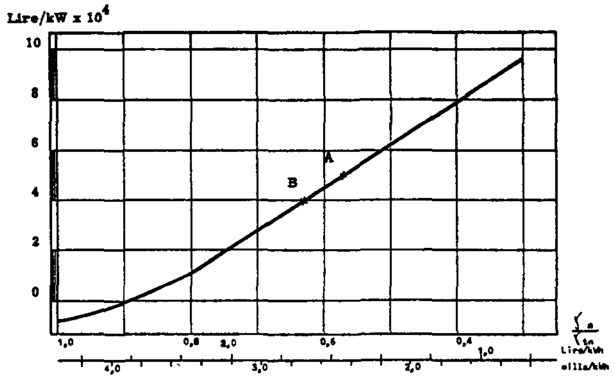

Figure 15. Alternative 1 — Extra capital charge compensated by savings on operating costs

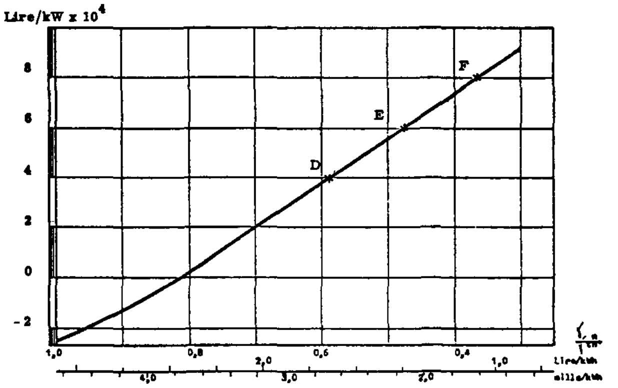

Figure 16. Alternative 2 — Extra capital charge compensated by savings on operating costs

in order to evaluate the cost figure of the nuclear calorie under which a plant may become competitive.

In this way one is placed in a position to calculate what maximum additional costs can be accepted for the construction of a nuclear plant instead of the conventional one, assuming identical overall operational costs. For example, the diagram of Fig. 15 shows at A a non competitive situation for a BWR of 300 MW, while at B and C the same nuclear plant should be competitive. For a BWR of 150 MW the competitivity solutions (at D, E and F) are reported in Table 3.

Table 3[a]

Solutions	Capital cost		Fuel cost	
	Lire/kW	$/kW	Lire/kWh	mills/kWh
Solution 1 (see point D)	110 000	177	1.68	2.71
Solution 2 (see point E)	130 000	210	1.31	2.12
Solution 3 (see point F)	150 000	242	1.05	1.7

[a] See also Figs. 15 and 16.

Conclusions

The planning exercise developed in the previous part of this paper enable us to draw the following conclusions as regards the economy of a nuclear power plant:

(*a*) One may not reasonably consider *a priori* a 7-8 000 hours/year load factor for a nuclear power plant. The diagrams appearing in Figs. 14 and 15 show that the load factors depend strictly on the fuel costs of nuclear plants, as compared to the corresponding thermoelectric costs, and also on the relationship between the capacities involved. The same diagrams show that the role of thermoelectric stations operating in parallel with the nuclear plants may vary so much as to affect the total operating costs of the whole system. It is sufficient to consider the various load factors of the 64 MW thermoelectric plant when the nuclear capacity varies, as in the two cases compared.

(*b*) Each system has a maximum amount of nuclear capacity whose operation at full efficiency can be guaranteed. The diagram of Fig. 14 shows that under the conditions of the network, and load considered, the installed capacity of 300 MW station would already be excessive; as a matter of fact, the service factor is always below 1. The demonstration that nuclear energy is competitive, on the basis of large-capacity plants able to operate for long periods of time is not, in itself, a determining factor. Such large-capacity plants may satisfactorily be incorporated in networks (not numerous today) which supply heavy and concentrated consumers.

(*c*) Furthermore, the introduction of high-capacity nuclear plants entails a higher probability of forced outage with the result that, the installed capacity being the same, the loss-of-load probability increases as the nuclear unit capacity increases. A comparison between the diagrams appearing in Figs. 10 and 11 shows that by introducing 300 MW units into the network under study, the loss-of-load probability is much higher in the fifth year of the programme (0.8 day/annum, which is not satisfactory) than that obtained, always in the fifth year, by inserting 150 MW nuclear units (0.12 day/annum, which is fairly satisfactory). The introduction of large-capacity nuclear units would therefore require the addition to the system of some reserve capacity the cost of which might offset the lower unit capital cost of nuclear plants with a larger unit capacity. For any given network there is an optimum nuclear power plant capacity. A mistake in the assessment of such capacity may lead to an incorrect judgement regarding the ability of nuclear power to compete.

(*d*) Finally, the diagrams in Figs. 12 and 13, which relate to the use of the plants included in the network, and the diagrams appearing in Figs. 14, 15 and 16 show that the total operating cost of the network is a complex function of all cost parameters of the plant making up the system (i.e., thermoelectric, hydroelectric and nuclear). Therefore the total annual operating costs of the network are complex functions; they reflect, in fact, the frail equilibrium of fuel costs during the various days of the year.

The diagrams thus show that a study concerning the convenience of installing a nuclear power plant whose capital cost exceeds that of a corresponding thermoelectric station but whose fuel is cheaper must be conducted by simulating a co-ordinated operation of the whole network during all the years of the plant's life. It should moreover be ascertained that the total amount of fixed expenditures and operating costs in respect of the entire network incorporating the nuclear plant is inferior to the total amount entailed by the alternative electric system which includes the conventional thermal station.

In other words, nuclear energy ought to prove its ability to compete, within the framework of a programme.

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ABSTRACT - RÉSUMÉ - АННОТАЦИЯ - RESUMEN

A/731 Italie

Etude des aspects techniques et économiques de l'insertion d'une centrale nucléaire dans des réseaux électriques de tailles diverses pour les autoproducteurs ou pour la distribution nationale

par S. Pittori *et al.*

Dans la première partie du mémoire, on considère les aspects techniques et économiques du problème de l'insertion d'une centrale nucléaire dans un réseau énergétique national ou dans un réseau desservant un ensemble de sociétés autoproductrices, eu égard spécialement à la distribution géographique de la consommation et de la production, aux variations saisonnières, hebdomadaires et journalières des diagrammes de charge, et aux échanges avec d'autres réseaux.

L'objet principal du mémoire est de présenter une méthode améliorée de comparaison de divers types de centrales: hydro-électriques, thermiques et nucléaires. Les méthodes employées précédemment pour analyser les caractéristiques techniques et économiques d'un programme de construction de centrales reproduisent toutes les conditions de demande et de charge sur le réseau en admettant la fourniture de courant au réseau par ces centrales, puis simulent leur fonctionnement coordonné. L'analyse peut être faite en quelques heures seulement avec un calculateur rapide. Les résultats demandent cependant une interprétation soigneuse, et la méthode actuelle introduit une série de simplifications.

Cette méthode est illustrée en détail par l'établissement d'un plan concernant un réseau imaginaire. Celui-ci présente des caractéristiques très voisines de celles d'un secteur du réseau italien, mais la méthode peut être appliquée à un réseau de taille quelconque. L'intérêt principal de cet exemple est d'évaluer l'aspect économique de l'intégration dans le réseau d'une ou de plusieurs centrales nucléaires et d'éprouver leur valeur compétitive dans les conditions d'exploitation.

A/731 Италия

Анализ технико-экономических аспектов включения атомной электростанции в электрические системы различных размеров для покрытия собственных нужд производителей энергии или для национального распределения

Л. Бионди *et al.*

Доклад состоит из трех частей. В первой части рассматриваются технико-экономические аспекты проблемы подключения атомных электростанций к большой национальной энергетической системе. Во второй части рассматриваются возможные характеристики энергетической системы, обслуживающей ряд компаний, которые производят энергию для собственного потребления. При этом особое внимание уделяется географическому распределению потребления и производства энергии, сезонным, недельным и суточным диаграммам нагрузки, взаимообмену с внешними системами и т. д.

Подчеркивается, что такая система, которая, безусловно, меньше по размеру и имеет больше особенностей, чем национальная энергосистема, может привести к возникновению специфических проблем, которые труднее решить с точки зрения экономичного включения атомных электростанций.

Указанная подводимая мощность, обычно производимая в больших количествах и при значительном коэффициенте использования установки, может привести к нарушению в большей или меньшей степени производства электроэнергии на других станциях обычного типа.

Анализируются требования, которым должна отвечать вышеупомянутая априорная система,

чтобы наиболее экономично принимать этот новый вид энергии.

Особое внимание уделяется проблемам взаимообмена и помощи, которые могут возникнуть в связи с появлением ядерной энергетики между системами, производящими электроэнергию для собственных нужд, и внешними энергосистемами. Отсюда необходимость политики сотрудничества между производителями энергии для собственных нужд и энергетическими компаниями.

В третьей части доклада описывается код для электронных цифровых вычислительных машин, разработанный для анализа экономических характеристик атомной электростанции, включенной в систему любого размера и характера.

A/731 Italia

Análisis de los aspectos técnicos y económicos de la inclusión de una central nuclear en redes eléctricas de distintas capacidades para autoconsumo o su distribución nacional

por S. Pittori *et al.*

En la primera parte de este trabajo, el autor discute brevemente los aspectos técnicos y económicos de los problemas que encierra la elección de una central nuclear y su inclusión en *a*) una red eléctrica nacional y *b*) una red eléctrica que sirva a varias compañías que producen energía para su propio consumo, tomando en consideración especialmente la distribución geográfica del consumo y producción, las variaciones de carga estacionales, semanales y diarias y los intercambios con redes externas.

El propósito principal del trabajo es presentar un método revisado para comparar los distintos tipos de central (hidroeléctrica, térmica y nuclear) como generadores de energía. Los métodos anteriores encaminados a analizar las características técnicas y económicas de un programa de construcción de centrales, reproducen todas las condiciones de carga y demanda de la red suponiendo que se conectan a ella tales centrales y luego simulan su funcionamiento coordinado. El análisis exige solamente unas cuantas horas en una calculadora rápida. No obstante, los resultados se deben interpretar cuidadosamente y el método que se presenta introduce varias simplificaciones.

El método se explica en detalle siguiendo un ensayo de planificación en un sistema eléctrico imaginario que se supone de características muy parecidas a las de un sector de la red italiana, aunque se puede aplicar a un sistema de cualquier tamaño. Este ejemplo se propone principalmente evaluar el resultado económico de introducir en el sistema una o más centrales nucleares a fin de poner a prueba su capacidad para competir bajo condiciones de funcionamiento.

Intégration de l'énergie nucléaire dans le réseau électrique français

par R. Janin*

Malgré ses progrès continus sur le plan technique, l'énergie nucléaire n'a pas encore atteint, sous l'angle économique, des résultats suffisamment assurés pour déclencher son introduction massive dans les programmes d'équipement. L'expérience acquise, les centrales en fonctionnement, l'évolution des techniques fournissent des espoirs sérieux. Mais il est encore trop tôt pour savoir quand et comment sera effectivement franchi le seuil de rentabilité, et par suite à quelle date "le nucléaire" interviendra d'une manière substantielle dans le développement de l'énergie électrique.

L'intégration dans le réseau de centrales nucléaires prototypes ne pose guère de problème. La faiblesse de leur puissance rend les bilans énergétiques assez peu sensibles à leur mode de fonctionnement. D'autre part leur caractère expérimental conduit à les faire fonctionner pour obtenir quasi uniquement une connaissance meilleure de leurs performances, dût-il en coûter une dépense supplémentaire en exploitation. Ce surprix éventuel constitue, comme le supplément d'investissement, le coût de l'expérience nécessaire pour acquérir une connaissance suffisante du nouveau domaine. Au total, ces centrales prototypes sont en quelque sorte exploitées pour elles-mêmes et non pour leurs livraisons au réseau.

Au contraire, un développement important d'une ou de plusieurs filières conduira à des choix dans la répartition des moyens de production pouvant affecter non seulement le nucléaire mais aussi les moyens concurrents et complémentaires. Il paraît donc indispensable de se préparer à l'évolution des structures puisque le point de départ d'un développement accéléré paraît se rapprocher, bien qu'on soit encore incapable de le fixer.

Nous porterons notre attention essentiellement sur les modifications qu'imposera la nouvelle forme d'énergie dans le système de production d'Electricité de France, sans envisager le problème connexe des conséquences pour l'industrie du développement rapide de certaines branches. Au terme de ce rapport, nous ne pourrons donc conclure sur le meilleur programme à engager sous l'angle national, puisque nous n'aurons examiné que le point de vue du producteur d'électricité mais pas celui de l'industrie des biens d'équipements.

Le problème que nous envisageons n'est certes pas nouveau; certaines tendances qui se sont peu à peu affirmées dans la composition du coût de l'énergie nucléaire — outre les espoirs qu'elles autorisent — permettent aujourd'hui de prévoir avec moins d'incertitudes ce que pourront être les conséquences de son développement quelle qu'en soit la date.

NATURE DES PROBLÈMES

Le placement de l'énergie d'origine nucléaire dans un système de production se fera différemment selon la forme de la courbe de charge et selon la nature des autres moyens de production. L'utilisation d'une centrale nucléaire, qui a un rôle déterminant dans sa rentabilité compte tenu de l'importance des investissements, ne sera donc pas systématiquement la même selon les pays (influence de la courbe de charge), ce qui est largement admis, ni selon les époques, ce sur quoi l'accent n'a peut-être pas été mis.

Or la décision qui conduirait à engager des programmes nucléaires importants doit reposer sur l'assurance de leur rentabilité et par voie de conséquence de leur perspective d'utilisation, qui dépend elle-même des programmes portant sur les différents moyens de production.

Cette "itération logique" entre le placement de l'énergie et les décisions n'a rien qui doive surprendre puisque le nucléaire est supposé venir bousculer largement les structures de production, donc nos habitudes. Elle met seulement en évidence l'intérêt de l'analyse des problèmes soulevés par les nouveaux moyens de production et montre en passant que le problème de la compétitivité du nucléaire n'est pas aussi simple qu'il y paraît, et ceci indépendamment des hypothèses économiques nombreuses qu'il faut introduire dans les calculs pratiques. Il va de soi que l'étude doit porter non seulement sur le facteur de charge qui constitue un facteur quantitatif, mais aussi sur le plan qualitatif, en ce qui concerne la sécurité et la souplesse du fonctionnement des installations nucléaires.

Il est bien connu que la taille des aménagements est un élément fondamental pour le coût d'inves-

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tissement et par suite pour la rentabilité; indépendamment des difficultés techniques de mise au point, quelle est la puissance unitaire que le réseau permet? On retrouve ici encore l'enchaînement entre le placement de l'énergie et l'économie du nucléaire.

En ce qui concerne la souplesse, la relation est quelque peu différente: selon que le nucléaire pourra plus ou moins facilement (du point de vue technique) participer aux variations de charge, les autres moyens à mettre en œuvre pour faire face au diagramme de consommation seront différents. La nature même des critères de base fixant les possibilités du réseau en sera affectée.

Avant d'exposer la situation française, il paraît bon de s'arrêter sur la nécessité d'adopter une attitude prospective malgré les difficultés inhérentes à toute prévision dès lors qu'elle doit porter sur une longue durée.

Pour être intéressant, c'est-à-dire utile, l'essai de prévision doit porter sur une durée recouvrant au moins la durée de vie des premières centrales nucléaires considérées comme industrielles. Comme l'on s'accorde généralement pour admettre que la durée de vie d'un nucléaire rentable sera au moins de vingt ans et que par ailleurs le coup d'envoi des programmes massifs de développement nucléaire n'a pas été donné, il faut considérer au minimum une période s'étendant jusqu'en 1985 ou 1990.

Ces dates qui paraissent relativement proches pour notre problème ont l'avantage de s'accorder avec des études entreprises par le Commissariat au plan français qui envisagent l'horizon 1985.

Tenter de prévoir l'évolution des structures d'un système de production pour une telle durée est néanmoins une entreprise délicate. Ceci non seulement par suite de l'incertitude qui règne sur le nucléaire, mais parce qu'interviennent dans ce problème un ensemble d'éléments très divers dont la quasi-stabilité constatée pour le passé n'est pas toujours un gage de pérennité.

Pour la demande d'énergie électrique, l'évolution est suffisamment constante, et si fondamentalement liée aux processus de développement économique que l'on ne voit aucune raison à une rupture brutale dans le rythme exponentiel de la consommation. Une erreur sur le taux d'accroissement, voisin du doublement en dix ans, ne conduit d'ailleurs qu'à une erreur de quelques années sur la date d'obtention de l'objectif de consommation. En ce qui concerne la France, on peut s'en tenir à un objectif de 500 TWh* pour l'horizon 1985-1990 à considérer pour notre problème.

Une prévision précise est beaucoup moins aisée en ce qui concerne la forme de la courbe de demande. Par le passé, on a pu constater une augmentation progressive de l'utilisation du réseau, à un rythme qui a été accéléré dans les dernières années par une action tarifaire. Il n'est pas certain que cette tendance se conserve, ni même que les résultats actuels soient définitivement acquis. Sur une période aussi longue, il n'est pas exclu que se manifestent des besoins nouveaux des modes de vie différents ou des structures industrielles inusitées qui conduisent à des modifications imprévisibles même quant à leur sens de variation. Fort heureusement l'évolution dans chaque pays, ainsi que les comparaisons entre pays ayant des habitudes très variées, montrent que l'utilisation annuelle ne s'écarte jamais beaucoup d'une valeur de 5 500 heures. Lorsqu'on envisage les différents moyens de production qui seront utilisables dans vingt ans, on est tenté de ne considérer que ceux actuellement connus. Or, ne peut-on pas imaginer que sur une aussi longue période puissent se développer telle source d'énergie ou telle innovation technique actuellement imprévisibles?

L'argument qui consisterait à dire que les nombreuses réflexions faites jusqu'à ce jour permettent d'éviter ce risque ne paraît pas valable puisque par hypothèse tout inventaire repose sur les connaissances de l'époque où il est fait.

Plus forte paraît être la constatation maintes fois mise en lumière et confirmée par l'expérience du nucléaire que la mise au point de l'échelle industrielle, donc sur le plan économique, demande de longues années. Le progrès technique dans tous les domaines rend plus difficile peut-être qu'autrefois la compétition à toute nouvelle source d'énergie. Quoiqu'il en soit, il ne paraît pas imprudent d'affirmer que pour l'horizon 1985-1990, d'éventuels nouveaux moyens de production non recensés actuellement, ne dépasseront en aucun cas le niveau de prototypes expérimentaux. En conséquence, la position du nucléaire doit se faire par rapport au thermique sous la forme de centrales utilisant les turbines à vapeur ou les turbines à gaz, l'hydraulique sous ses différentes formes en y incluant les centrales de pompage et l'énergie des marées.

PLACEMENT DE L'ÉNERGIE NUCLÉAIRE

Depuis longtemps les producteurs d'électricité ont l'habitude de décomposer le prix de revient de l'énergie produite par une usine en:

un terme fixe constitué par les charges de capital et les charges d'exploitation (à l'exclusion du combustible) qui sont les unes et les autres invariables quelle que soit la production de la centrale;

un terme proportionnel correspondant essentiellement à la consommation de combustible directement liée à la fourniture d'énergie.

Cette décomposition s'impose pour effectuer à chaque instant la répartition optimale de la production entre les diverses usines en service. L'hydraulique dont le coût proportionnel est pratiquement nul sera toujours placé par priorité, les centrales thermiques n'étant sollicitées que dans la

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* La consommation de l'année 1963 a atteint 88,8 TWh.

mesure où toutes les centrales ayant un coût proportionnel moindre seront déjà en service.

Compte tenu du progrès continu dans le rendement des groupes classiques, ceci amenait pratiquement à classer les centrales selon leur âge, la fourniture de l'énergie de pointe étant dévolue aux centrales les plus anciennes.

Quelques correctifs s'imposent bien entendu en pratique par rapport à cet "empilage" théorique tenant à la situation particulière de certains groupes. Les pertes dans le réseau de transport ainsi que le coût de l'approvisionnement en combustible prennent également un rôle de plus en plus prédominant au fur et à mesure que les progrès techniques s'amenuisent en valeur relative.

Le schéma théorique de l'empilage reste une image suffisamment valable pour voir comment le nucléaire se comporte vis-à-vis des autres moyens.

Il faut noter dans ce qui précède que seul le coût proportionnel intervient dans cette répartition, ce qui distingue par conséquent ce problème de celui de la rentabilité où seul le coût global intervient.

Un point commun à toutes les estimations relatives au nucléaire paraît être la faiblesse relative de ce coût proportionnel par rapport au thermique classique. Cette conclusion paraît valable pour toutes les filières ayant à l'heure actuelle reçu une sanction industrielle, pour les réacteurs utilisant l'uranium enrichi et, à fortiori, pour ceux qui consomment l'uranium naturel comme la filière française graphite-gaz carbonique. Cette constatation sera encore valable semble-t-il pour les réacteurs rapides dont on attend un emploi plus poussé de l'uranium.

Ainsi, sans prendre parti sur la ou les filières nucléaires qui seront développées dans les vingt ou trente prochaines années, on peut affirmer sans risque d'erreur qu'elles seront utilisées par priorité pour fournir l'énergie de base, après le fil de l'eau hydraulique, supplantant dans ce rôle les centrales thermiques classiques.

Certes, une hypothèse comme celle-ci pourrait être mise en défaut soit parce que les tendances actuelles du nucléaire ne se confirmeraient pas, soit parce qu'une évolution rapide en baisse du coût proportionnel du thermique classique se produirait.

Mais l'écart actuel entre les deux coûts proportionnels est suffisamment net (de l'ordre du simple au double pour la situation française actuelle) pour laisser place encore à un progrès thermique notable sans modifier l'hypothèse de base.

D'autre part, compte tenu du supplément de prix d'investissement par kW installé qui semble être général pour le nucléaire, il faut bien admettre que le coût proportionnel en est plus faible lorsque l'on envisage son développement massif.

De même que l'on envisage d'avoir simultanément dans un système de production des moyens thermiques classiques sous forme de turbines à gaz et de turbines à vapeur, chacune mieux adaptée pour fournir économiquement l'énergie de pointe ou l'énergie de base respectivement, de même on peut envisager que plusieurs filières, disons deux pour être réaliste, trouvent chacune un développement économique à divers niveaux d'utilisation, compte tenu d'une répartition différente entre coûts fixes et proportionnels.

Le diagramme de charge d'une journée pourrait être celui de la figure 1 où le niveau relatif des différents moyens sera bien entendu variable selon la saison.

On conçoit qu'il n'est pas exclu que deux filières puissent coexister si l'on pouvait représenter leur rentabilité relative avec l'utilisation annuelle comme indiqué schématiquement sur la figure 2.

Compte tenu de l'importance que revêt le coût proportionnel, il est intéressant de l'analyser rapidement. On peut l'écrire (en F/kWh):

$$p = \frac{P - P_1}{r\ I}$$

avec: P = coût (en francs) du kg d'uranium gainé
P_r = valeur résiduelle (en francs) du kg de combustible rejeté
r = rendement thermique de la centrale
I = irradiation de rejet du combustible (en kWh thermique par kg)*

A tout moment, P et r sont, en général, parfaitement déterminés. Mais P_r et I ne sont connus que bien après que le combustible ait été consommé: en effet, P_r dépend de l'état du marché du plutonium, au moment du rejet des éléments combustibles irradiés et I des performances métallurgiques du combustible et des possibilités neutroniques du réacteur.

L'uranium en pile est constitué par des lots de combustibles de prix différents, éventuellement de caractéristiques différentes, dont les éléments disséminés dans le réacteur ne fourniront pas la même quantité d'énergie**. Il est alors délicat de calculer le coût marginal instantané bien que le coût proportionnel moyen, obtenu par constatation de la quantité et du prix de l'uranium brûlé soit, après coup, d'obtention plus aisée.

En toute rigueur d'ailleurs la différence entre coût fixe et coût proportionnel n'est pas nette: même si le combustible est renouvelé à l'identique et au même prix, la valeur à attribuer au combustible immobilisé dans le réacteur se modifiera avec la quantité et la qualité du plutonium en pile. La valeur du stock qui intervient dans les coûts fixes se trouve ainsi modifiée, du moins en théorie, par la production d'énergie.

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* 1 kWh thermique par kg est égal à 1/24 MW jour par tonne.

** Les différences proviennent d'une part des éléments déchargés précocement (par suite de rupture de gaine par exemple), et d'autre part pour les éléments "normaux" de l'impossibilité de décharger tous les éléments centraux et périphériques à la même irradiation quelle que soit la filière.

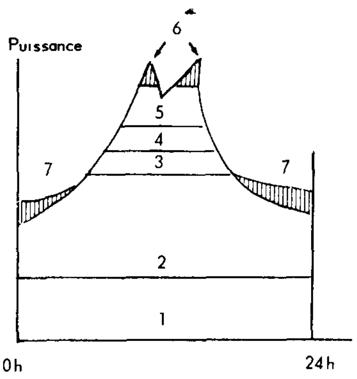

Figure 1. Diagramme de charge journalier

1, Usines hydrauliques au fil de l'eau et usines thermiques intégrées dans un processus de fabrication; 2, Nucléaire (filière 1); 3, Nucléaire (filière 2); 4, Thermique à vapeur; 5, Usines hydrauliques à réservoir saisonnier; 6, Moyens de pointe (turbines à gaz, usines de pompage et éclusées); 7, Consommation des usines de pompage

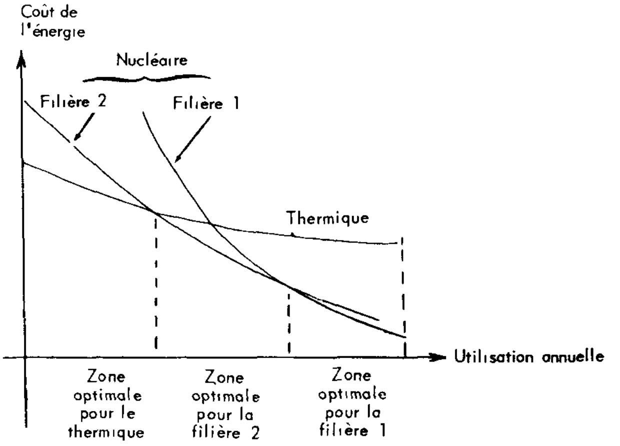

Figure 2. Coût de l'énergie en fonction de l'utilisation annuelle

Tout ceci peut se résumer en constatant que le coût proportionnel ne sera pas parfaitement connu au moment où l'on "brûle" le combustible, ce qui est un fait sans précédent*; cette situation pourra s'améliorer avec nos connaissances, mais l'exploitant futur sera amené de ce fait à considérer la répartition de la charge entre les diverses centrales nucléaires comme une décision dans le domaine de l'incertain.

Pour ce qui suit nous n'entrerons pas dans ce détail; il sera suffisant de considérer que le coût proportionnel du nucléaire (quel qu'il soit) est toujours compris entre celui des énergies au fil de l'eau (hydraulique et thermique fatal) et celui de l'énergie des turbines à vapeur.

ÉVOLUTION DU SYSTÈME FRANÇAIS

Nous examinerons donc l'horizon 1985-1990 représenté par une consommation de 500 TWh. La forme du diagramme de charge est plus délicate à apprécier, mais pour fixer les idées nous nous référerons à l'utilisation de la pointe actuellement constatée, ce qui conduit à considérer à cette échéance une valeur de l'ordre de 90 GW. Il est important de constater que le rapport des puissances entre la pointe et le minimum de charge de l'année est de l'ordre de 2 environ, ce qui nécessite une puissance continue de base de 45 GW environ.

Jusqu'ici l'énergie hydraulique et l'énergie thermique se sont partagé sensiblement par moitié la fourniture de la consommation, ce qu'on a pu démontrer correspond à un optimum économique. Ceci a donné au système de production français une allure assez stable minimisant les "à-coups" sur les secteurs industriels des biens d'équipement.

Depuis quelques années, toutefois, les programmes hydrauliques sont restés pratiquement à un niveau constant en valeur absolue à un rythme compris entre 1,5 et 2 TWh par an.

D'après l'inventaire du gisement hydroélectrique français, le potentiel économiquement équipable est estimé à environ 80 TWh alors que fin 1963 les usines en fonctionnement avaient un productible de 42,6 TWh et que les chantiers ouverts représentent un productible d'environ 5 TWh supplémentaires. Si l'on avait cherché à conserver la parité entre hydraulique et thermique, l'épuisement des ressources naturelles se serait produit en quelques années, ce qui aurait été déraisonnable pour les industries intéressées. En adoptant un rythme constant qui assure une continuité pour une vingtaine d'années encore, les transitions sont beaucoup mieux assurées. Pour l'horizon retenu, on peut admettre que la totalité de cet hydraulique possible sera installé. En ce qui concerne les marémotrices, après mise en service de la Rance, il restera essentiellement le gisement du mont Saint-Michel. Mais il paraît vraisemblable que pour l'époque envisagée cet équipement ne sera pas en service, à supposer qu'il ait été engagé.

Les autres énergies fatales, en désignant ainsi toutes les sources qui, intégrées à un processus de fabrication (charbonnages, sidérurgie, papeteries, etc.) doivent être utilisées par priorité, peuvent être estimées pour l'horizon étudié à environ 30 TWh (contre 20 TWh environ actuellement).

Ainsi la totalité des moyens que l'on peut admettre comme parfaitement définis représente de l'ordre de 110 TWh laissant un peu moins de 400 TWh à fournir par le thermique classique et le nucléaire.

Si l'hydraulique conservait sa structure actuelle la contribution à la puissance de pointe du réseau en hiver sec serait de l'ordre de 13 GW; mais les projets futurs, actuellement en cours d'étude, sont orientés vers un suréquipement en puissance de pointe. Avec la contribution du thermique "fatal" estimée à 5 GW, la contribution des moyens au fil de l'eau s'établit à environ 20 GW laissant 90 — 20 = 70 GW à fournir par les centrales classiques, le nucléaire et les moyens de pointe (turbines à gaz et usines de pompage).

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* Les mélanges de charbon dans les parcs des centrales portent sur des quantités parfaitement déterminées dont le prix d'achat est connu lors de l'utilisation du combustible.

Les valeurs précédentes font apparaître une évolution sensible du rôle des énergies thermique et nucléaire: le thermique EDF avait jusqu'ici un rôle de régulation en ne fournissant qu'une fraction faible de la consommation (en 1963 25,1 TWh soit moins de 30%) alors qu'en 1985-90 ce sera environ 80%. En conséquence si jusqu'à présent les utilisations des diverses centrales thermiques EDF pouvaient être schématisées par un triangle, on est actuellement dans une phase de transition où se développe une forme de trapèze dans lequel l'énergie de base représente une fraction de plus en plus élevée (figure 3).

Ce changement de forme a une importance considérable pour le placement du nucléaire. Si le schéma passé était resté valable, le nucléaire en se développant aurait réduit son utilisation moyenne et chaque centrale nucléaire aurait eu la perspective d'une diminution progressive de son utilisation annuelle.

Le schéma probable est heureusement plus rassurant pour le nucléaire: tant que le niveau de puissance du nucléaire ne dépassera pas le seuil *S*, son utilisation annuelle sera aussi longue qu'elle pourra l'être technologiquement*. Si l'on pose que le niveau de ce seuil est de l'ordre de 40 à 45 GW**, on voit que pour la France une expansion moyenne à un rythme annuel légèrement inférieur au doublement tous les trois ans serait possible à partir de la situation de 1970 sans que la centrale la plus ancienne voit son utilisation se réduire pour l'horizon étudié.

D'une manière plus générale il faut suivre les évolutions relatives du niveau *S* et de la puissance nucléaire installée. La puissance de base se développera très rapidement dans les prochaines années, mais à partir de 1985 la prédominance thermique et nucléaire sera telle que le niveau *S*, voisin de la puissance minimale appelée par le réseau, se développera au rythme de la consommation sauf modification de structure de celle-ci.

Il est bien évident que le développement du nucléaire avec doublement en trois ans, s'il devait être envisagé, ne pourrait se maintenir au-delà du seuil puisque très rapidement non seulement l'utilisation diminuerait, mais encore le thermique serait complètement chassé du diagramme.

Il est aisé de voir que la durée annuelle d'utilisation du nucléaire le plus haut dans le diagramme est à ce stade très sensible au taux de développement du nucléaire au-delà du seuil et même plus précisément à la différence entre le rythme du nucléaire et celui du niveau du seuil. On peut ainsi arriver aisément à des hypothèses qui fassent décroître l'utilisation de centrales ayant moins de dix ans d'âge.

Bien entendu, il peut se faire que malgré cette réduction, l'énergie nucléaire puisse apparaître rentable si le coût global calculé avec cette utilisation reste plus faible que celui du thermique, comme on peut le montrer par un exemple très schématique.

En effet, en appelant:

t_f la charge fixe annuelle de 1 kW thermique

t_p le coût proportionnel de la meilleure centrale thermique

n_f et n_p les mêmes quantités pour le nucléaire;

En régime "stationnaire" l'utilisation U qui réalise l'égalité des coûts est:

$$U = \frac{t_f - n_f}{n_p - t_p}$$

quantité très sensible aux variations des différents termes.

Le problème réel est notablement différent de cette formulation: il faut tenir compte du développement continu à partir d'une situation éloignée de l'équilibre et surtout la plupart des paramètres ne sont pas connus d'une manière certaine (la durée de vie par exemple). Il est aisé de voir cependant que la sensibilité restera très grande.

Notons au passage que dans un système de ce genre la centrale thermique classique la plus récente n'est utilisée qu'avec une utilisation réduite lors de sa mise en service.

La conclusion qui ressort de l'examen précédent conduit à penser qu'il n'y aura pas de problème de placement de l'énergie nucléaire pendant au moins quinze ans. Ceci n'assure pas pour autant que toutes les centrales du programme auront leur pleine utilisation au-delà.

Fort heureusement les décisions seront à prendre à l'origine sur les équipements dont la pleine utilisation est la mieux assurée au départ, le coefficient d'actualisation donnant par ailleurs un poids relativement faible aux dernières années. Mais plus les programmes nucléaires se développeront et plus il faudra prendre garde à ne pas construire des centrales trop vite déclassées. La meilleure connaissance des filières permettra fort à propos de mieux définir les options de l'époque.

Du point de vue méthodologique, l'exemple traité montre clairement que la notion de rentabilité doit

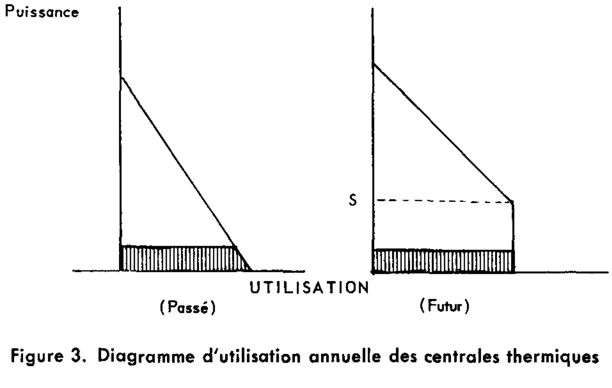

Figure 3. Diagramme d'utilisation annuelle des centrales thermiques

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* Le diagramme trapézoïdal tracé suppose que l'utilisation annuelle technologiquement possible est la même pour le thermique et le nucléaire.

** Ce chiffre est obtenu en déduisant du minimum du diagramme de charge (40 à 45 GW) les énergies au fil de l'eau, et en divisant ce chiffre par le facteur de charge techniquement admissible.

s'apprécier non seulement en fonction de la forme de la courbe de charge mais aussi d'après le rôle assigné au nucléaire: le cas de la centrale nucléaire unique est tout différent de celui du programme massif, et les modes de calcul doivent être adaptés en conséquence.

QUELQUES CONSÉQUENCES

Parti de la simple hypothèse d'un coût proportionnel nucléaire plus faible que celui du thermique classique — et ceci quel que soit le nucléaire — on arrive ainsi à la conclusion que pour quinze ans au moins le nucléaire ne fournira que de l'énergie de base.

Ceci a quelques répercussions sur le nucléaire lui-même qui peut, au moins à l'origine, avoir assez peu de souplesse. Augmenter la réserve de réactivité pour passer un pic xénon dû à des modulations hebdomadaires ou quotidiennes de la puissance présente peu d'intérêt puisqu'il en résulte un surprix sans compensation utile. La participation au réglage du réseau devrait même être réduite au minimum.

Le choix du déchargement, en marche ou à l'arrêt, se pose dans un contexte clair: on ne peut compter sur des périodes de faible demande pour modifier les éléments combustibles.

En ce qui concerne la taille des équipements, dont le rôle est fondamental dans l'économie du nucléaire, les chiffres précédents montrent que pour le réseau français la limite paraît provenir du côté constructif et non du réseau.

Pour les installations nucléaires de puissance élevée le schéma unitaire est difficile à envisager, et ne paraît pas s'imposer puisque c'est l'augmentation de la taille du réacteur qui est la source principale des économies d'investissements.

Les risques d'indisponibilités d'une installation proviennent pour la plupart des appareils tournants (pompes, soufflantes, turbines, alternateurs, etc.) et non du réacteur proprement dit. Par conséquent, si les circuits attenant à un réacteur sont suffisamment indépendants pour que la réparation de l'un d'entre eux soit possible les autres étant en fonction, la taille maximale à considérer pour le réseau est uniquement celle d'un circuit et non de leur ensemble. C'est là une simplification puisque le risque n'est pas nul d'avoir l'appareil de chargement indisponible lorsque se produit une rupture de gaine à évolution rapide. Quoiqu'il en soit, au moment où l'on vient de commander les premiers groupes de 600 MW thermique classique qui seront mis en service dans un réseau de 20 GW environ solidement interconnecté avec les réseaux voisins, il n'est pas exclu de penser que dans des conditions analogues, cinq ans plus tard, un réseau de 30 GW pourrait accueillir une installation nucléaire composée d'un réacteur ayant deux et même quatre groupes d'une puissance voisine.

L'étude de l'horizon 1985-1990 permet de tirer quelques enseignements sur les moyens de production autre que nucléaire: le kWh marginal sera encore produit à toute époque par le thermique classique. Le coût de la calorie classique sera donc l'élément directeur pour les calculs économiques de dimensionnement des projets hydrauliques ou pour l'énergie consommée par le pompage. Ceci n'est pas sans importance pour les décisions actuelles. On pourra enfin noter qu'à cette époque le thermique classique le moins utilisé sera vraisemblablement constitué par les premiers groupes du palier 125 MW dont la consommation spécifique est d'environ de 2 550 calories par kWh.

CONCLUSION

Les valeurs qui précèdent ne sont que des ordres de grandeur qui permettent cependant de rendre compte valablement de l'environnement dans lequel le nucléaire pourra se développer. Au cours des travaux préparatoires du cinquième Plan d'équipement, les perspectives seront précisées mieux qu'il n'a pu être fait ici en traçant avec plus de détail la courbe de charge de l'ensemble thermique classique et nucléaire. Mais les conclusions que nous avons dégagées resteront valables.

Il serait bien tentant d'essayer de bâtir à partir de ces données ce que pourrait être un programme de développement nucléaire. Mais pour dépasser le stade que nous avons analysé, il devient indispensable de faire de nombreuses hypothèses économiques.

Que ce soit pour les analyses marginales qui permettent d'estimer l'intérêt d'un équipement, que ce soit pour des calculs globaux donnant la répartition optimale des divers moyens de production, ou encore pour l'étude de la date du démarrage d'un programme massif en tenant compte de l'incertitude sur le progrès technique, pour tous ces problèmes, il faut disposer d'un ensemble d'hypothèses portant:

sur l'évolution des coûts du nucléaire;
sur l'évolution des coûts des moyens de production concurrents;
sur l'évolution de la structure même du réseau de production.

Pour l'instant il nous paraît de beaucoup plus important de dégager les évolutions quasi-certaines. Il n'est déjà pas si mal de pouvoir tirer cette conclusion que le risque concernant l'obsolescence des premières centrales nucléaires est pour les quinze ou vingt prochaines années infiniment moindre que les incertitudes économiques qui règnent encore sur les filières les plus évoluées et qu'en conséquence lorsque les efforts d'amélioration du nucléaire auront porté leurs fruits, son développement ne sera pas entravé en France par les caractéristiques du réseau électrique.

ABSTRACT - RÉSUMÉ - АННОТАЦИЯ - RESUMEN

A/43 France

Integrating nuclear power into France's electricity network

By R. Janin

Compared to fossile thermal power, nuclear power involves a higher capital cost, at least in its present stage of technical development. Nuclear power stations are therefore particularly preferable when they can operate for long periods.

Study of the possibilities of developing this new form of energy must be based on the load curve of the network.

Until now, hydro and thermal power have equally shared the task of supplying the French network. Allowing for its limited potential development, hydropower is now expanding at a constant rate, whereas consumption is increasing exponentially. The proportion to be supplied by fossile-based and nuclear fuel thermal power will therefore rise.

New hydrogenerating methods will, as far as possible, be more and more directed towards the generation of small units of power. Increased rating of existing power stations will also contribute towards proper operation of thermal and nuclear stations by supplying peak loads.

Since the ratio between the maximum and minimum points on the daily load diagram is about 2, the possibility of integrating basic nuclear power naturally involves no problem at present. It has been verified that, even with the highest possible expansion which may reasonably be expected for this power, it will not exceed the zone of maximum use during the next twenty years. It is therefore not the requirements of the load curve that are now hindering rapid development of this new source of power, but rather the uncertainty, now diminishing, regarding the physical and economical performance of the new power stations.

A/43 Франция

Включение энергии атомных электростанций во французскую электросеть

М. Жанен

По сравнению с тепловыми электростанциями, работающими на угле, атомные электростанции требуют значительно бóльших капиталовложений по крайней мере на современном уровне технического прогресса. Следовательно, атомным электростанциям можно отдать предпочтение лишь в том случае, если они будут работать длительный период времени.

Изучение возможностей развития этого нового вида энергии должно основываться на кривой графика нагрузки электросети.

До настоящего времени гидравлические и тепловые электростанции почти при одинаковых нагрузках вырабатывали энергию для французской электросети. В силу ограниченных возможностей развития гидравлические электростанции в настоящее время работают в постоянном ритме, тогда как потребление электроэнергии экспоненциально возрастает. Следовательно, удельный вес энергии вырабатываемой тепловыми электростанциями, работающими на угле, а также атомными электростанциями, будет непрерывно возрастать.

Гидроэлектростанции по мере возможности будут все больше и больше ориентироваться на производство энергии при плавно меняющихся нагрузках.

Переоборудование существующих заводов будет также способствовать развитию тепловых и атомных электростанций, которые будут работать при максимальной нагрузке графика.

Поскольку соотношение между максимальным и минимальным графиками нагрузки составляет примерно 2, возможность включения основной атомной электроэнергии в государственную электросеть не представляет, по-видимому, никакой проблемы на сегодняшний день. Было установлено, что при самом быстром развитии, которое только можно представить, атомные электростанции не выйдут за пределы максимального графика нагрузки в ближайшие 20 лет. Следовательно, быстрому развитию этого нового источника энергии мешает не напряжение графика нагрузки, а неуверенность, которая, хотя и несколько уменьшилась на сегодняшний день, все еще существует в отношении физических и экономических характеристик новых электростанций.

A/43 Francia

Integración de la energía nuclear en la red eléctrica francesa

por R. Janin

La energía de origen nuclear, comparada con la térmica de combustible fósil, presenta unos gastos de primer establecimiento más elevados, al menos en el estado actual de desarrollo técnico. Por tanto, una central nuclear es particularmente sensible al tiempo de utilización.

El estudio de las posibilidades de desarrollo de

esta nueva energía debe basarse en la curva de carga de la red.

Hasta el presente, las energías hidráulica y térmica han contribuido con cargas sensiblemente iguales al servicio de la red francesa. La hidráulica, dadas sus limitadas posibilidades de crecimiento, se desarrolla actualmente a un ritmo constante, mientras que el consumo continúa creciendo exponencialmente. En consecuencia, la proporción de energía térmica, tanto de combustible fósil como nuclear, tiene que aumentar.

Los nuevos medios de producción hidráulicos se orientarán cada vez más, dentro de lo posible, hacia la producción de energía de utilización baja. La renovación del equipo de algunas centrales ya existentes contribuirá también, al cubrir las puntas del diagrama de carga, a que las centrales térmicas, tanto clásicas como nucleares, funcionen con un buen factor de utilización.

La posibilidad de integración de la energía nuclear de base no presenta, evidentemente, ningún problema en la hora actual, dado que la relación entre la punta y el mínimo del diagrama diario de carga es aproximadamente 2. Se ha comprobado que, aun con el desarrollo más rápido que pueda imaginarse razonablemente, la energía nuclear no sobrepasará la zona de máxima utilización durante los próximos veinte años. No es, pues, la forma de la curva de carga lo que limita, actualmente, un rápido desarrollo de esta nueva fuente de energía, sino la incertidumbre, si bien hoy ya disminuida, que reina todavía sobre las características de funcionamiento, tanto físicas como económicas, de las nuevas centrales.

Planning for nuclear power in the Central Electricity Generating Board's system

By P. W. Cash and F. Faux*

This paper presents an up-to-date account of the integration of nuclear power into the system of the Central Electricity Generating Board, from the inception of the original programme to present plans extending to 1970.

The British Government announced in February 1955 a provisional programme of nuclear generation, then envisaged as providing some 2 000 MW of capacity by 1965. The nuclear power stations were to be owned and operated by the Electricity Authorities, it being evident that most of the stations would be installed in England and Wales on the system of what is now the Central Electricity Generating Board. Subsequent modifications in the programme led to an announcement in June 1960 of a target of about 5 000 MW by 1968.

In February 1955 the system comprised 275 power stations with an aggregate output capacity just over 17 000 MW of which over 99% was thermal and under 1% hydroelectric plant. At that time it was estimated that the growth of demand would require expansion of plant capacity to about 34 000 MW by the winter of 1965/66. The first sections of the 275 kV grid were then just coming into operation to strengthen the interconnection capacity of the transmission system. Among the other plans already settled were those for providing a number of major coal-fired stations near the highly productive East Midlands coalfield with a measure of bulk transmission of electricity to the south of the country, where little coal is produced.

The next year (1956) saw a departure from the post-war standard designs for generating units (30 MW and 60 MW) with the bringing into service of the first of the more advanced stations containing 100 MW units with steam conditions of 1 500 lb/in^2 and 565°C. 120 MW units were expected to be in operation by 1957, 200 MW units by 1959 and larger units in the early 1960s.

Such was the shape of the system into which nuclear power was to be introduced. Once the decision of principle had been made, investigations leading to the siting of the first two stations were compressed into the shortest possible time. Subsequent experience has improved knowledge of some of the siting factors and others have been modified by advances in reactor sizes, but broadly the original concepts of how best to integrate nuclear power into the system still hold good.

THE NUCLEAR PROGRAMME OF THE CEGB

The original announcement of the British programme stressed that it was to be regarded as provisional and subject to change in the light of events. An early change was an increase in size of reactor contemplated. Other decisions were subsequently made which influenced the rate of commissioning. Whereas originally an extrapolation from Calder Hall to reactors having a net electrical output of 75 MW was envisaged, the evolution of designs showed that it was technically feasible and economically attractive to roughly double the size for the first two stations, and site requirements were quickly amended. It was recognised that the system could accept even larger units, and, by continuation of the same trend of reactor engineering development, the next stations have reactors each giving 250-300 MW(e) net output, whilst the latest station for which a contract has been placed has reactors with a net output of 590 MW(e). Each of the stations has two gas-cooled graphite-moderated reactors fuelled by natural uranium clad in Magnox. The first seven stations have steel pressure vessels, while the two latest incorporate pre-stressed concrete pressure vessels.

Eight nuclear stations have been planned in England and Wales by the Central Electricity Generating Board; two have been operating since 1962 and the others are under construction. A list of these stations is given in Table 1. One station having a net output capacity of 300 MW(e) has recently been commissioned at Hunterston in Scotland for the South of Scotland Electricity Board. The Calder Hall and Chapelcross stations of the UK Atomic Energy Authority, each having four reactors and an output of 180 MW(e), feed surplus electricity into the English and Scottish systems respectively.

Nuclear stations represent about 12% of the CEGB programme of new generating plant capacity over the 10 years from 1961 to 1970. On the latest load estimates the total plant capacity required to be

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* Central Electricity Generating Board.

Table 1. CEGB nuclear power stations

Year of commissioning first reactor	Station	Location	Net output capacity of station MW
1962	Berkeley	Severn Estuary	275
1962	Bradwell	Essex Coast	300
1964	Hinkley Point "A"	Bristol Channel	500
1964	Trawsfynydd	North Wales	500
1964	Dungeness "A"	Kent Coast	550
1965	Sizewell	Suffolk Coast	580
1966	Oldbury	Severn Estuary	600
1968	Wylfa	Anglesey	1 180
			4 485

The first reactor in Dungeness "B" is provisionally proposed for commissioning in 1970.

in service in 1970 in England and Wales is about 67 000 MW of which about 5 000 MW will be nuclear, so that the proportion of nuclear plant will be about 7.5%. The total cost of these stations with their initial fuel charges will be over £600 million.

SYSTEM CHARACTERISTICS

The daily and seasonal variations of the simultaneous load demand on the CEGB system follow a consistent pattern on which is superimposed substantial short-term fluctuations in response to temperature changes. The seasonal variation is closely related to the normal seasonal temperature but is also influenced by changing hours of sunset and sunrise. At present the weekly minimum demand, which occurs at night at weekends, is about 25% of the corresponding weekly maximum demand. The annual minimum demand, which occurs on a summer weekend, represents some 13% of the winter peak demand. Fig. 1 illustrates the range of variation.

In Fig. 2, curve A shows the annual load-duration curve as estimated for 1970/71. The annual system demand load factor, at present about 47%, is expected to have risen to 50%.

The system has a high load density (about 1 000 kW per sq. mile in 1970/71) and, because of the moderate transmission distances, it has proved economic to interconnect strongly all power stations through 132 kV and 275 kV (later 400 kV) networks, thereby minimizing the proportion of spare generating plant needed. Because of the differences in production costs of the various coalfields, in transport distances to the power stations and in thermal efficiencies, fuel costs per kWh vary over a wide range, as shown in Fig. 2, curve B. This gives scope for substantial operating savings by selective loading of generators in merit order as a single integrated system. Full exploitation of merit-order loading is a cardinal feature of CEGB operation.

UTILISATION OF NUCLEAR PLANT

On account of increasing reactor size and other technological improvements, capital costs (inclusive of all site services but exclusive of first fuel charge) are expected to fall from £180 per kW for the first stations to £100 per kW for the later stations. There is also expected to be a fall in fuel replacement costs from 0.25d (pence) per kWh to 0.15d per kWh.

At the same time considerable progress is being made in the development of conventional plant. Ten conventional power stations, each having four

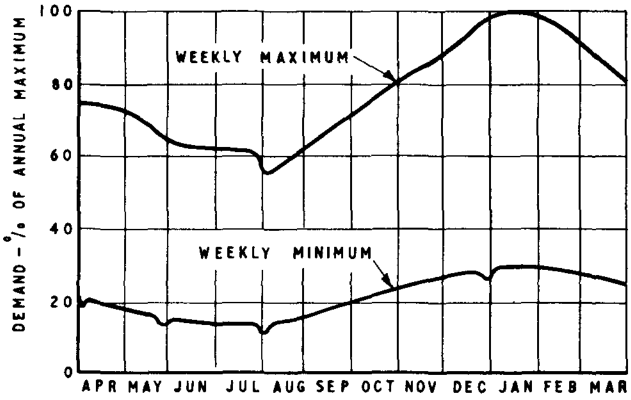

Figure 1. Typical weekly maximum and minimum load demands

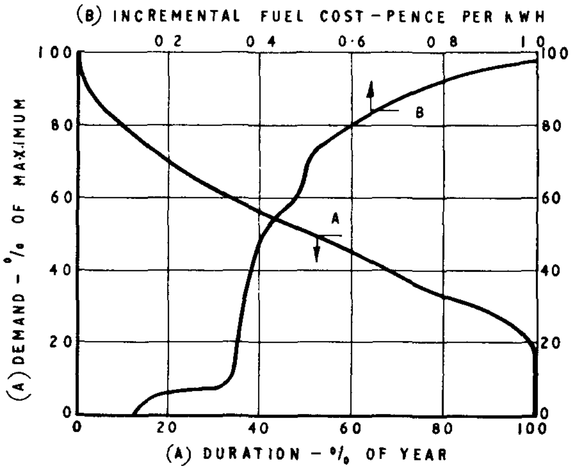

Figure 2. Estimated load duration curve and generation incremental fuel cost for 1970/71

500 MW generating units, which are expected to be commissioned in the period 1965-1970, are estimated to have a capital cost of about £37 per kW (the average for units ranging from 100 MW to 275 MW commissioned in 1962 was about £50 per kW) and fuel costs, depending on fuel source and transport distance, of between 0.35d per kWh and 0.50d per kWh. However, these advances are less dramatic than those achieved by nuclear plant, so the gap between the costs of nuclear and conventional power is being closed steadily although at a slower rate than was originally anticipated in 1955.

Curve B of Fig. 2 shows the fuel cost of successive increments of plant plotted against cumulative plant capacity in 1970/71. The abrupt change of shape in the lower part of the curve represents the transition from nuclear to conventional stations and emphasises the economic importance of operating nuclear plant at the highest possible load factor.

The modest system load factor which results from low night and summer loads could militate against high utilisation of base-load plant, but the capacity of nuclear plant so far in hand falls well below the point where limitation begins. From Figs. 1 and 2 it is clear that the only restriction on utilisation of a nuclear component amounting to 7.5% of the total capacity, adequately connected to the fully integrated system, will be the availability of the plant itself. With only limited operating experience it has been considered prudent to take for planning purposes what is believed to be a pessimistic assumption of 75% for the annual average availability of nuclear plant and of 85% at the time of system maximum demand.

The capacity of the system to accept a higher proportion of nuclear plant in the future has been examined in the course of periodic studies of possible ranges of development of the complete power system over periods of 20 to 30 years ahead. Such studies involve estimates (which become more speculative with time) of system power and energy growth, proportions and capital costs of different types of plant (nuclear, conventional and peaking) and the cost and availability of nuclear, coal and oil fuels. It has been deduced that, with a system demand load factor of 50% and making due allowance for probable out-of-merit running of some conventional plant because of inflexibility or transmission restrictions, the proportion of nuclear plant could approach 30% of the total system capacity before its annual load factor fell below 75%. This is on the assumptions that the average power level of the reactor can be reduced to 70% during daily off-peak hours without poisoning out and that the time to pick up to full load is no longer than for conventional plant.

Energy storage, if economical, could facilitate larger-scale base-load nuclear generation. A 320 MW pumped storage scheme, which has recently been constructed at Ffestiniog in North Wales, was decided upon prior to the nuclear power programme. Other schemes are being actively considered. At present, the night pumping power is supplied by conventional generation, but when the proportion of nuclear plant on the system exceeds some 30% of the total generating capacity a substantial part of the pumping power can be supplied by nuclear generation to considerable economic advantage.

A difficulty in economic evaluation of alternative new plant projects in an integrated system arises from the fact that they may have appreciably different load factors which also change to differing extents during the course of their lives. The simple approach comparing costs at a single load factor may be satisfactory when very similar projects are to be compared, e.g., different tenders for the same plant items, but for more complex studies involving different types of plant it is necessary to assess the difference in operating cost of the entire system with the alternative developments. Assessments are made for each year in the life of the plant under review and summed using the "present value" concept.

INFLUENCE OF ENERGY SOURCES

The rate of growth of the system is such that, despite the increasing proportion of energy supplied by nuclear power stations, the consumption of coal is expected to rise from 49 million tons in 1960/61 to over 80 million tons by 1970/71, the latter out of a total national production of about 200 million tons.

Table 2 shows the estimated contributions of various sources towards meeting the power and energy requirements of the CEGB system in 1970/71. For comparison the corresponding figures for 1960/61 are also shown.

The geographical pattern of electricity demand relative to the coalfields, in particular the highly productive central coalfields of the East Midlands and South Yorkshire, has an important influence on the siting of the nuclear stations.

Fig. 3 illustrates the main energy flows for electricity supply as estimated for the year 1970/71. The divisions shown are those of the Grid Control Areas (GCAs) used in operating the system, except that, for clarity of presentation, the Bristol Area is sub-divided to show the difference in coal production on opposite sides of the Severn Estuary and the two Thames Areas are combined. The Thames Areas and the South Western Zone account for 40% of the total electricity consumption of the country, but have negligible coal resources. The large energy surpluses in the Birmingham and Leeds Areas arise from the growing production in the central coalfields of cheaply mined coal which is suitable for electricity generation.

The surplus coal in the Newcastle Area is planned to be moved to the Thames Estuary by sea because

Table 2. Sources of power and energy for CEGB

Power sources for electricity generation	Net output capacity 1960/61 MW	Net output capacity 1960/61 %	Net output capacity 1970/71 MW	Net output capacity 1970/71 %	Energy production 1960/61 %	Energy production 1970/71 %
Nuclear	—	—	4 930	7.5	—	12
Pumped storage	—	—	920	1.5	—	—
Hydro	63	small	110	small	small	small
Oil	3 155	12	10 080	15	18	12
Coal	23 849	88	50 690	76	82	76
Total	27 067	100	66 730	100	100	100

coastwise transport is the cheapest method of energy movement where there are ports close to the coalfields and the receiving power stations can be served by collier. In contrast the central coalfields are some 60 miles from the coast, and a combination of coal transport by rail and overhead transmission of electricity is the cheapest method. The development of permanently-coupled block-train working together with rapid unloading at the power stations (one hour turn round for a complete train) has provided scope for economic generation at medium load factor in new stations at medium distances from the central coalfields. But, despite this tendency, it is economic to move the bulk of the energy surplus in the Birmingham Area to the Thames Areas by electrical transmission from stations sited close to the coalfields. In 1970/71 the total transfer of energy from the three exporting areas to the importing areas is estimated to be about 40 million tons coal equivalent, of which about half will be in the form of electricity.

Oil and nuclear generation are being introduced into the south of the country and to a lesser extent in the Manchester Area, which is also an energy-importing area, thus limiting the growth of expenditure on long-distance transport of coal or transmission of electricity. The deployment of oil is influenced by the location of the main oil terminals and refineries. Two major oil-fired stations and one dual-fired station are at present being constructed in the south.

All the nuclear stations are in the energy-importing areas since nuclear fuel transport costs are virtually the same wherever the station is located. Within these importing areas the actual sites chosen follow a somewhat different pattern from that of coal-fired stations by reason of the siting factors discussed in the next section. Fig. 4 shows the location of the 245 stations that will exist in 1970.

SITING REQUIREMENTS

Collectively, the siting requirements of nuclear power stations are so exacting that the desired combination of physical characteristics is geographically rare in England and Wales.

Technically the most important requirement is an adequate supply of cooling water. The steam conditions of nuclear stations are materially lower than those of modern conventional stations but, despite the improvement in thermal efficiency of the later nuclear stations, they still require well over 50 per cent more cooling water than conventional plant.

The largest English rivers have insufficient dry-weather flows for direct cooling of even the smallest nuclear station. Inland water resources can best be used in supplying cooling water for conventional stations, usually in the form of make-up for cooling towers. Hence all the nuclear stations, with the exception of Trawsfynydd which employs surface cooling on a large reservoir, are located on the coast or major estuaries.

Those conventional stations which are located on the coast have usually been sited on harbours or estuaries, or near to oil refineries, where sea-borne fuel supplies can be unloaded from vessels with sheltered berthing facilities and where cooling water works are not unusually difficult. The use of more exposed sites for nuclear stations has brought many added problems. As cooling water tunnels can cost several thousands of pounds per yard, it is important to have deep water fairly close in-shore. The intake and outfall structures, and any associated works such as dredging, must be devised so as not to endanger navigation or permit changes in the littoral drift regime which might result in scour, erosion or accretion of sections of the coastline.

Foundation conditions are important since a reactor structure can weigh around 60 000 tons and impose bearing pressures of up to 12 tons/ft^2. In the west of the country, rock at Hinkley Point, Trawsfynydd and Wylfa, and marl at Berkeley and Oldbury, provide firm foundations. On the east coast, more difficult conditions have had to be accepted; clay at Bradwell, shingle at Dungeness and sand at Sizewell have all introduced a variety of foundation problems.

A site should be flat and at about high-tide level in order to avoid excessive pumping head. There should be no danger of flooding and, although the buildings themselves may occupy no more than

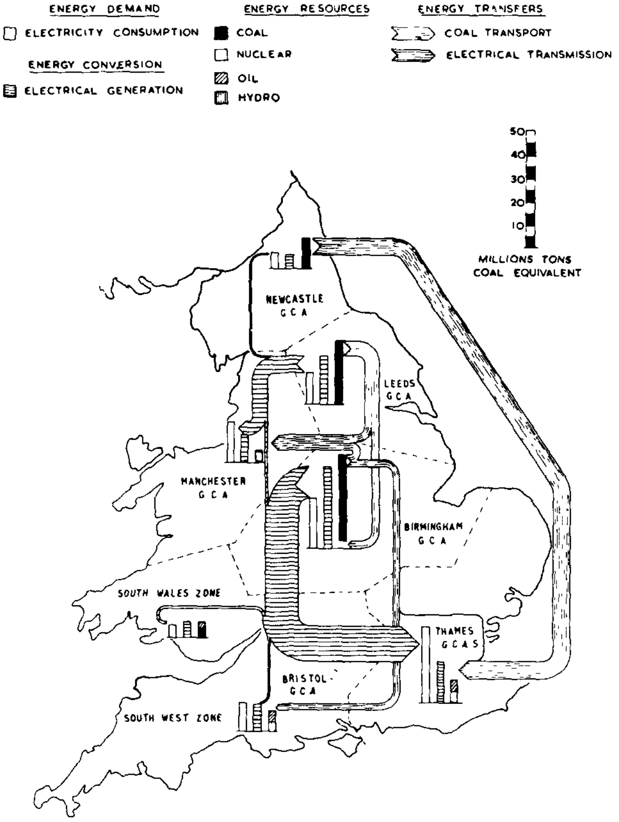

Figure 3. Estimated energy transfers in 1970/71

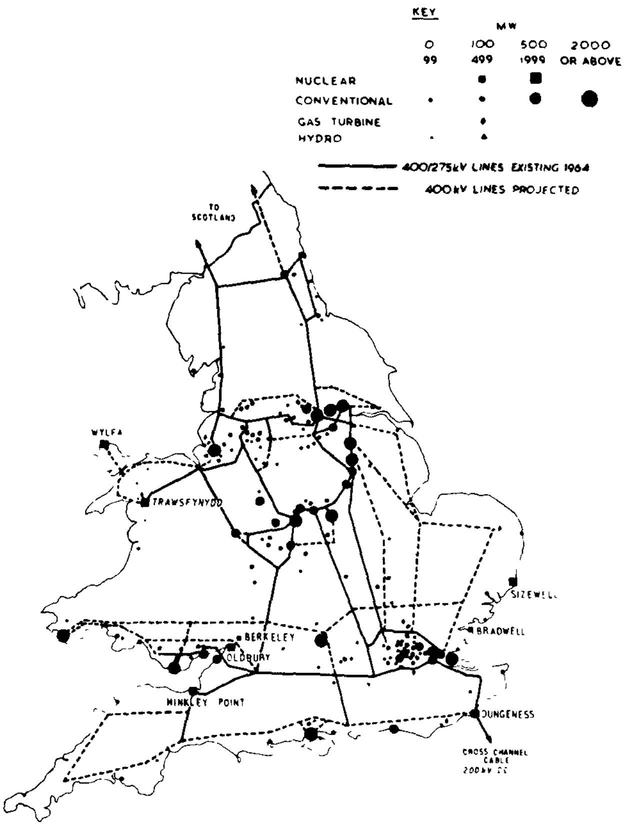

Figure 4. Power stations and 400/275 KV transmission system in 1970

25 acres, additional land is essential for rapid construction and to permit prefabrication of large components. Broadly, sites of 100–200 acres have been selected; in most of these cases there is sufficient space for further development, in at least one instance up to 3 000 MW or more.

Transportation of heavy and bulky construction loads presents problems. Good road access is essential but, even so, in some cases it has been found more convenient to float complete heat exchangers, having dimensions of the order of 80 ft long and 20 ft diameter, by sea from the makers' works. For some sites special port facilities have been built as close to the site as practicable to permit large and heavy components to be transported by coastwise shipping. Rail access cannot be justified for transportation of fuel as the limited amounts handled can easily be taken by road to the nearest rail-head.

The siting of a nuclear power station is further restricted by safety considerations. Although in normal operation nuclear plants produce very little addition to the normal background radioactivity and it is a major objective of design and operation to guard against every credible combination of faults, it nevertheless remains impossible to guarantee absolute immunity from an accident leading to an escape of radioactivity. Wide population-exclusion areas are not feasible in England and Wales with an average population density of 800 per square mile. Initially sites were classified in accordance with population groups of a few people, 500, 10 000 and 100 000 being contained within certain distances.

Experience revealed that a more refined approach was required to allow a fair comparison to be made between sites around which population is distributed in very different ways. Experimental work and the study of accidental releases, in particular that from one of the air-cooled reactors at Windscale in 1957, established that the inhalation of radioactive iodine presented the greatest hazard for immediate control, while contamination of milk would be the most widespread hazard. The basis of the siting policy subsequently adopted has been published by the UKAEA [1]. Four classes of site have been defined corresponding to population densities equivalent to 6%, 12%, 25% and 50% of the maximum obtainable in a built-up area. All the sites so far selected conform to Class 1 (equivalent population density 6% of maximum) although recent assessment of the additional safety afforded by concrete pressure vessels will permit the use of Class 2 for Magnox stations incorporating this feature.

Special consideration has to be given to the hazards that might arise within 1 mile of the site. The population in any sector must be considered in relation to the ease or difficulty of control or evacuation should a release of radioactivity occur. Only a few people should be resident in a 30° sector within 0.3 mile and not more than 500 within 1 mile.

In addition to the technical and economic factors, great importance attaches to considerations of town and country planning. Indeed, the Board have a statutory duty in considering possible sites to have regard to the effect a power station may have on what is usually known as "amenity". Nuclear stations do not need tall chimneys, facilities for handling large quantities of coal or ash nor, if on the coast, large cooling towers; and in these respects they are less objectionable than conventional stations. However, coastal sites which are sufficiently remote are often in areas that are particularly highly prized.

In England and Wales, over 40% of the total land area and 30% of the coastline is protected in the form of green belts, national parks, nature reserves, etc., and much of the remaining land is of good agricultural quality. In addition, on the south coast particularly, much of the coastline is built up. The siting of power stations, therefore, involves consultations with a wide range of interests such as the statutory Planning Authorities, Government Departments, River Boards, the Nature Conservancy and the National Parks Commission. It is as difficult to find sites having a reasonable combination of the desired technical and safety features as it is easy to see the objections to them, and the choice of the right compromise is a matter of some delicacy. There are elaborate procedures for obtaining statutory consent, including provision for discussion at public inquiries. By this means the public interest is fully safeguarded, though the procedures have not always proved entirely compatible with the speed of decision required in connection with the nuclear power programme.

LOCATION OF STATIONS

The influence of energy sources, which has been previously discussed, indicated a need for nuclear power stations in the south, particularly in the Greater London area and, to a lesser extent, in the north-west. Figure 4 shows the locations that have actually proved possible having regard to the factors discussed in the previous section.

The nearest suitable site to London was at Bradwell, on the Blackwater Estuary, where one of the first commercial stations to be commissioned in England and Wales has now been operating for nearly two years. Apart from the usual objections to putting a power station in a rural area, the public discussions of this proposal centred mainly on the risk that warming and chlorination of the condenser cooling water would harm the oyster industry of the estuary. Actual conditions are being monitored to determine whether it will be possible to extend the station at some future date; experience to date is encouraging.

Dungeness and Sizewell are open coastal sites further from the heaviest load centres, both with a large ultimate potential for generation. Both are in areas of interest to naturalists and special arrangements have been made to minimise disturbance and afford preservation. The central south coast has built-up areas with heavy electrical demands and, being remote from the coalfields, is clearly one of the most advantageous positions for nuclear generation. It is unfortunate that the limited siting possibilities found on this coast have raised issues of such difficulty as not to be soluble in time to enable them to form part of the present nuclear power programme.

In the south-west, the Severn Estuary brings tidal cooling water well inland and, apart from the city of Bristol and its port of Avonmouth, the shores are not heavily built up. Berkeley Power Station is already operational whilst Hinkley Point and Oldbury, the first station to utilise pre-stressed concrete pressure vessels, are under construction. The physical features of the estuary result in swift currents and a tidal rise and fall of about 40 ft in most places; exceptionally heavy silt burdens are encountered, 5% being not uncommon. The designing of reliable cooling-water systems as inexpensive as possible is an exacting task. The Oldbury site has been chosen to take advantage of a large rock shelf at about half-tide level in the estuary; a shallow 350 acre tidal reservoir is being constructed on it to supply cooling water during the lower half of the tidal cycle. A large hydraulic model of the estuary has been used to study siltation problems and the cooling-water conditions at Oldbury, also in association with Berkeley, and to assist in solving the problems associated with establishing further stations on the estuary in the future.

The remaining stations in the course of construction are in North Wales, inland at Trawsfynydd and at Wylfa on the Island of Anglesey. The former station, which is the exception to coastal siting, is 600 ft above sea level in a mountainous area of heavy rainfall, and will use an existing CEGB hydro-electric storage reservoir some two square miles in area for surface cooling. The site is in the Snowdonia National Park in a district of some scenic beauty. Here, as in most cases, the Board have engaged the services of a landscape consultant from the outset to advise, in conjunction with an eminent architect, on the treatment of the site and its setting in developing the design and layout.

Further sites are under consideration on the east and south coasts, the Severn Estuary and in North Wales. The broad picture that emerges is of nuclear stations being sited in the coastal areas remote from the coalfields, with transmission lines to carry power to inland load centres.

TRANSMISSION

The main transmission system in England and Wales comprises a national 275 kV network interconnecting the various regional 132 kV networks. The existence of this system made it relatively easy to integrate nuclear power stations with a large capacity of conventional plant, thus providing scope for long-term operation at the highest attainable load factor and extracting the maximum benefit from the high investment in nuclear plant. Only slight adaptation of the preconceived development of the transmission system has been needed to accommodate the nuclear stations so far constructed or planned.

Beginning in 1965, the voltage of most of the national network will be raised to 400 kV and, by 1970, 275 kV will be confined to the extreme north and to certain routes around the principal conurbations. Fig. 4 shows the network configuration planned for 1970; it will comprise some 3 400 miles of 400 kV line and some 1 400 miles of 275 kV line, all of double-circuit construction. The network will have wide geographical coverage and, as well as interconnecting the principal load and generating centres, it will be used to distribute supplies over the intervening territories where the loads are large but dispersed.

The station siting problems, as well as economic considerations, make it desirable to provide for development of individual nuclear sites to the limit of their capabilities, and in some cases over 3 000 MW can be envisaged. For stations of such size to be operated at high load factor the transmission connections must permit distribution of the output over wide areas at light-load periods. Overhead lines as well as power stations have an impact on amenity, and this factor combines with economic considerations to dictate the use of few circuits of high voltage for connecting the nuclear stations. For these reasons the transmission arrangements for all but one of the stations provide for connection at 400 kV.

The transmission distances for this purpose are comparatively short and yield circuit capabilities of 1 000 MW to 1 500 MW, which, in most cases, allow the overhead-line routes from each site to be kept to two in number. Also, the requirements for wide distribution of the generated output are readily satisfied because of the national coverage of the 400 kV network.

Berkeley, the smallest of the nuclear stations, is connected into the 132 kV network. Bradwell, Sizewell and Oldbury, connected at 132 kV initially, will have transmission lines of 400 kV construction with a view to future uprating if further stations are sited nearby. The remaining nuclear stations will be connected into the 400 kV network. Hinkley Point will be connected by means of a short deviation of a line being constructed to reinforce supplies to the extreme south west of the country. Trawsfynydd will share the use of a line being built to link the Ffestiniog pumped-storage station with the main system. Dungeness will similarly share the use of the connexion to the Cross Channel cable, though a second line will extend westwards to reinforce supplies along the south coast. Oldbury is close to the 275 kV overhead crossing of the Severn Estuary and to a future 400 kV line which is being provided to strengthen the ties to South Wales. Only in the case of Sizewell and Wylfa will substantial additional spur lines be required. The connection for Sizewell will be two lines of 400 kV construction leading westwards and that for Wylfa will be a single 400 kV line to the mainland, joining with an extension from Trawsfynydd and continuing eastwards to complete a ring around North Wales.

CONCLUSIONS

A closely knit high-voltage system like that of the CEGB, on which fully integrated operation of all the power stations is well established, provides favourable conditions for the introduction of nuclear power. A system capacity of 67 000 MW will permit the fullest utilisation of the 5 000 MW of nuclear plant planned for 1970, and with a transmission circuit capability of 1 000 to 1 500 MW there is no difficulty in accepting reactor units of 600 MW of electrical output.

A lack of potential water power and an uneven geographical distribution of indigenous fuel resources are further circumstances favourable to the introduction of nuclear power, provided that sites suitable for nuclear power stations can be found in high fuel-cost areas. Despite the remoteness of the stations to meet exacting safety requirements, very little reorientation of transmission development has been entailed.

The continuing scale of installation of nuclear plant on the CEGB system will depend upon appraisals of fuel resources and relative economics that go beyond the scope of this paper. Although the consumers' load factor does not yet exceed 50% the system as a whole is well suited to it; for example, even the largest and most efficient coal-fired units have been designed with an eye to nightly shutting down as they become relegated to lower-load-factor working. A substantial amount of additional nuclear plant could be utilised to the limit of its availability, and if larger reactors could effect worth while capital savings without sacrifice of reliability the system would be able to accept them.

REFERENCE

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ABSTRACT - RÉSUMÉ - АННОТАЦИЯ - RESUMEN

A/561 Royaume-Uni

Plan d'intégration de l'énergie d'origine nucléaire dans le réseau du Central Electricity Generating Board

par P. W. Cash et F. Faux

Le Royaume-Uni a entrepris un large programme de construction de centrales nucléaires, dont la plus grande partie relève du CEGB. Deux centrales nucléaires ont été mises en service et fonctionnent d'une façon satisfaisante. Six autres sont en construction et une est à l'étude. En 1970, la puissance installée d'origine nucléaire devrait être de quelque 5 000 MW sur une puissance totale d'environ 67 000 MW fournie au réseau de distribution électrique de l'Angleterre et du Pays de Galles.

L'intégration des centrales nucléaires dans le réseau pose des problèmes économiques, techniques et sociaux. Des décisions fermes sur la puissance, l'emplacement des nouvelles centrales et les lignes de transport doivent être prises cinq ans avant leur mise en service, compte tenu du taux d'augmentation de la demande, de la forme de la demande, de la sécurité du réseau et de la disponibilité de sites convenables. La valeur économique des divers projets est comparée compte tenu de la durée de leur vie utile, et eu égard au développement d'ensemble possible, à l'aide des concepts actuels de valeur.

La distribution géographique de la demande d'électricité par rapport aux régions houillères a un effet marqué sur l'implantation des centrales au charbon et des centrales nucléaires dans le pays. Un nouvel accord de transport ferroviaire a rendu l'utilisation du charbon hors des régions houillères plus attrayante, mais un important transport d'énergie électrique vers le Sud-Est, avec un facteur de charge élevé, demeure rentable. Les grandes centrales au mazout sont situées à proximité des importantes raffineries de pétrole.

Les considérations pratiques, tel que le fait de trouver des emplacements convenant techniquement pour les centrales nucléaires, sont également importantes. L'eau de refroidissement présente la principale difficulté et c'est pour cette raison que jusqu'en 1970 toutes les centrales sauf une sont prévues sur la côte ou dans de grands estuaires. Les fondations doivent pouvoir supporter les fortes charges imposées par les structures des réacteurs. Il faut disposer d'un terrain suffisant pour les bâtiments et pour permettre une construction rapide; un accès facile est également essentiel. Le choix d'un emplacement est restreint aussi par des considérations de sécurité. La politique fixée par les pouvoirs publics veut que ces premières centrales soient situées dans des zones à faible densité de population.

Jusqu'à présent les centrales ont été installées dans les zones importatrices de courant du Sud et du Nord-Ouest du pays. Il est cependant possible que les futures centrales puissent être situées ailleurs. Faute d'un réseau national de transport à 275 kV et fortement interconnecté, maintenant en cours de conversion à 400 kV, l'énergie d'origine nucléaire n'aurait pas pu être introduite à son échelle actuelle.

A/561 Соединенное Королевство

Планы использования атомной энергии в системе Центрального энергетического управления

П. У. Кэш, Ф. Фокс

Великобритания осуществляет широкую программу по атомной энергетике, причем строительство значительной части станций возложено на Центральное энергетическое управление. Две атомные электростанции уже введены в строй и успешно работают. В настоящее время строится еще шесть ядерных электростанций и планируется строительство еще одной. Ожидается, что к 1970 году общая мощность атомных станций составит около 5000 *Мвт* при общей установленной мощности в Англии и Уэльсе приблизительно 67 000 *Мвт*.

Включение атомных станций в общую сеть представляет экономические, технические и социальные проблемы. Окончательные решения относительно мощности и размещения новых станций, оборудования по передаче электроэнергии должны приниматься за пять лет до того момента, когда они потребуются, учитывая увеличение спроса, его распределение, систему техники безопасности и наличие подходящих площадок. На основании современных стоимостных данных сравниваются экономические аспекты отдельных проектов на период их использования в рамках предположительного общего развития энергетики.

Географическое распределение спроса на электроэнергию в зависимости от расположения главных каменноугольных залежей оказывает сильное влияние на размещение в стране электростанций, как работающих на каменном угле, так и на ядерном топливе. Хотя новое соглашение относительно перевозок по железным дорогам и способствовало увеличению производства электроэнергии станциями, работающими на угле, однако передача значительного количества производимой электроэнергии на юго-восток при высоком коэффициенте нагрузки все же остается экономичной. Основные электростанции, работающие на нефти, располага-

ются преимущественно вблизи крупных нефтеочистительных заводов.

Равным образом важными представляются практические соображения, такие, например, как нахождение подходящих с технической точки зрения площадок для строительства атомных электростанций. Наличие воды для охлаждения является самым большим затруднением, и поэтому до 1970 года все электростанции, за исключением одной, будут строиться на берегу моря или в устьях больших рек. Грунт должен выдерживать большую нагрузку отдельных узлов реактора, причем необходимо располагать достаточным земельным участком для размещения помещений и для быстрого строительства; существенное значение играют также удобные подъездные пути к площадке. При выборе места для строительства реактора следует принимать во внимание проблему безопасности. Правительство требует, чтобы первые атомные электростанции располагались в районах с незначительной плотностью населения.

До настоящего времени электростанции строились на юге и северо-западе страны, то есть в районах, импортирующих электроэнергию. Однако представляется, что будущие станции могут строиться в любых местах. Использование ядерной энергии в ее теперешнем масштабе было бы неосуществимым без наличия общегосударственной системы передачи энергии напряжением в 275 *кв*, причем эта сеть в настоящее время перестраивается на 400 *кв*.

A/561 Reino Unido

Planificación de la energía de origen nuclear en el sistema de la Central Electricity Generating Board

por P. W. Cash y F. Faux

El Reino Unido ha emprendido un amplio programa de energía nuclear, cuya realización está encomendada en su mayor parte a la CEGB. Se han puesto en marcha dos centrales nucleares que están funcionando con buenos resultados. Hay otras seis en construcción y una más en proyecto. Se espera que en 1970, de la potencia total instalada, que en Inglaterra y Gales será de unos 67 000 MW, se encontrará en servicio una potencia nuclear de 5 000 MW aproximadamente.

La integración de las centrales nucleares en el sistema presenta problemas de orden económico, técnico y social. Con cinco años de antelación a su entrada en servicio, hay que tomar decisiones en firme sobre la capacidad y emplazamiento de las nuevas centrales de producción de energía y líneas de transporte, teniendo en cuenta el ritmo de crecimiento de la demanda, la distribución de ésta, la seguridad del sistema, así como la disponibilidad de emplazamientos adecuados. Se compara la economía de cada uno de los proyectos a lo largo de sus vidas útiles en relación con un supuesto desarrollo que utiliza el concepto del valor actual.

La distribución geográfica de la demanda de electricidad en relación con las regiones carboníferas tiene un efecto importante sobre el emplazamiento, dentro del país, tanto de las centrales nucleares como de las térmicas de carbón. Un nuevo acuerdo sobre transporte por ferrocarril ha hecho más atractiva la generación fuera de las regiones carboníferas; sin embargo, resulta aún económico el transporte en cantidad de energía eléctrica al sureste del país, con un factor de carga elevado. Las centrales importantes alimentadas con fuel-oil o gas-oil se sitúan actualmente en lugares muy próximos a las grandes refinerías de petróleo.

Son igualmente importantes consideraciones de tipo práctico tales como el problema de encontrar emplazamientos técnicamente adecuados para las centrales nucleares. El agua de refrigeración presenta la dificultad principal; por esta razón todas las centrales, excepto una, que entren en explotación hasta 1970, se han situado en la costa o en grandes estuarios. La cimentación debe ser capaz de soportar las pesadas cargas impuestas por las estructuras del reactor; hay que disponer también de terreno suficiente para distribuir los edificios y permitir una rápida construcción, siendo esencial que el emplazamiento posea buenos accesos. La elección de un emplazamiento está además restringida por consideraciones de seguridad. La política del Gobierno impone que estas primeras centrales estén situadas en áreas de baja densidad de población.

Hasta ahora las centrales se han emplazado en zonas de gran consumo y sin recursos energéticos, como son el sur y el noroeste del país. Es posible, sin embargo, que las futuras centrales se emplacen en otras regiones. Sin la existencia de un sistema de transporte de energía a 275 kV, ampliamente interconectado por todo el país, que actualmente se encuentra en proceso de conversión a 400 kV, no hubiese sido posible la introducción de la energía nuclear a su escala actual.

Current methods for long-term planning of electricity supply in Sweden

By N. Holmin,* G. Lindstrom** and M. Mårtensson***

In 1962 a study was made of the probable structure of the electricity supply industry in Sweden during the seventies in order to determine the most economic allocation of future power production between various sources [1]. This study, referred to here as the 1962 CDL study, was initiated by the Central Operating Management (CDL)—the joint organisation for the Swedish State Power Board and the private and municipal undertakings. The purpose of this paper is to illuminate the background for the study [2-11]. In particular we will deal with the procedures used by the power companies for the optimum operation of their power systems as well as the problems involved in planning for expansion of supply.

Hitherto the Swedish power system has been based almost entirely upon hydro power, and this situation will prevail for some years to come. However, as the cheap hydro power resources are being developed, new generating capacity will mainly be thermal in the seventies. As cheap power resources have been harnessed, the marginal costs of electricity may increase and this may compel the consumer to choose other energy forms. Thus, for example, oil has already begun to gain in importance in industry, and this trend may continue. The main concern of the power companies in their long-term planning is the consideration of nuclear power as an alternative power source which might possibly reverse the trend towards greater use of oil and lower the marginal costs of electricity.

Since industry is responsible for about two-thirds of the total consumption of electricity in Sweden, development in this section is particularly important. In forecasting industrial demand, CDL uses the method of questioning directly all large consumers as to their views regarding future power requirements. In addition, CDL makes separate forecasts, using econometric models, mainly based upon extrapolation of historical trends of different characteristics decisive for power consumption.

Outside industry, electricity is required for traction and retail consumption. Development in the former section has come to a standstill and is assumed not to influence consumption to any degree in the near future. On the other hand retail consumption, amounting at present to 30% of the national total, the greatest part being household consumption, is of considerable interest, both from social and economic points of view. About three million subscribers are now responsible for household consumption, and CDL uses different methods for predicting the increase in their consumption, for example, by considering (*a*) the changes of housing structure and specific consumptions for dwellings of different sizes and types; (*b*) the saturation tendencies in the use of electrical equipment and the annual consumption per unit of each type of equipment; and (*c*) the tendencies for electrical tarrifs, and in particular in relation to the price of oil.

The annual rate of increase in total electricity consumption in Sweden has been slightly over 6.5% since 1910, while the total energy requirements have increased at the rate of 3% per annum. At present electricity is responsible for about 40% of the total energy consumption in Sweden, and the possibility of further increasing electricity's share of the energy market appears to be rather limited. Thus a reduction of the annual increase in consumption seems almost inevitable. The latest CDL estimate concludes that the increase will be reduced to slightly below 6 per cent by 1970. This reduction is likely to continue during the seventies. As electric power may capture hitherto untapped sectors of the energy market, however, this development may be counterbalanced. In the 1962 CDL study it was assumed that the most probable annual increase during the seventies would be 5.5%, the uncertainty range being ± 1% (Figs. 1 and 2) [2, 11].

The power industry in Sweden is subdivided among a large number of concerns. Through the Swedish State Power Board, the State is responsible for about 42% of the production whilst municipal undertakings produce 8%; 20% of the capacity is operated by industry and 30% by investor-owned companies. The separate utilities co-operate in exchanging power between their systems. This power-pooling has the advantage of smoothing our deficits during dry years, and also of balancing the production of separate companies at different stages of

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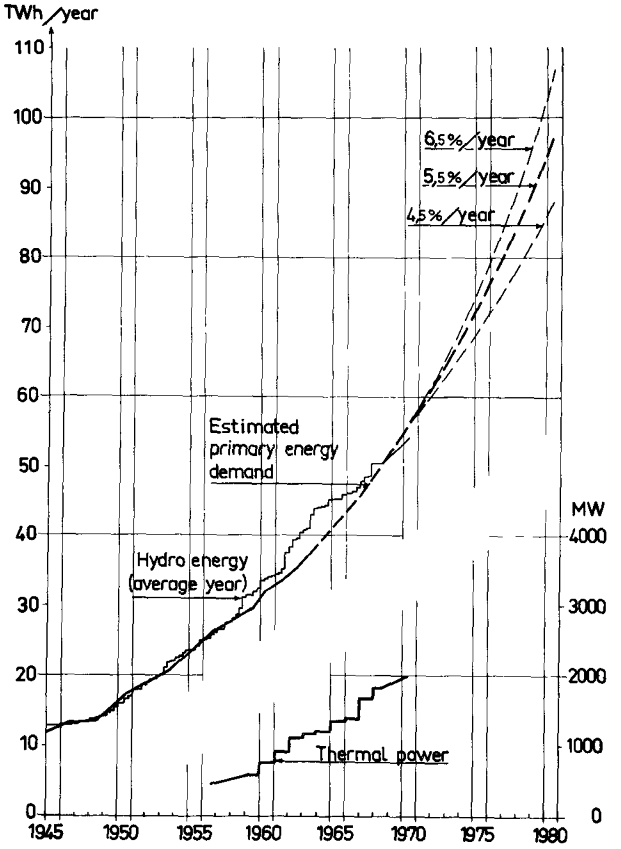


Figure 1. Electricity consumption and production in Sweden: energy demand, hydro energy production and installed thermal power

development. The exchange of power is facilitated by the well-developed transmission grid which has been built for the task of transmitting power from the northern parts of the country, where the hydro power resources are concentrated, to the load centre in the more densely populated southern part (Fig. 3).

The expected trends of power costs from different sources

At present the economic conditions in Sweden imply a nominal interest rate of 7%, or somewhat lower. This is consistent with the policy adopted by the State Power Board [12], and is also in accordance with the financing principles generally applied by the private undertakings. The 1962 CDL study assumes that the same level of nominal interest would be justified also for future planning.

Hydro power

The total hydro-power resources in Sweden are estimated to be capable of yielding some 200 TWh per annum, if exploited completely. Most of these resources are uneconomic, however, and a realistic evaluation suggests an upper limit of 87 TWh per annum for hydro power, exploitable under reasonably economic conditions (Table 1).

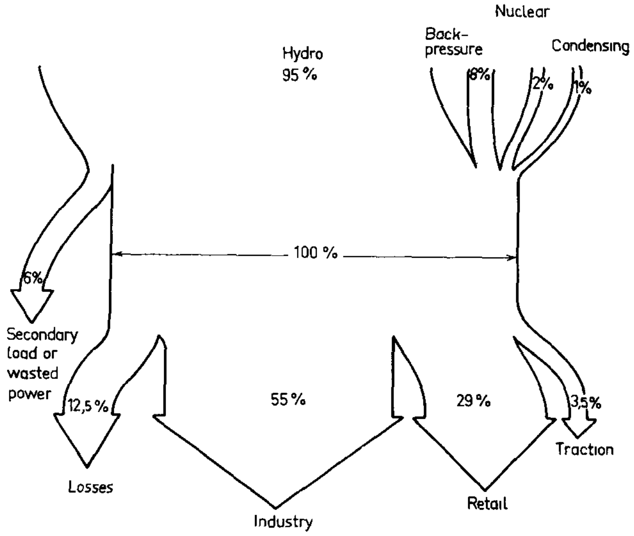


Figure 2. Production and consumption of electric supply in 1970 in per cent of primary load

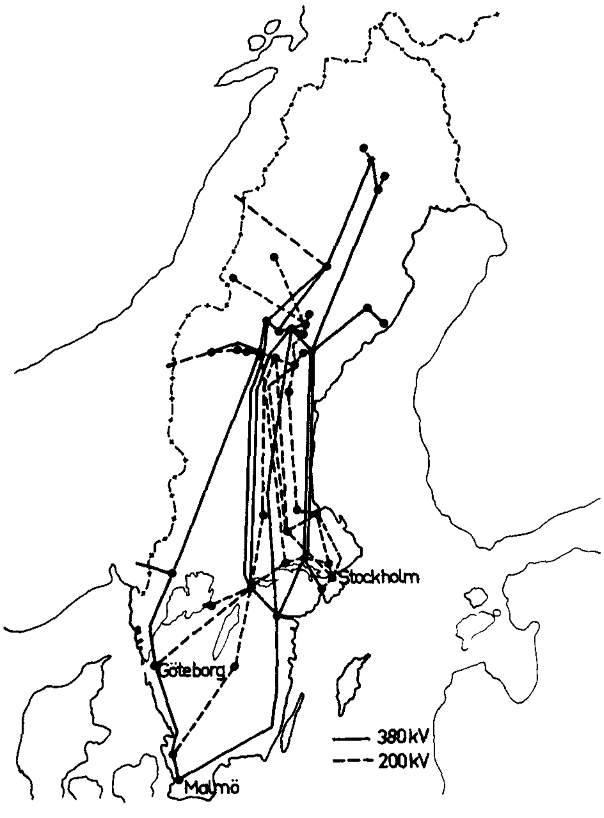


Figure 3. The main transmission grid about 1970

The installation costs given in Table 1 are based upon existing engineering practice. About 55% of the total costs are costs of civil works. During the fifties, by adopting improved methods, considerable reductions of these costs could be achieved. Great reductions were in particular obtained by substituting earth for concrete dams, and by improved excavating techniques. Other improvements during

Table 1. The costs and potential of hydro power resources remaining for development by 1970

Installation costs dollar/kW [a]	Fixed costs dollar/kW, annum [b]	TWh
less than 260	less than 22	5.0
260-320	22-28	8.0
320-370	28-32	7.6
370-420	32-36	4.0
greater than 420	greater than 36	3.2
no information available		6.2
Total		34.0

[a] Including costs of water storage reservoirs but excluding costs of transmission.

[b] Assuming 7% interest and 40 years' depreciation.

this period were better knowledge of hydrographic conditions, enabling new hydro-power stations to be better adapted to meet these conditions, improved methods of soil investigation and reinforcing techniques, permitting smaller constructional volumes and more economic arrangements.

These improvements were estimated to have resulted in total installation cost reductions amounting to 2% per annum during the past decade. This trend is expected to continue, though at a somewhat reduced rate [3, 13].

Thermal power

Separate studies were made of the future costs of nuclear power and conventional thermal power [6, 7]. In both cases, an analysis was made of the costs of plant in operation, under construction or planned. The tendencies for such plant show that cost reductions occur due to technical progress and the simultaneous increase of unit ratings. These different trends could be distinguished by means of statistical methods. With the information obtained in this way, and on the basis of definite tenders from manufacturers of thermal aggregates to be in operation in the late sixties, it was possible to estimate the costs of reference stations assumed to be commissioned in 1970.

Starting from the cost situation in 1970 for the various types of station, developments during the seventies were assessed by extrapolation. In so doing, decelerated rates of technical progress were assumed, compared with that during the sixties, especially as regards reactor types which by 1970 will have already attained a high level of development. Similar arguments were applied when estimating the cost reductions obtained due to increased ratings during the seventies.

Table 2. Costs for conventional thermal power

Date of completion	1970	1975	1980
Size of station, MW	4×300	4×450	4×600
Total installation cost, $/kW	124	112	100
Fixed costs, $/kW, annum [a]	14.2	13	11.8
Running costs, mills/kWh if			
fuel costs 1.8 $/Gcal	4.4	4.4	4.4
fuel costs 1.4 $/Gcal	3.6	3.6	3.6

[a] Assuming 7% interest and 28 years' depreciation.

The main results of these studies are shown in Tables 2 and 3. The costs given in these tables were used as basis for the 1962 CDL study.

The operation of a predominantly hydro-electric system

A hydro-electric system may be described in terms of two fundamental quantities, the hydro-power ratio and the storage ratio. The first magnitude is the ratio between hydro-power production, including surplus, during a year of average hydrographic conditions (the "normal" year) and the load. The latter is the total volume of the water storage reservoirs in proportion to the mean annual inflow. The present tendency in Sweden is a decline of the hydro-power ratio (from a value at present above one), while the storage ratio is substantially unchanged.

Since the running costs of hydro power are low compared with those for thermal power, the main objective in operating a hydro-electric system is to minimize the costs of thermal energy production. This means maximum utilization of the natural water inflow and is obtained by optimum management of the water storage reservoirs.

As shown in Fig. 4 the seasonal variation of the natural inflow differs widely from the seasonal load variations. By means of storage reservoirs, however, the flow can be more or less completely adapted to the load. Fig. 4 is typical for the Swedish system in a stage of development, when the hydro-power ratio just exceeds one. Since ideal regulation of the

Table 3. Costs for nuclear power

Date of completion	1970		1975		1980	
Size of station, MW	2 × 300		2 × 450		2 × 600	
Type of reactor	BWR/PWR	PHWR	BWR/PWR	PHWR	BWR/PWR	PHWR
Total installation cost,			157	224	139	200
$/kW	182	272				
Fixed costs, $/kW, annum [a]	25	32.2	21.6	26.6	18.8	23.4
Running costs, mills/kWh	2.4	1.6	2.2	1.4	2.0	1.2

[a] Assuming 7% interest and the depreciation period to increase from 23 years for reactors commissioned in 1970 to 28 years for reactors put into service by 1980.

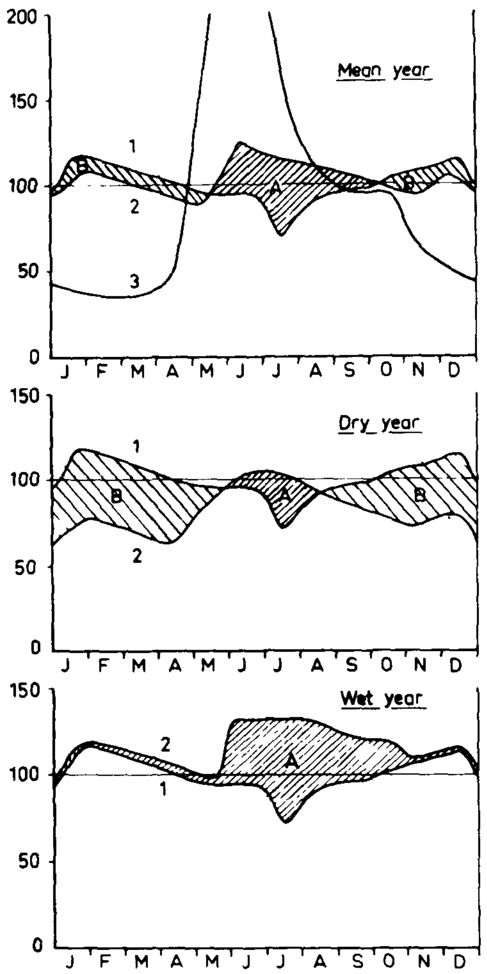


Figure 4. The State Power Board's annual variation in load and run-off during different hydrological years, making certain assumptions about hydro-capacity and regulating conditions

A: Surplus hydro power, including power balance spilling; B: required additional energy in thermal power; curve 1: load; curve 2: regulated run-off; curve 3: natural run-off (mean year only)

storages cannot be fully realized, there will be some surplus during the summer and a deficit during the winter. The primary function of the thermal power in a predominantly hydroelectric system is therefore to complement the energy production from hydro-power sources during dry periods. Furthermore, the conventional steam power in Sweden is designed for peak-load production, to some extent even during wet years.

The objective of minimizing the costs of thermal energy production over the year is subject to an important restriction, imposed by the need to guarantee the reliability of supply up to a certain degree of probability. This means that thermal power production must be started early enough in the autumn or winter to enable the total production of thermal energy until the next spring flood to be sufficient to replace all deficiencies of hydro energy, even though the water shortage during the winter should be serious and extended. Obviously, this means that a certain risk of producing thermal energy in vain must be taken. When this happens, a certain amount of thermal energy produced during the winter will be lost due to overflow of an equivalent amount of water from the storage reservoirs during the spring flood. On the other hand, in periods of plentiful water supply, surplus hydro production can be delivered for secondary, non-obligatory load.

The operation scheme will be more complicated when the different thermal plants have different running costs. In order to reduce the total costs of energy generated by thermal power, generation by the units with the highest running costs should be postponed as long as can be ventured with regard to the reliability of supply. In particular, since the running costs of nuclear power is generally much lower than those of conventional thermal power, a system containing each of them as a supplement to hydro power has to be operated so that nuclear energy production replaces as much as possible the conventional thermal energy production. This can be achieved by means of a deliberately early start of the nuclear energy production and a corresponding delay in the generation of energy by conventional thermal units. At any time during the year, a certain probability exists that thermal energy production will be necessary later in order to avoid a deficiency before the next spring flood. This probability is primarily given by the contents of the storage reservoirs and the expectation of future inflow, as based upon statistics. As soon as the probability exceeds a predetermined value, production of nuclear energy should begin. An operation scheme of this nature means in fact that the production of nuclear energy will be extended over the year, regardless of temporary requirements, and that hydro production will be saved to an equivalent extent. This means in turn that water will be stored in the reservoirs and utilized later in periods when water shortage otherwise would have arisen and made necessary production of conventional thermal energy. The net result is that nuclear energy will supersede conventional thermal energy with higher costs. The important consequence will be that it is possible to attain an economically high load factor for the nuclear power installations in spite of the average load factor for all thermal power being low.

The starting point, when solving numerically the problem outlined, is to evaluate the expected incremental value of stored water by statistical methods. This value is determined from the statistics for the inflow, and from such system characteristics as the hydro-power ratio, the storage ratio, load variations, the capacities of different kinds of installations, the different running costs of thermal power and the possible income from secondary, non-obligatory load. It is obtained as a function of the contents of the storage reservoirs and the time of year. The primary principle of operation is that the different thermal plants should be operated when their individual running costs are lower than the instantaneous incremental water value. However, several constraints set limits to the complete realization of this principle, the most important being the restraints in thermal power production imposed by unregulated water inflow, and those restrictions that result from the variation of daily and weekly load.

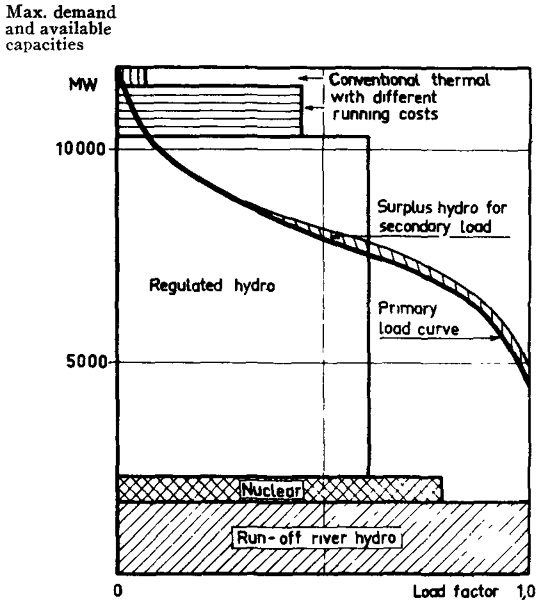
The problem is solved in Sweden by two separate methods which differ with regard to the procedures, applied to ensure reliability of supply. In one of the methods a certain amount of storage is kept in reserve until all thermal power plants are in production. The magnitude of this reserve is a function of time and determined by inflow statistics, the expected load before next spring flood, and the available thermal capacities [14]. In the other method, a certain penalty cost is assumed for rationed power. By an appropriate choice of this cost, the probability of rationing can be given a predetermined value [15].

Planning for expansion of a hydro-electric system

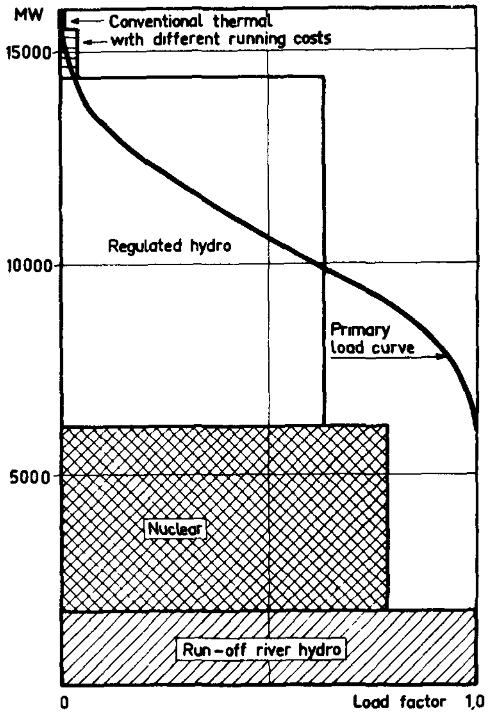
Some detailed examples

The diagrams in Fig. 5 show a possible development of a typical hydroelectric system during a five-year period. The Swedish system as a whole would grow in a similar manner in the late seventies if the future tendencies of power consumption and production were to follow the assumptions made in the 1962 CDL study.* The representation shown here is simplified to illustrate the fundamentals only.**

The diagrams in Fig. 5 show the the load-duration curve and the superimposed blocks of energy generated by different capacities. The appropriate energy production from different sources was obtained by simulation procedures. To take into account unpredictable variations in water inflow, these were based upon statistics of inflow, gained from observations over a thirty-year period. For each year of this sequence the operating principles outlined above were followed. The diagrams represent the annual mean values obtained by averaging over the thirty-year period.



a. The early stage of development



b. Five years later

Figure 5. The introduction of nuclear power in a hydro-power system

The energy generated by hydro power derives from inflow of two kinds: (*a*) run-of-river flow, and (*b*) inflow which can be stored. The first group in turn is divided into flow originating downstream from the storage reservoirs, and flow which passes the reservoirs but cannot be stored because a certain minimum river flow has been prescribed. The run-of-river flow amounts on an average to about 25% of the total inflow and, owing to its compulsory nature, it is used for base load. The inflow of the second group is stored and then utilized in the manner, described above, which normally means use for primary load. In periods of plentiful water supply, the expected incremental water value will decrease and, when it reaches a certain level, production of hydro energy for secondary load is justified. When overflow of the reservoirs occurs, the corresponding water may be utilized for primary or secondary load, if demand exists, but otherwise it

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* The examples given in this section correspond in detail rather to the Power Board System than to the Swedish system as a whole. The scales of size and growth are however appropriate to the integrated Swedish system.

** For instance, back-pressure production is excluded from consideration.

must be spilled. These distinctions as regards the behaviour of the different kinds of hydro power to the load are further illustrated by Fig. 5.

At the early stage of development (Fig. 5a), the load factors for the individual thermal plants range from between 0.80 for nuclear power and 0.07 for the conventional thermal plant with the highest running costs. These figures are mean values and would apply to normal years. When years with different hydrographic conditions are studied, great variations appear. Fig. 6 gives the possible variations of the load factors for nuclear power and conventional thermal power, if it is assumed that any of those yearly hydrographic conditions, which have occurred in Sweden during the past 30 years, were to appear once again during the early stage of nuclear power development. The reason for the differences in behaviour between nuclear and conventional thermal power is that the variations of hydro-power production, amounting to ± 15-20% as compared to the mean annual inflow, are for the most part counterbalanced by the variations of conventional thermal energy production. However, this will not necessarily be true for a later stage of development (Fig. 5b).

The drastic relegation of conventional thermal plants to progressively higher positions in the load curve is a result of the optimum management of the system, and it is possible to this extent, thanks to a high storage ratio (0.6 in the examples given here). As already mentioned, the important consequence will be a high load factor of nuclear power. On the other hand, it must be recognized that the scope of nuclear power is limited in a hydro-electric system with high hydro-power ratio.

During the five-year development, illustrated in Fig. 5, it is assumed that all additions of new plant are nuclear. It may be noticed that during this transition period, which involves a decline of the hydro-power ratio from 0.90 to 0.70, the surplus hydro power vanishes, since it can be utilized for primary energy demand. Obviously, this change is favourable with regard to the marginal costs of electricity. Another important change is the continued displacement of conventional thermal plant from loading priority. The same effect will be obtained in a purely thermal system, but is much more pronounced in a hydro-power system with high storage ratio. The replacement of existing production of conventional thermal energy favours the introduction of nuclear power.

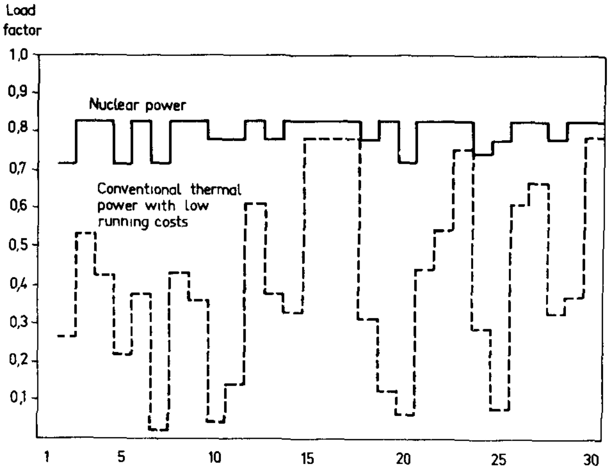

Figure 6. The variations in load factor for different thermal stations in the early stages of nuclear power introduction and for years with different hydrographic conditions

The procedures of planning

The main criterion of planning adopted in the 1962 CDL study is that the incremental costs of supply for a defined expansion should be minimized. These incremental costs are made up by the sum of the fixed costs of additional power and the running costs of the whole system, including existing plants. The problem has several degrees of freedom corresponding to the different kinds of plant available for extension. A simplified approach was used considering only three kinds of power: hydro power, conventional thermal power and nuclear power.* The latter was assumed to have a "harmonized" cost characteristic, obtained by taking the mean values of the fixed and running costs of the types of reactors given in Table 3.

When planning for extensions during a period of, for instance, five years, a number of main alternative hydro-power developments are first considered. The remaining power and energy demanded has to be supplied by the appropriate addition of new thermal power. Within each main alternative, the proportions of new nuclear and conventional thermal power are varied and the incremental costs for each possible combination determined. In order to obtain the running costs of thermal power the above mentioned simulation technique must be applied to each possible combination. In this way a suboptimum to each main alternative is determined, given by the minimized sum of fixed costs of additional thermal power and the running costs of all thermal power. When sale of surplus power occurs the corresponding income should be credited. By adding the fixed costs of additional hydro-power (including costs of transmission), the total optimum is readily obtained, i.e. the most favourable division of additional power between the three kinds considered.

Results and conclusions

The final result will be greatly dependent on the cost assumptions. The two main uncertainties con-

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* A more detailed analysis would take into account different possibilities for peak load production, for instance, by gas turbines or marginal hydro-power installations. Such an analysis would influence the division of power with some 100 megawatts or about 10-20% of the total demand of additional power.

siderably affecting the calculations are the future trends for the installation costs of nuclear power and the price of fossil fuels. To investigate the effect of different tendencies, the 1962 CDL study made calculations for deviations with ± 15% from the basic assumptions of fixed costs, given in Table 3, and for two levels of fuel price corresponding to 1.4 and 1.8 dollar per Gcal.

A typical result of these calculations is shown in Fig. 7.

Some of the conclusions that can be drawn from the figure are:

(*a*) Variations in the price of oil and the fixed costs of nuclear power do not affect to any great extent, within the range considered, the optimum balance between hydro-power and thermal power, whether conventional or nuclear. Assuming the higher price of oil and the mean alternative for nuclear costs, an addition of some 600 to 1 000 MW hydro-power would be consistent with optimum balance in the system. Only small differences in the incremental costs are caused, when the additions of hydro-power are varied within these limits. Supposing for instance, that the nuclear share of additional thermal power is always one-half (regardless of the hydro-power addition), the operating conditions of the system would follow the line 1 1′ 1″, when the additional hydro-power increases from 0 to 1 600 MW. Similar stationary conditions will be obtained for other alternative thermal costs and other combinations of thermal power. These conclusions do not apply generally, but apply only to a certain stage of development in a hydroelectric system, when the costs of remaining hydro-resources approach the exploitable limit (as compared to thermal alternatives). As long as these costs increase only slowly, a certain addition of hydro plant will always be justified.

(*b*) Assuming a certain addition of hydro power, for instance 600 MW (Fig. 7b), the problem of establishing the optimum division of thermal power remains. This is greatly influenced by the assumption that if the price of oil were to remain at the lower level in the future, and the costs of nuclear power were to develop unfavourably, the appropriate additions of thermal power would correspond to point 2 (additions of about fifty-fifty nuclear and conventional); in the other extreme, corresponding to the higher price of oil and a favourable development of nuclear power costs, we arrive at 2′ (only nuclear additions). Thus the problem of finding the optimum combination of additional thermal power appears to be subject to great uncertainty.

(*c*) The balance between nuclear and conventional thermal power must therefore be based on certain assumptions which may later appear

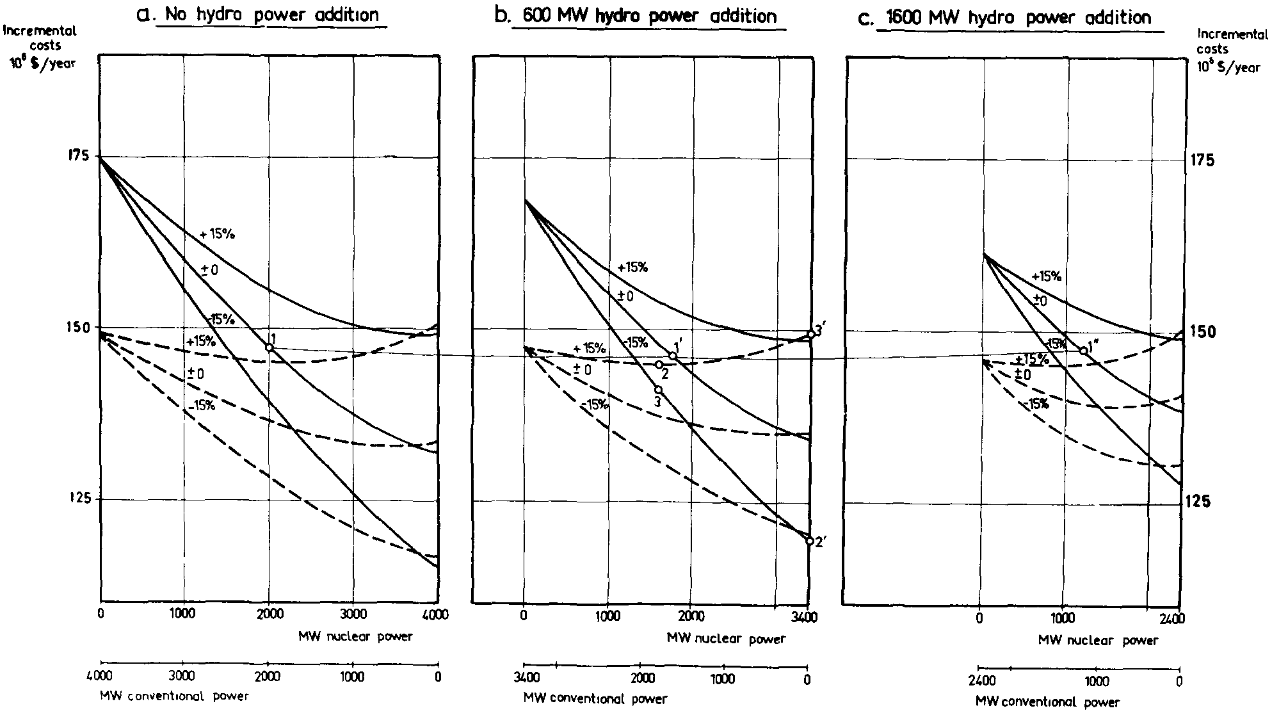

Figure 7. Incremental costs obtained by extension of the system by 4 000 MW

Assumptions: Three main alternative hydro-power developments are considered (addition of 0 600 and 1 600 MW respectively). The remaining power demand is assumed to be supplied by different combinations of nuclear and conventional thermal power. The price of oil is supposed to be 1.8 $/Gcal (continuous lines) or 1.4 $/Gcal (dotted lines). Each family of curves corresponds to + 15%, ± 0 and — 15% of the nuclear costs, given in Table 3. Sale of surplus power is assumed.

(*Note that this affects the relative course of the curves in particular so that the total costs will be lower for the higher price of oil when nuclear power approaches 100% of additional thermal power.*)

erroneous. It is therefore also necessary to assess the consequences of any actual development which differs from that assumed. As may be deduced from Fig. 7, such consequences can vary considerably, depending on the actual course of events. If, for example, the costs of nuclear power should develop in a favourable way, appreciable differences in general result around the optimum points (for example, point 2′) by varying the contribution of nuclear power. This may be a significant disadvantage, if the balance between nuclear and conventional thermal power should prove to be incorrect (compare, for example, the points 2′ and 3). On the other hand, if nuclear power costs should develop unfavourably, the differences compared with conventional power will be less marked, and the optima will be less clearly defined (for example, point 2 compared to 3′). Thus if planning were based on an unfavourable course of development for nuclear power, the opportunities of taking advantage of nuclear power may be limited, if the true course of development should prove more favourable. But if planning were based on a more favourable alternative, advantages would result if the premises were fulfilled, and if not, no hard setback would be suffered, assuming that the costs remain within the limits considered here. By means of these arguments, a basis for judging extensions of the system is obtained, despite the prevailing uncertainty regarding the price of fossil fuels and nuclear costs.

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ABSTRACT - RÉSUMÉ - АННОТАЦИЯ - RESUMEN

A/604 Suède

Méthodes utilisées en Suède pour la meilleure détermination à long terme de la production d'électricité

par N. Holmin *et al.*

La production d'électricité en Suède est à présent presque entièrement basée sur les ressources hydrauliques, mais, ces ressources à bon marché étant utilisées, les sources nouvelles pour la production d'électricité seront, après 1970, principalement d'origine thermique.

Le mémoire expose les méthodes appliquées par les entreprises d'électricité en fonction des conditions suédoises, pour atteindre l'optimum dans la gestion de leurs réseaux.

Diverses méthodes pour la prévision à court et à long terme de la consommation d'électricité sont mentionnées. L'importance pour la gestion à long terme de paramètres tels que les coûts de capitaux, de main-d'œuvre, de combustible et autres est soulignée. Les fonctions de coûts pour les diverses possibilités de production d'électricité, soit des centrales hydrauliques, réservoirs compris, des centrales thermiques et des centrales nucléaires, et de transmission sont données ainsi que les méthodes appliquées pour la prévision des tendances futures possibles des coûts relatifs. Le problème de la puissance de réserve en tant que facteur de limitation de la grandeur de l'unité de production est examiné.

D'après des évaluations de la demande et des coûts, la composition la plus économique du système futur de production d'électricité est déterminée par des méthodes fondées sur les programmes utilisés par les entreprises d'électricité pour réaliser l'utilisation optimale de la capacité d'accumulation d'eau.

Une présentation détaillée est faite des méthodes employées pour atteindre l'optimum de coordination d'un réseau comprenant des centrales thermiques classiques et nucléaires avec diverses caractéristiques de coûts pour compléter la puissance installée hydraulique. La distinction entre un réseau principalement hydraulique et un réseau entièrement thermique pour ce qui est du rôle de la puissance thermique, et nucléaire en particulier, est discutée. Dans un réseau hydroélectrique, la puissance installée nucléaire doit être adaptée non seulement à l'énergie thermique classique mais également aux réservoirs d'accumulation d'eau et à leurs caractéristiques d'alimentation. Ainsi, il est possible d'atteindre un facteur de charge élevé pour les centrales nucléaires au moyen du système d'accumulation et d'un schéma d'exploitation fondé sur l'évaluation des valeurs marginales de l'eau.

Des exemples numériques sont donnés pour les

conditions suédoises et particulièrement pour les désavantages économiques qui résulteraient si les coûts évoluaient dans une direction autre que celle prévue comme optimale.

A/604 Швеция

Современные методы перспективного планирования производства электроэнергии в Швеции

Н. Холмин *et al.*

В настоящее время энергетическая система Швеции почти полностью основана на гидроэнергии, но, поскольку использованы дешевые источники гидроэнергии, новые производственные мощности в 1970-е годы будут основываться главным образом на тепловой энергии.

С учетом особых условий Швеции описаны методы, использованные энергетическими компаниями для оптимизации их энергетических систем.

Приведены различные методы, использованные для определения ближайших и отдаленных перспектив потребления энергии. Обсуждается важность перспективного планирования таких параметров, как капиталовложения и заработная плата, топливная составляющая и др. Приведены функции стоимости для различных способов получения энергии, а именно: гидроэлектростанции, включая сооружение водохранилищ; обычные паровые электростанции; атомные электростанции и линии передач, а также описаны методы, использованные для предварительной оценки возможных будущих тенденций развития относительных расходов. Рассматривается проблема создания резервных мощностей как ограничивающий фактор по отношению к размеру одного агрегата.

На основе предварительных оценок потребностей в энергии и ее стоимости при помощи методов, основанных на программах, применяемых энергетическими компаниями для достижения оптимального использования запасов воды в водохранилищах, рассчитан наиболее экономичный вариант будущей энергетической системы. Детально описаны методы, использованные для оптимизации системы, состоящей из производственных мощностей в виде обычной паровой энергии и ядерной энергии с различными характеристиками стоимости в дополнение к гидроэлектроэнергии. Обсуждается отличие преимущественно гидроэнергетической системы от чисто тепловой системы по отношению к функции тепловой энергии, и в особенности к ядерной энергии. При сравнении с гидроэнергетической системой ядерная энергия должна конкурировать не только с обычной тепловой энергией, но при этом следует учитывать и соответствующие хранилища для воды и статистику притока воды в них. При этом можно достичь высокого коэффициента нагрузки для атомной электростанции, если учесть, что сама система запасания воды и схема эксплуатации основаны на оценке значения притока воды.

Приведены цифровые данные для условий Швеции и, в частности, условий, связанных с экономическими санкциями, если стоимость будет развиваться в другом направлении, отличном от того, которое было принято при оптимизации системы.

A/604 Suecia

Métodos actuales de programación, a largo plazo, del suministro de electricidad en Suecia

por N. Holmin *et al.*

El sistema eléctrico sueco está basado, en el momento actual, casi completamente en la energía hidroeléctrica; pero, dado que los recursos hidráulicos baratos son los más aprovechados, la nueva producción, a partir de 1970, será principalmente de origen térmico. En el informe se describen, refiriéndose especialmente a las condiciones de Suecia, los métodos empleados por las compañías productoras de energía eléctrica para optimizar sus sistemas energéticos.

Se describen los diferentes métodos empleados para prever el consumo de energía a corto y largo plazo, y se discute la importancia que tienen en la programación a largo plazo algunos parámetros, tales como el coste de primera instalación y mano de obra, los costes de los combustibles y otros. Se presenta la estructura de los costes en los diferentes medios de producción de energía, es decir, centrales hidroeléctricas incluyendo las de embalse, centrales térmicas clásicas y centrales nucleares, así como en las líneas de transporte de la misma, y se dan también los métodos empleados para prever las posibles tendencias futuras de los costes relativos. Se discute el problema de la capacidad de reservas como un factor que limita, a este respecto, la potencia unitaria.

Tomando como base las previsiones en lo que respecta a demanda y costes, se calcula la combinación más económica del futuro sistema de producción de energía, con métodos basados en los programas empleados por las compañías suministradoras para lograr la utilización óptima de las reservas de agua embalsada. Se presentan, con todo detalle, los métodos utilizados para optimizar un sistema que sirva de suplemento a la energía hidroeléctrica, y esté basado en la producción de energía térmica, tanto clásica como nuclear, con diferentes características de coste. Se discute la diferencia entre un sistema predominantemente hidroeléctrico y un sistema térmico puro en relación con la función que desempeña la energía térmica y especialmente la nuclear. En un sistema hidroeléctrico, la energía nuclear tiene que estar equilibrada no solamente con la energía térmica clásica, sino también con la procedente de agua embalsada y con las fluctuaciones estadísticas de éstas. Así se puede lograr para la energía nuclear un elevado factor de carga, gracias al sistema de almacenamiento y a un esquema de funcionamiento basado en la evaluación del aumento de valor del agua.

Se citan ejemplos numéricos para las condiciones suecas y se ponen de manifiesto, en particular, las desventajas que se producirían si los costes evolucionaran en dirección distinta a la empleada en la optimización del sistema.

Record of Session 1.6

Technical and economic aspects of the use of nuclear power

Chairman: I. H. Usmani (Pakistan)

Paper P/216 (presented by L. H. Roddis)

DISCUSSION*

D. Lawley-Wakelin (United Kingdom): I should like to put two questions to the authors of this paper. The first refers to the statement at the end of the paper that "nuclear power has met the economic and technical criteria for integration into at least 60 per cent of the power networks in the United States". Does this mean that in certain instances nuclear power costs are already competitive in the United States with conventional power costs?

My second question refers to the statement at the beginning of the paper that "of the 365 reactors constructed under the broad-based development programme of the United States Atomic Energy Commission, 11 have been operating as network suppliers in varying degrees for one year or more". Could the authors please enlarge on this statement by giving factual information in terms of total megawatt hours of network operating experience? A detailed answer to this question would be most useful in helping to evaluate the statement referred to in my first question.

L. H. Roddis (United States of America): The answer to the first question is "yes". As for your second question, I think this has been answered in other sessions of the Conference. It is also covered in Table 1 of the paper. There would be no point, I think, in discussing it again at the present session.

J. P. Roux (France): Table 4 of your paper quotes a capital cost for Yankee of \$220/kW. This is considerably less than the corresponding figure for the SENA station (266 MW(e)), which is \$300/kW, not counting the enriched uranium cost for the first load. Does the figure for Yankee include the cost of uranium for the first load?

L. H. Roddis (United States of America): I think it does but I am not quite sure. The figure for Oyster Creek certainly does include the fuel inventory invested. I should emphasize that Table 4 is merely intended to show the effect of size on plant investment.

Paper P/597

DISCUSSION

R. Janin (France): I have a question on the subject of interest rates but I should like to preface it by one general remark.

To ensure normal economic development, you must have either a money market which fixes interest rates on the basis of supply and demand or a central body which lays down a rate of return in the light of investment needs and resources. Sometimes a firm enjoys special conditions (tax rates, premiums, etc.) and in cases of this sort it is important to be clear about the fact that a certain imbalance in economic development is liable to result.

I notice that Mr. Yusuf and the authors of paper P/216 quote interest rates of 4 and 4.25 per cent respectively. Could they perhaps indicate how these rates are to be understood?

M. Yusuf (Pakistan): The Rooppur Nuclear Power Project is sponsored by the Government of Pakistan. For all Government-sponsored power projects in Pakistan, the Government borrows money at a rate of generally less than 4 per cent and re-loans it to the projects at about 4 per cent. I should perhaps mention that in Pakistan nearly 95 per cent of the power projects are Government-sponsored. This 4 per cent interest rate is also applied in the case of the Rooppur Nuclear Power Project. Incidentally, the bank rate in Pakistan is also 4 per cent.

L. H. Roddis (United States of America): The investment rates set out in Table 3 of paper P/216 are based on private investment, two thirds of the investment being in 4¼ per cent bonds and one-third in equity capital at 10 per cent. This, together with other items, represents an 11 per cent fixed-charge rate. I should add that this rate is only applicable in Pennsylvania and New Jersey, because there are no real-estate taxes there but only sales taxes. In the rest of the United States the fixed-charge rate is about 13½ per cent.

Paper P/561 (presented by F. Faux)

DISCUSSION

N. Holmin (Sweden): In any economic comparison of nuclear with conventional power stations,

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* See also this page, discussion on paper P/597.

the question of availability is obviously of great importance, as has been pointed out in various papers. In our Swedish studies on the introduction of nuclear power into the electricity system, we have gone on the assumption that the availability factor will be the same for our first nuclear power installations as it is for our conventional stations. In other papers, too, the point is made that availability is at least as good for nuclear as it is for conventional stations.

In paper P/561 we are told that for planning purposes in England and Wales an availability of 75 per cent is assumed for nuclear power as an annual average and 85 per cent at the time of system maximum demand. These figures are rather low compared with those usually mentioned for conventional stations, particularly in view of the fact that the reactors in question are refuelled during operation and that the United Kingdom now has a fair amount of experience in station operation. Assuming you adopt the usual figures for conventional stations, I would have thought that this factor would place the nuclear stations at a disadvantage in any real economic choice between the two types of plant.

Are you, in fact, at the Central Electricity Generating Board using the low figures quoted for nuclear station availability for the availability of conventional stations, e.g. for the stations with 400 and 500 MW aggregates now under construction?

F. Faux (United Kingdom): It has been considered prudent to use this figure of 75 per cent for the average annual availability until more experience has been obtained. The results of the experience obtained at Bradwell and Berkeley are described in paper P/128* but it is much too early to alter the basis which we are currently using for our long-term planning.

The figures we use for conventional stations are somewhat similar on a long-term basis, i.e. about 77.5 per cent average annual.

Of course, if we were talking in terms of load factor, the considerations would be quite different.

N. Holmin (Sweden): Does Mr. Roddis have any comment on this question?

L. H. Roddis (United States of America): The availability of nuclear power stations in the United States is better than that of conventional stations — in general it is 90 per cent or over.

Paper P/11 (presented by P. H. G. Spray)

DISCUSSION

P. Verstraete (Switzerland): I notice that you amortize over the whole life of the station the half-charge of fuel that remains in the reactor when the latter finally ceases to operate. It seems to me that a half-charge of fuel is also lost at the time the plant is put into operation and that this half should be amortized as well. There seems to be no provision for any amortization of this kind nor is this initial half-charge included under "Commissioning and training", the cost estimate for which is of the same order of magnitude as the cost of the half-charge. To what extent would you say that the half-charge which is lost at the beginning and which is only partially irradiated can be used at the cessation of reactor operation?

I also note that the salvage value of the heavy water at the end of plant operation is disregarded in your estimates, it being considered that this represents an operational bonus. If this is done would it not be right to disregard the final half-charge, or indeed the final and initial half-charges, in view of the fact that the operational bonus on the heavy water represents approximately the value of three complete fuel charges?

P. H. G. Spray (Canada): In amortizing only that half of the fuel charge that remains in the reactor at the end of the life of the plant, we assume that the first half is burned and this is charged to the operating cost since it produces revenues. In the estimates presented in the paper the whole of the heavy water is amortized over the same life as is assumed for the plant. It is recognized that the heavy water will probably have some residual value but it would be extremely difficult to try to make an estimate and we prefer our present method.

GENERAL DISCUSSION

G. F. Kennedy (United Kingdom): As a power engineer, I find it difficult to understand the complacency with which the supporters of certain light-water reactors are facing the problem of reactor shutdown for refuelling. I would submit that the time required for this purpose is too long and that the fixed period between successive shutdowns is very inconvenient to power-system operators.

Let us assume that a 500 MW boiling-water reactor is installed in a system which also has considerable thermal-plant capacity. It would not be unreasonable to suppose that the fuel cost for the thermal plant used to replace the BWR during the refuelling period would be not less than 0.3d. (3.4 mils) per kWh higher than that for the reactor. If, as at the Dresden Station, the refuelling period lasts six weeks, the additional cost to the electricity supplier of running such a high-fuel-cost plant in place of the reactor would be nearly £550 000 ($1 500 000) per annum.

I would submit further that even this is not the whole story. Once a year it is customary to shut down conventional steam boilers for about six weeks to comply with statutory regulations on cleaning and inspection. Consequently, in comparing the economics of a reactor with further conventional plant

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* These Proceedings, Vol. 5.

with a view to an extension of system capacity, it is not usual to set a penalty against the reactor if it does not have to be shut down annually for a period longer than six weeks. What is the position, however, if the power system concerned has already installed, or can install alternatively, different types of reactor plant which can be refuelled on load and which — to comply with boiler inspection regulations — need only be shut down every two or even three years at a time suitable to the requirements of the power system? In such cases it seems to me that there is a deficiency in the fuel cycle of light-water reactors which should be taken into account in the balance sheet.

It would perhaps be going too far not to assign any kilowatt value to the light-water reactors in a comparison of this sort, but it would certainly not be correct to set the penalty as low as the additional fuel costs of the thermal plant used as a replacement during light-water-reactor refuelling periods.

It seems to me that this is an important factor which needs to be taken into account when making economic comparisons of reactor types.

L. H. Roddis (United States of America): Speaking as a power-plant engineer and also as a power-company executive, I can assure Mr. Kennedy that fossil-fuelled plants also have shutdown periods for scheduled inspections and unscheduled outages that are quite comparable with those of nuclear plants. The newer water-cooled nuclear plants have refuelling intervals generally exceeding one year and reloading times of about two weeks. The position is, therefore, comparable with the position for fossil-fuelled plants.

Papers P/746, P/43, P/598 (presented by A. Leite *Garcia*) *and* P/316 (presented by G. S. Zelevinsky)

There was no separate discussion of these papers.

Compte rendu de la séance 1.6

Utilisation de l'énergie d'origine nucléaire: aspects techniques et économiques

Président: I. H. Usmani (Pakistan)

Mémoire P/216 (présenté par L. H. Roddis)

DISCUSSION*

D. Lawley-Wakelin (Royaume-Uni): Je voudrais poser deux questions aux auteurs du mémoire. La première concerne la fin du document, où il est dit que l'énergie d'origine nucléaire répond maintenant aux critères économiques et techniques qui justifieraient son intégration dans 60% au moins des réseaux de distribution aux Etats-Unis. Cela signifie-t-il que, du point de vue du prix de revient, cette énergie peut déjà dans certains cas faire concurrence à l'énergie de sources classiques aux Etats-Unis?

La seconde question concerne l'information donnée au début du mémoire selon laquelle, sur les 365 réacteurs construits dans le cadre du vaste programme de développement de la Commission de l'énergie atomique aux Etats-Unis, 11 alimentent déjà à des degrés divers les réseaux de distribution depuis une année au moins. Je serais heureux si les auteurs pouvaient compléter cette remarque et nous donner des renseignements concrets sur le nombre total de mégawattheures fournis aux réseaux de distribution par les réacteurs en question. Une réponse détaillée serait très utile car elle permettrait de mieux mesurer la portée de la phrase à laquelle se réfère ma première question.

L. H. Roddis (Etats-Unis d'Amérique): En ce qui concerne la première question, la réponse est "oui". Quant à la seconde, je crois que nous y avons déjà répondu à d'autres séances de la Conférence, comme d'ailleurs dans le tableau 1 du mémoire. Je pense qu'il est inutile de revenir sur ce point à la présente séance.

J. P. Roux (France): D'après le tableau 4 de votre mémoire, le coût d'installation de la centrale Yankee a été de 220 dollar/kW. Ce coût est sensiblement inférieur à celui de la centrale SENA [266 MW(e)], soit 300 dollar/kW, sans compter le prix de l'uranium enrichi correspondant à la première charge. Le chiffre donné pour la centrale Yankee comprend-il le coût de l'uranium de la première charge?

L. H. Roddis (Etats-Unis d'Amérique): Je crois que oui, mais je n'en suis pas certain. Le coût indiqué en ce qui concerne Oyster Creek comprend certainement celui du stock de combustible. Je dois préciser à ce propos que le tableau 4 a pour seul objet de montrer l'incidence de la puissance de la centrale sur le montant des investissements requis.

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* Voir également, ci-après, la discussion du mémoire P/597.

Mémoire P/597

DISCUSSION

R. Janin (France): Je voudrais poser une question au sujet des taux d'intérêt; mais tout d'abord une remarque générale me paraît nécessaire.

Un développement économique harmonieux présuppose l'existence soit d'un marché de l'argent où les taux d'intérêt sont fixés par confrontation de l'offre et de la demande, soit d'un organisme central qui établit un taux de rentabilité en tenant compte des besoins en investissements et des ressources. Il arrive que des conditions spéciales soient faites à une entreprise (imposition, primes, etc.) mais, dans les cas de ce genre, il est important de prendre parfaitement conscience des déséquilibres qui peuvent en résulter pour le développement économique.

Je constate que M. Yusuf et les auteurs du mémoire P/216 mentionnent respectivement des taux d'intérêt de 4% et de 4,25%. Quelle signification faut-il, selon eux, accorder à ces chiffres?

M. Yusuf (Pakistan): Le projet de la centrale nucléaire de Rooppur est entrepris sous l'égide du Gouvernement du Pakistan. Pour tous les projets de ce type, l'Etat emprunte des capitaux à un taux qui est généralement inférieur à 4%, et les prête à un taux de 4% environ. Sans doute dois-je préciser qu'au Pakistan l'Etat est le promoteur de près de 95% des projets de centrales. Le taux d'intérêt de 4% a été appliqué dans le cas du projet de Rooppur. D'ailleurs, le taux bancaire est également de 4% au Pakistan.

L. H. Roddis (Etats-Unis d'Amérique): Les taux indiqués dans le tableau 3 du mémoire P/216 se rapportent aux investissements privés. En effet, les deux tiers des placements sont effectués en obligations à 4¼% et l'autre tiers se compose d'un capital social rémunéré à 10%, ce qui, compte tenu d'autres éléments, représente un taux fixe de 11%. J'ajouterai que ce taux n'est valable qu'en Pennsylvanie et dans le New Jersey, où l'on ne perçoit qu'un impôt sur le chiffre d'affaires et pas d'impôt foncier. Dans le reste des Etats-Unis, le taux fixe s'élève à 13½% environ.

Mémoire P/561 (présenté par F. Faux)

DISCUSSION

N. Holmin (Suède): Comme cela a été souligné dans plusieurs mémoires, toute comparaison d'ordre économique entre centrales atomiques et centrales de type classique soulève une question incontestablement très importante: celle de la disponibilité. En Suède, lorsque nous avons étudié les modalités d'intégration des centrales nucléaires dans le réseau de distribution d'électricité, nous sommes partis de l'hypothèse que le degré de disponibilité serait le même pour nos premiers aménagements nucléaires que pour nos centrales de type classique. En outre, selon d'autres mémoires, la disponibilité des installations nucléaires serait au moins aussi grande que celle des centrales classiques.

Dans le mémoire P/561, nous voyons qu'en Angleterre et au Pays de Galles on a, dans des buts de planification, évalué à 75% la valeur annuelle moyenne de disponibilité des installations nucléaires, cette disponibilité atteignant 85% au moment où le réseau fait l'objet d'une demande maximale. Ces chiffres sont assez bas par rapport à ceux que l'on cite généralement pour les centrales de type classique, d'autant plus que les réacteurs utilisés sont rechargés en combustible pendant leur fonctionnement et que le Royaume-Uni a acquis une expérience étendue en matière d'exploitation des centrales. J'aurais pensé que, si l'on partait des chiffres normalement indiqués pour les centrales classiques en vue d'effectuer un choix entre les deux types de centrales, les centrales nucléaires se trouveraient réellement désavantagées du point de vue économique.

Est-ce qu'au *Central Electricity Generating Board* vous utilisez, en ce qui concerne la disponibilité des centrales de type classique, c'est-à-dire des centrales actuellement en construction ayant une puissance de 400 à 500 MW, des chiffres aussi peu élevés que ceux que vous citez dans le cas des centrales nucléaires?

F. Faux (Royaume-Uni): Jusqu'à ce que nous ayons plus d'expérience, nous avons jugé prudent de fixer à 75% la disponibilité annuelle moyenne. Le mémoire P/128* décrit les résultats obtenus à Bradwell et à Berkeley, mais il est encore beaucoup trop tôt pour modifier les données sur lesquelles nous fondons actuellement nos plans à long terme.

Les chiffres que nous utilisons pour les centrales de type classique sont à peu près les mêmes sur une longue période, soit une moyenne annuelle de 77,5%.

Il est évident que si nous considérions le facteur de charge le point de vue serait tout à fait différent.

N. Holmin (Suède): M. Roddis a-t-il quelque chose à dire à ce sujet?

L. H. Roddis (Etats-Unis d'Amérique): Aux Etats-Unis, la disponibilité des centrales nucléaires est plus grande que celle des installations classiques; en général, elle est de 90% au moins.

Mémoire P/11 (présenté par P. H. G. Spray)

DISCUSSION

P. Verstraete (Suisse): Je constate que vous répartissez sur la vie entière de la centrale l'amortissement de la demi-charge de combustible qui reste dans le réacteur lorsque celui-ci cesse de fonc-

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* Voir les présents Actes, vol. 5.

tionner. Il me semble qu'une demi-charge est déjà perdue au moment où la centrale est mise en service et que cette demi-charge doit être amortie elle aussi. Il ne semble pas que cette sorte d'amortissement ait été prise en considération, ni que l'on ait tenu compte de cette demi-charge initiale sous la rubrique intitulée « Formation et mise en marche », où le coût indiqué est du même ordre de grandeur que la valeur d'une demi-charge de combustible. Pouvez-vous indiquer dans quelle mesure la demi-charge perdue au début, qui n'est que partiellement irradiée, peut être utilisée lorsque l'exploitation du réacteur prend fin?

Je constate également que votre estimation néglige la valeur de récupération de l'eau lourde, qui est considérée comme représentant un bénéfice d'exploitation. Dans ce cas, ne serait-il pas juste de négliger également la demi-charge finale, voire les demi-charges initiale et finale, puisque le bénéfice d'exploitation sur l'eau lourde représente approximativement la valeur de trois charges de combustible complètes?

P. H. G. Spray (Canada): En ne prévoyant que l'amortissement de la demi-charge de combustible qui reste dans le réacteur au terme de l'existence utile de la centrale, nous supposons que la première demi-charge est épuisée et, puisque cette opération produit des recettes, nous en imputons le coût sur les frais d'exploitation. Dans l'estimation présentée dans le mémoire, toute l'eau lourde est amortie sur une période égale à l'existence supposée de la centrale. Certes, on reconnaît que l'eau lourde aura peut-être une valeur de récupération, mais, comme il serait extrêmement difficile de l'estimer, nous préférons nous en tenir à la méthode actuelle.

DISCUSSION GÉNÉRALE

G. F. Kennedy (Royaume-Uni): En tant qu'ingénieur des centrales électriques, je m'étonne de l'optimisme avec lequel certains partisans des réacteurs à eau légère abordent le problème que pose l'arrêt de la pile pendant le renouvellement du combustible. A mon sens, le temps nécessaire est trop long et les intervalles fixes entre chaque arrêt successif gênent considérablement l'exploitation du réseau de distribution.

Admettons par exemple qu'un réacteur à eau bouillante de 500 MW soit intégré dans un réseau déjà alimenté par des centrales thermiques de grande puissance. On peut raisonnablement supposer que le coût du combustible destiné à la centrale thermique que l'on substitue au réacteur, pendant la période de remplacement du combustible nucléaire, doit être d'au moins 0,3 penny (3,4 mils) par kWh plus élevé que dans le cas du réacteur. Si la période en question dure six semaines, comme à la centrale de Dresden, le prix de revient supplémentaire, pour le fournisseur d'électricité qui utilise à la place du réacteur une centrale dont le coût d'alimentation est aussi élevé, approcherait de 550 000 livres sterling (1 500 000 dollars) par an.

Je dirais même que ce n'est pas tout. Une fois par an, on doit normalement arrêter pendant six semaines environ les chaudières à vapeur de type classique, en vertu des règlements relatifs au nettoyage et à l'inspection. Par conséquent, lorsque l'on a l'intention d'augmenter la puissance d'un réseau et que l'on évalue à cet effet les avantages économiques d'un réacteur en comparaison d'une nouvelle installation de type classique, on ne retient généralement pas comme défaut du réacteur des arrêts annuels qui ne dépassent pas six semaines par an. Qu'arrive-t-il lorsque l'on a déjà intégré ou lorsque l'on peut intégrer dans le réseau des types différents de réacteurs nucléaires dont le combustible peut être remplacé en fonctionnement et que, pour se conformer aux règlements relatifs à l'inspection des chaudières, on ne doit arrêter que tous les deux ou trois ans, au moment qui risque le moins de perturber le réseau de distribution? En l'occurrence, il me semble bien que, pour établir un bilan, on devrait tenir compte des défauts que présentent les réacteurs à eau légère pour ce qui est de leur cycle de combustible.

Peut-être serait-il exagéré, dans une comparaison de cette sorte, de n'assigner aucune valeur aux réacteurs à eau légère comme producteurs d'énergie électrique, mais il serait certainement erroné de ne retenir contre eux que le montant des dépenses supplémentaires nécessitées par l'alimentation en combustible de la centrale thermique d'appoint utilisée pendant le remplacement du combustible du réacteur à eau légère.

C'est là, me semble-t-il, un facteur important dont il faut tenir compte quand on évalue les avantages économiques respectifs des différents types de réacteurs.

L. H. Roddis (Etats-Unis d'Amérique): En tant qu'ingénieur des centrales électriques, et aussi en tant que cadre d'une entreprise de production d'énergie, je puis garantir à M. Kennedy que, du fait des inspections régulières et pour d'autres causes imprévues, les périodes d'arrêt sont aussi longues ou presque pour les centrales utilisant des combustibles fossiles que pour les centrales nucléaires. Dans le cas des derniers modèles de réacteurs nucléaires à refroidissement par l'eau, le remplacement du combustible intervient généralement moins d'une fois par an et n'exige que deux semaines environ. Ces réacteurs supportent donc la comparaison à cet égard avec les centrales utilisant des combustibles fossiles.

Mémoires P/746, P/43, P/598 (présentés par A. Leite Garcia) et P/316 (présenté par G. S. Zelevinsky)

Ces mémoires n'ont pas fait l'objet d'une discussion distincte.

Протокол заседания 1.6

Технические и экономические аспекты использования ядерной энергии

Председатель: И. Х. Усмани (Пакистан)

Доклад P/216 (представил Л. Г. Роддис)

ДИСКУССИЯ*

Д. ЛОУЛИ-ВЕЙКЛИН (Соединенное Королевство): Мне хотелось бы задать авторам этого доклада два вопроса. Первый относится к утверждению в конце доклада: «Ядерная энергия отвечает экономическим и техническим критериям, позволяющим использовать ее по крайней мере в 60% энергетических сетей США». Означает ли это, что в некоторых случаях стоимость ядерной энергии в США уже конкурирует со стоимостью энергии, получаемой от обычных электростанций?

Второй вопрос относится к утверждению в начале доклада: «Из 365 реакторов, построенных в соответствии с широкой программой разработок, проводимой Комиссией по атомной энергии США, 11 реакторов уже около года или больше дают энергию в энергетические сети». Не будут ли авторы любезны подробнее разъяснить это утверждение, приведя фактические данные по общей выработке энергии для сети, исходя из опыта эксплуатации? Подробный ответ на этот вопрос был бы наиболее полезным для оценки утверждения, на которое я ссылался в моем первом вопросе.

Л. Г. РОДДИС (США): Ответ на первый вопрос — «да». Что касается Вашего второго вопроса, то я думаю, что ответ на него был дан на других заседаниях конференции. Он содержится также в табл. 1 этого доклада. Я полагаю, что нет смысла обсуждать его снова на настоящем заседании.

Д. П. РУ (Франция): В табл. 4 Вашего доклада приводится стоимость капиталовложений для реактора фирмы «Янки», равная 220 *долл/квт*. Она значительно меньше соответствующей цифры для атомной электростанции SENA в Арденнах (300 *долл/квт* при электрической мощности 266 *Мвт*), не считая стоимости обогащенного урана для первой загрузки. Включает ли указанная цифра для реактора фирмы «Янки» стоимость урана первой загрузки?

Л. Г. РОДДИС (США): Я думаю, что включает, но не вполне в этом уверен. Цифра для атомной станции в Ойстер-Крике, конечно, включает капиталовложения на загрузку топлива. Я хотел бы подчеркнуть, что табл. 4 имеет своей целью просто показать влияние мощности установки на капиталовложения.

Доклад P/597

ДИСКУССИЯ

Р. ЖАНЕН (Франция): Мой вопрос касается процентов на капитал, но вначале мне хотелось бы сделать одно общее замечание.

Для обеспечения нормального экономического развития необходимо иметь либо денежный рынок, фиксирующий размер процентной ставки на основе предложения и спроса, либо центральную организацию, устанавливающую норму прибыли в зависимости от потребностей в капиталовложениях и денежных средствах. Иногда фирма пользуется особыми привилегиями (ставки налогов, премии и т. д.), и в таких случаях важно уяснить себе тот факт, что в результате может иметь место некоторая неустойчивость в экономическом развитии.

Я обратил внимание, что г-н Юзуф и авторы доклада P/216 ссылаются на процентные ставки в размере 4 и 4,25% соответственно. Может быть, они могли бы указать, как следует понимать эти проценты?

М. ЮЗУФ (Пакистан): Проект Руппурской атомной электростанции осуществляется под руководством правительства Пакистана. При осуществлении всех своих проектов по строительству электростанций правительство Пакистана занимает деньги под проценты (обычно меньше 4%) и в свою очередь дает ссуду для выполнения этих проектов под проценты, приблизительно равные 4%. Я, вероятно, должен упомянуть, что в Пакистане почти 95% проектов электростанций являются правительственными. Эти процентные начисления в размере 4% применимы также и для проекта сооружения Руппурской атомной станции. Между прочим, ставка банковского учета в Пакистане также равна 4%.

Л. Г. РОДДИС (США): Проценты на капитал, приведенные в табл. 3 доклада P/216, основаны на частных капиталовложениях, причем

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* См. также ниже дискуссию по докладу P/597.

$^2/_3$ этих капиталовложений представляют собой 4,25%-ные облигации, а $^1/_3$ — обыкновенные акции при 10%. Этот процент вместе с другими процентами образует процентные начисления на фиксированные расходы в размере 11%. Мне следует добавить, что этот процент применим только в штатах Пенсильвания и Нью-Джерси, потому что там нет налогов на недвижимость, а только налоги с оборота. В остальной части Соединенных Штатов норма фиксированных расходов составляет около 13,5%.

Доклад Р/561 (представил Ф. Фокс)

ДИСКУССИЯ

Н. ХОЛМИН (Швеция): При любом экономическом сравнении атомных электростанций с обычными большое значение, как уже указывалось в различных докладах, имеет, очевидно, коэффициент использования станции. При изучении в Швеции вопроса включения атомной электростанции в систему энергоснабжения исходили из предположения, что коэффициент использования для первых шведских атомных энергетических установок будет таким же, как и для обычных электростанций. В других докладах также указывается, что коэффициент использования для атомных станций является по крайней мере столь же удовлетворительным, как и для обычных электростанций.

В докладе Р/561 нами сообщается, что при планировании в Англии и Уэльсе средний годовой коэффициент использования атомной станции принимается равным 75% и 85% во время максимального потребления электроэнергии в системе. Это довольно низкие цифры по сравнению с теми, которые обычно приводятся для обычных электростанций, особенно если учесть, что в реакторах, о которых идет речь, замена топлива производится во время работы и что Англия в настоящее время располагает достаточным опытом эксплуатации атомных станций. Даже если принять стандартные значения коэффициентов использования для обычных электростанций, то, по моему мнению, эти цифры поставят атомные электростанции в невыгодное положение при любом действительном экономическом выборе между двумя типами станций.

Действительно ли в Центральном энергетическом управлении используются низкие коэффициенты использования для атомных и обычных электростанций, например для станций с блоками на 400 и 500 *Мвт*, строящихся в настоящее время?

Ф. ФОКС (Соединенное Королевство): Считается разумным использовать средний годовой коэффициент использования 75% до тех пор, пока не будет накоплен большой опыт. Результаты опыта, полученного в Брадуэлле и Беркли, описываются в докладе Р/128*, однако еще слишком рано изменять основу, используемую нами в настоящее время для перспективного планирования.

Цифры, принимаемые нами для обычных электростанций, являются до некоторой степени такими же при перспективном планировании, то есть средний годовой коэффициент использования принимается равным 77,5%.

Конечно, если бы речь шла о коэффициенте нагрузки, то соображения были бы совершенно другими.

Н. ХОЛМИН (Швеция): Есть ли у г-на Роддиса какие-либо замечания по этому вопросу?

Л. Г. РОДДИС (США): Коэффициент использования атомных станций в США лучше, чем у обычных электростанций; в общем он составляет 90% или выше.

Доклад Р/11 (представил П. Х. Г. Спрей)

ДИСКУССИЯ

П. ВЕРСТРАЕТЕ (Швейцария): Я обратил внимание, что в течение всего срока службы станции Вы амортизируете половину топливной загрузки, которая остается в реакторе после его окончательной остановки. Мне кажется, что половина топливной загрузки теряется также во время пуска установки и что эта половина также должна амортизироваться. По-видимому, амортизация такого рода не предусмотрена, как и не включена эта первоначальная загрузка в статью «Ввод в эксплуатацию и обучение обслуживающего персонала», ориентировочная стоимость которой такой же величины, что и стоимость половины загрузки. Не скажете ли Вы, в какой степени при прекращении работы реактора может быть использована та половина загрузки, которая теряется вначале и которая только частично облучается?

Я также обратил внимание, что в Ваших сметных предположениях не учитывается стоимость спасенной тяжелой воды по окончании работы установки, причем эта сумма рассматривается как эксплуатационное вознаграждение. Если это так, то не будет ли правильным не учитывать конечную половину загрузки или, может быть, конечную и первоначальную половины загрузок, поскольку это эксплуатационное вознаграждение, связанное со спасенной тяжелой водой, представляет приблизительно стоимость трех полных загрузок топлива?

П. Х. Г. СПРЕЙ (Канада): При амортизации только той половины топливной загрузки, которая остается в реакторе в конце срока службы установки, мы предполагаем, что первая половина загрузки сгорает и ее стоимость относится к эксплуатационным расходам, поскольку она приносит прибыль. В оценках, представленных в докладе, вся тяжелая вода амортизирует-

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* Настоящее издание, т. 5.

ся в течение того же срока службы, который принимается для установки. При этом признается, что тяжелая вода будет, вероятно, иметь некоторую остаточную стоимость, но было бы чрезвычайно трудно попытаться оценить ее, и мы предпочитаем наш настоящий метод.

ОБЩАЯ ДИСКУССИЯ

Д. Ф. КЕННЕДИ (Соединенное Королевство): Мне, как инженеру-энергетику, трудно понять благодушие, с которым сторонники некоторых реакторов на обычной воде встречают проблему остановки реактора для замены топлива. Я смею утверждать, что время, требуемое для этой цели, слишком продолжительно и что установленный период между последующими остановками весьма неудобен для оператора энергетических систем.

Допустим, что кипящий реактор мощностью 500 *Мвт* является составной частью системы энергоснабжения, которая имеет также значительную мощность за счет обычных тепловых станций. Разумно предположить, что стоимость топлива для тепловой станции, используемой вместо кипящего реактора во время замены в нем топлива, будет не менее чем на 0,3 *пенс/квт·ч* (0,34 *цент/квт·ч*) выше стоимости реакторного топлива. Если, как на Дрезденской атомной электростанции, период замены топлива продолжается шесть недель, то дополнительные расходы фирмы-поставщика электроэнергии, связанные с заменой реактора обычной тепловой станцией с более высокой топливной составляющей, составили бы почти 550000 ф. ст. (1 500 000 долл.) ежегодно.

Я смею утверждать далее, что даже это еще не все. Как правило, раз в год обычные паровые котлы выключаются приблизительно на шесть недель в соответствии с установленными правилами для чистки и осмотра. Следовательно, при сравнении экономических показателей реактора и обычной электростанции в целях увеличения мощности энергосистемы обычно не устанавливается «штраф» на реактор, если он не требует ежегодных остановок на период не свыше шести недель.

Каково же будет положение, однако, если рассматриваемая энергетическая система уже включает или может включить различные типы реакторных установок, замена топлива в которых может производиться во время работы установки и которые в соответствии с правилами котлонадзора требуют остановки только раз в два или три года на время, отвечающее требованиям энергетической системы? В таких случаях, мне кажется, в топливном цикле реакторов на обычной воде имеется дефицит, который следует принимать во внимание при составлении баланса.

При подобного рода сравнении, вероятно, разумно было бы определить стоимость 1 *квт* установленной мощности для реакторов на обычной воде, но было бы, конечно, неправильно определить «штраф», равный дополнительной стоимости топлива для обычной станции, используемой в период замены топлива в реакторе на обычной воде.

По-моему, это важный фактор, который следует учитывать при сравнении экономических характеристик реакторов различных типов.

Л. Г. РОДДИС (США): Как инженер-энергетик и как руководитель энергетической фирмы я могу заверить г-на Кеннеди, что электростанции на ископаемом топливе также требуют остановок для запланированных осмотров и имеют незапланированные простои, которые вполне можно сравнить с соответствующими остановками и простоями на атомных станциях. В более новых водоохлаждаемых ядерных установках периоды между заменами топлива обычно превышают один год, а время, необходимое для перегрузки топлива и повторного пуска,— около двух недель. Такое положение, следовательно, можно сравнить с положением на обычных станциях.

Доклады P/746, P/43, P/598 (представил А. Лейте Гарсиа) и доклад P/316 (представил Г. С. Зелевинский)

По этим докладам дискуссии не было.

Acta de la sesión 1.6

Aspectos técnicos y económicos de la utilización de la energía nucleoeléctrica

Presidente: I. H. Usmani (Pakistán).

Documento P/216 (presentado por L. H. Roddis)

DISCUSIÓN*

D. Lawley-Wakelin (Reino Unido): Deseo hacer dos preguntas a los autores de este documento. La primera se refiere a la afirmación que figura al fin del mismo de que "la energía nuclear ha llegado a reunir los requisitos de orden económico y técnico necesarios para su integración en el 60%, como mínimo, de la red eléctrica de los

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* Véase también más adelante la discusión sobre el documento P/597.

Estados Unidos". ¿Quiere esto decir que en algunos casos los costos de la energía nucleoeléctrica son ya competitivos en los Estados Unidos con los de la energía convencional?

Mi segunda pregunta se refiere a la afirmación con que comienza el documento de que "De los 365 reactores construidos de conformidad con el amplio programa de desarrollo de la Comisión de Energía Atómica de los Estados Unidos, 11 han venido funcionando para suministrar energía a la red eléctrica en mayor o menor grado durante un año o más". Ruego a los autores que amplíen su exposición facilitando una información objetiva en lo que respecta al total de megavatios-hora suministrados. Una respuesta detallada a esta pregunta nos ayudaría mucho a evaluar la afirmación citada en mi primera pregunta.

L. H. Roddis (Estados Unidos de América): La respuesta a la primera pregunta es afirmativa. En cuanto a la segunda, creo que ya se ha contestado a ella en otras sesiones de la Conferencia. También figura en la tabla 1 del documento. No veo la utilidad de examinarla de nuevo en esta sesión.

J. P. Roux (Francia): La tabla 4 de su documento indica un costo de inversión para la central Yankee de 220 dólares de los EE.UU. el kilovatio. Esto representa una suma bastante inferior a la cifra correspondiente de la central SENA [266 MW(e)] que es de 300 dólares de los EE.UU. el kilovatio, sin contar el costo del uranio enriquecido para la primera carga. ¿Comprende la cifra correspondiente a la central Yankee el costo del uranio para la primera carga?

L. H. Roddis (Estados Unidos de América): Creo que sí, pero no estoy seguro de ello. La cifra correspondiente a la central de Oyster Creek incluye de seguro la cantidad invertida en el acopio de combustible. Debo destacar que en la tabla 4 sólo se trata de poner de manifiesto la relación entre el tamaño y la inversión efectuada en la central.

Documento P/597

DISCUSIÓN

R. Janin (Francia): Tengo que hacer una pregunta acerca de los tipos de interés, pero quiero que la preceda una observación de carácter general.

Para asegurar el desarrollo económico normal, es preciso contar con un mercado monetario que fije los tipos de interés sobre la base de la oferta y la demanda o con un organismo central que establezca el porcentaje de los beneficios según las necesidades de inversión y los medios. A veces, una firma goza de condiciones especiales (tasas fiscales, primas, etc.) y en tales casos importa dejar bien sentado que es probable se produzca cierto desequilibrio en el desarrollo económico.

Observo que el Sr. Yusuf y los autores del documento P/216 citan tipos de interés del 4 y el 4,25%, respectivamente. ¿Podrían explicarnos cómo han de entenderse esos porcentajes?

M. Yusuf (Pakistán): La central nucleoeléctrica de Rooppur está patrocinada por el Gobierno del Pakistán. Para todos los proyectos de centrales patrocinadas en dicho país por el Gobierno, éste emite un empréstito a un tipo de interés por lo general inferior al 4% y a su vez presta el dinero así obtenido para los proyectos al 4% aproximadamente. Quizá deba indicar que en el Pakistán casi el 95% de los proyectos de producción de energía están patrocinados por el Gobierno. Este tipo de interés del 4% es asimismo aplicable a la central nucleoelélectrica de Rooppur. Sea dicho de paso, el tipo de interés bancario en el Pakistán es también del 4%.

L. H. Roddis (Estados Unidos de América): Los tipos de interés de las inversiones enunciados en la tabla 3 del documento P/216 se basan en la inversión privada. Dos tercios de la inversión consisten en obligaciones al 4,25% y un tercio en el capital en acciones al 10%. Esto, unido a otras partidas, representa un tipo fijo de imposición del 11%. Debo agregar que este tipo de interés sólo se aplica en Pennsylvania y en Nueva Jersey, porque no hay impuesto sobre la propiedad inmobiliaria, sino únicamente impuesto sobre las ventas. En el resto de los Estados Unidos el tipo fijo de imposición es del 13,5% aproximadamente.

Documento P/561 (presentado por F. Faux)

DISCUSIÓN

N. Holmin (Suecia): Como se ha indicado en diversos documentos, siempre que se trate de comparar, desde el punto de vista económico, las centrales nucleoeléctricas con las de tipo corriente, la cuestión de la disponibilidad revestirá por supuesto la mayor importancia. En los estudios realizados en Suecia acerca de la introducción de la energía nucleoeléctrica para la producción de electricidad, nos hemos basado en la hipótesis de que el factor de disponibilidad será el mismo para nuestras cuatro primeras centrales nucleoeléctricas que para nuestras centrales convencionales. También se precisa en otros documentos que la disponibilidad es, cuando menos, tan favorable para las centrales nucleoeléctricas como para las centrales convencionales.

En el documento P/561 se nos dice que, a los efectos de la planificación, en Inglaterra y en Gales se supone una disponibilidad de 75% para la energía nucleoeléctrica como promedio anual y 85% en el momento de la demanda máxima a la central. Estas cifras son más bien bajas si se comparan con las que se suelen mencionar para las centrales de tipo corriente, teniendo sobre todo en cuenta que los reactores de que se trata se cargan de nuevo mientras están en marcha y que el Reino Unido posee ahora una experiencia considerable en el funcionamiento de centrales nucleoeléctricas. En el supuesto de que se adopten las cifras habituales para las centrales de tipo corriente, me inclino a pensar que este factor colocaría a las centrales nucleares en una situación desfavorable en cualquier elección, entre los dos tipos de central, realmente inspirada en consideraciones económicas.

¿Utilizan ustedes en realidad en la Central Electricity Generating Board las cifras poco elevadas que se citan para la disponibilidad de las centrales nucleoeléctricas cuando se trata de apreciar la disponibilidad de las centrales convencionales, por ejemplo, de las centrales de 400 y 500 MW que ahora se están construyendo?

F. Faux (Reino Unido): Se ha considerado prudente utilizar esta cifra de 75% para el promedio anual de disponibilidad hasta que se haya adquirido más experiencia. En el documento P/128* se describen los resultados experimentales obtenidos en Bradwell y Berkeley, pero es demasiado pronto para modificar la base que estamos utilizando en la actualidad para nuestra planificación a largo plazo.

Las cifras que utilizamos para las centrales convencionales son un tanto análogas considerando las cosas a largo plazo, es decir, de un 77,5% de promedio anual.

Por supuesto, en función del factor de carga, las consideraciones serían completamente distintas.

N. Holmin (Suecia): ¿Desea el Sr. Roddis formular alguna observación al respecto?

L. H. Roddis (Estados Unidos de América): La disponibilidad de las centrales nucleoélectricas en los Estados Unidos es mayor que las de las centrales de tipo corriente (en general, de 90% o más).

Documento P/11 (presentado por P. H. G. Spray)

DISCUSIÓN

P. Verstraete (Suiza): Observo que ustedes amortizan a lo largo de toda la vida de la central la mitad de la carga de combustible que queda en el reactor cuando éste deja de funcionar. Estimo que la mitad de la carga de combustible se pierde también cuando la central comienza a funcionar y que de igual modo debe amortizarse dicha mitad. No parece incluirse ningún fondo para una amortización de este género ni la mitad de la carga inicial está incluida tampoco en la partida "Programa de puesta en servicio y formación del personal", cuyo cálculo del costo es del mismo orden de magnitud que el costo de la mitad de la carga. ¿Hasta qué punto diría usted que la mitad de la carga que se pierde al principio y que sólo es irradiada parcialmente puede utilizarse cuando cesa el reactor de funcionar?

Observo también que en sus cálculos no se tiene en cuenta el valor de recuperación del agua pesada al fin del funcionamiento de la central, por considerarse que representa una prima sobre las operaciones. En tal caso, ¿no procedería hacer caso omiso de la mitad de la carga final, o incluso de las mitades final e inicial, dado que la prima sobre las operaciones para el agua pesada representa el valor de unas tres cargas completas de combustible?

P. H. G. Spray (Canadá): Al amortizar sólo la mitad de la carga de combustible que queda en el reactor al terminar la vida de la central, suponemos que la primera mitad se ha consumido, y esto se carga al costo de funcionamiento, ya que produce ingresos. En el cálculo presentado en el documento, la totalidad del agua pesada se amortiza en el mismo período que se presume para la central. Se reconoce que es probable que el agua pesada tenga algún valor residual, pero sería sumamente difícil tratar de hacer un cálculo y preferimos nuestro método actual.

DISCUSIÓN GENERAL

G. F. Kennedy (Reino Unido): Como ingeniero especializado en cuestiones de energía, se me hace difícil comprender la complacencia con la que los partidarios de algunos reactores de agua ligera afrontan el problema de la parada del reactor para repostarlo. Debo indicar que el tiempo necesario para ello es demasiado largo y que el período fijado entre las paradas sucesivas es muy poco conveniente para los que hacen funcionar las centrales.

Supongamos que un reactor de agua hirviendo de 500 MW se instala en una central que posee asimismo una capacidad térmica considerable. No sería absurdo suponer que el costo del combustible destinado a la central térmica utilizada para sustituir al reactor de agua hirviendo durante el período de carga sería superior, cuando menos en 0,3 peniques (3,4 milésimas de dólar de los EE.UU.) por kWh, al del reactor. Si, como ocurre en la central Dresden, el período de carga dura seis semanas, el costo adicional que para la empresa de electricidad representara el hacer funcionar una central con un combustible a un costo tan elevado en vez del reactor equivaldría a cerca de 550 000 libras esterlinas (1 500 000 dólares de los EE.UU.) anuales.

Debo indicar también que la cuestión no se limita a esto. Se tiene la costumbre de parar una vez al año las calderas de tipo corriente durante unas seis semanas para cumplir las disposiciones legales relativas a la limpieza e inspección. Por consiguiente, al comparar los datos económicos relativos a una central nucleoeléctrica con los de una central de tipo corriente a fin de ampliar la capacidad de la empresa, sólo se suele considerar como factor adverso el que haya que parar el reactor anualmente durante un período superior a seis semanas. Sin embargo, ¿cuál es la situación si la empresa de que se trata ha instalado ya, o puede instalar, de un modo supletorio diferentes tipos de centrales nucleoeléctricas

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* Véanse las presentes actas, Vol. 5.

cuyos reactores pueden repostarse en marcha y que, para cumplir con los reglamentos de inspección de las calderas, sólo hay que parar cada dos años, o incluso cada tres, en un momento que convenga a las necesidades del tipo de central? En tales casos, me parece que hay una deficiencia en el ciclo del combustible de los reactores de agua ligera que debe tenerse en cuenta al hacer el balance.

Quizá sería exagerado el no asignar un valor en kilovatios a los reactores de agua ligera en una comparación de este tipo, pero de seguro no sería correcto considerar que el factor adverso equivale a los costos adicionales de combustible de la central térmica utilizada como elemento sustitutivo durante los períodos de carga del reactor de agua ligera.

Me parece que esto constituye un factor importante y es preciso tenerlo en cuenta al comparar los datos económicos de los distintos tipos de reactor.

L. H. RODDIS (Estados Unidos de América): Hablando como ingeniero especializado en cuestiones de energía y también como elemento directivo de una compañía de electricidad, puedo asegurar al Sr. Kennedy que las centrales que utilizan combustibles fósiles tienen también períodos de parada para inspecciones previstas e interrupciones imprevistas totalmente comparables a los de las centrales nucleoeléctricas. Las centrales nucleares más recientes refrigeradas con agua tienen intervalos de carga del combustible que, por lo general, exceden de un año y períodos de nueva carga de dos semanas aproximadamente. Por consiguiente, la situación es comparable con la de las centrales que funcionan a base de combustibles fósiles.

Documentos P/746, P/43, P/598 (presentados por A. Leite Garcia) y P/316 (presentado por G. S. Zelevinsky)

No hubo discusiones separadas sobre estos documentos.

Session C

INTERNATIONAL COLLABORATION IN NUCLEAR REACTOR PROJECTS, INCLUDING DEVELOPMENTS OF MAJOR CO-OPERATIVE INSTALLATIONS

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International cooperation on nuclear power

By H. D. Smyth*

I should like to begin by making four statements which I believe most of you will accept as obviously true.

First: It is impossible to know what scientific discoveries, however abstract, will ultimately prove to be useful;

Second: The general advance of scientific knowledge is promoted by the widest possible exchange of information;

Third: Industrial and military technology depend heavily on scientific knowledge;

Fourth: The power and influence of nations depend heavily on the strength of their industrial and military technology.

These facts force statesmen into a dilemma. National rivalries persist in a world increasingly fearful of war. The industrial strength of a country will be enhanced by international cooperation in science and technology, but the military strength of any one nation relative to its rivals may be lessened by such cooperation. A country confident of its power and righteousness may say: "Let us exchange information freely, let us cooperate fully to advance knowledge and thereby improve the lot of mankind." A country afraid of its neighbors or eager for power and conquest may say: "We must keep to ourselves all the knowledge we have, add to it, apply it to our military and industrial technology so that we can defend ourselves and if need be destroy our neighbors."

The degree to which either of these extreme positions makes sense depends on many other factors than science and technology in ways that are outside the scope of this paper. It also depends on the weight assigned to the relative importance of cooperation versus secrecy. This will vary from time to time, from place to place, and from one field of science and technology to another. Nor can this relative importance be determined by any so-called "scientific" method. It is a matter of judgment, a balancing of risk versus advantage, an evaluation of future probabilities as to events inherently unpredictable. If at any time political cooperation appears impossible, statesmen must consider whether scientific cooperation is desirable, weighing the question more carefully than in the past because of the appalling power of modern weapons and their close dependence on current science and technology.

This then is the problem: the balance between the long-run advantage of international cooperation and the short-run advantage of secrecy. In science this problem has become important only in the last generation. Let me review how such a change has come about.

HISTORICAL BACKGROUND

I need hardly remind you that science has always been linked with civilian and military technology. Perhaps this linkage was weakest in the eighteenth and nineteenth centuries, when science made great progress by focusing on deliberately simplified problems, while technology progressed by empirical development and ingenious invention. The dependence of technology on science in this period was not strong, and the tradition of free international exchange of scientific information became firmly established.

By the time of the First World War the methods of science had become sufficiently powerful to attack complex technological problems. At the same time, the very complexity of these problems made progress without science more difficult. During that war scientists were used in such special fields as sound ranging, development of poison gases, and communication, but the dependence of military technology on science was neither very great nor clearly recognized.

The First World War marked only the beginning of the direct impact of science on military technology, but it emphasized the indirect influence of science through civilian technology. The concept of "total war" involved civilian industrial technology in a nation's military strength to a much greater degree than formerly.

The progress of science had not been seriously affected by the First World War, but did go forward with great rapidity in the two decades between the world wars, particularly in the United States. During that period the traditional methods of international scientific cooperation continued with increasing vigor. These methods are, of course, the exchange of information through publication, through international conferences and symposia, and through the visits of scientists. So far as I am aware the exten-

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sive and fruitful international cooperation in the field of science during these two decades received little or no assistance from government sources, nor did the governments involved show any particular interest.

By the time the Second World War broke out the importance of science to industrial technology, and the importance of industrial technology to military technology, had begun to be generally recognized. The extensive application of known science and of scientific methods to warfare had become inevitable. Every country recognized the situation and organized its scientists in one way or another to meet it. Great effort and great amounts of money succeeded in fashioning various tools of war out of scientific knowledge. I need only mention such examples as radar, the proximity fuse and rocket bombs.

The moment the importance of science to weapons became evident, the importance of secrecy was accepted as a matter of course. Traditional scientific interchange of information was interrupted, not only by the inevitable restrictions of a state of war but by policy decisions. Such interchange as continued was either in secret among allies or in fields of science considered to have no possible bearing on military affairs.

By an ironic twist of fate, the scientific discovery which was to impinge most violently on military technology and at the same time offer the greatest hopes for improving our peacetime lot was made just as war was breaking out.

THE DISCOVERY OF THE FISSION OF URANIUM

The discovery of the fission of uranium in the early months of 1939 and of the first chain reaction, achieved in December 1942, have often been described. Scientifically they are of enormous interest in terms of nuclear structure and in terms of the release of energy from a source totally unfamiliar on the earth. From the point of view of technology, the new source of energy was immediately recognized as having great potential both for weapons and as a source of power.

As the technology developed it became clear that the kind of chain reaction likely to be most useful in producing power for civilian uses was also a convenient way of producing nuclear explosives for use in weapons. To use a crude analogy, it is almost as if the ashes from coal burned in the boilers of a power plant could be readily converted into gun powder.

THE POST-WAR PERIOD

At the end of the war in 1945, when the cloak of secrecy was partially withdrawn, it was clear that the world was confronted with a totally new situation. Weapons had been developed thousands of times more powerful than any previously known. The same material from which they were made was potentially a more plentiful source of energy for civilian use than all the coal and oil in the world. The technologies of making nuclear explosives and of making nuclear power plants were inextricably mixed.

Six years later, it was shown that even more powerful nuclear weapons could be built using the nuclear fusion of hydrogen instead of the nuclear fission of uranium. Here again the possibility existed that this source of energy could be used for civilian purposes. But the technologies involved in fusion were quite different, and the problem of controlling nuclear fusion as a practical source of electric power is still to be solved.

Emphasis on the close relation between nuclear power technology and nuclear explosives technology is essential to an understanding of the difficulties encountered in the promotion of international cooperation in the field of nuclear power. These difficulties have affected the history of such cooperation and still pose an important dilemma.

Immediately after the Second World War a great effort was made by the United States to establish international control of atomic weapons. Primary responsibility for this effort was focused in the United Nations, and an atomic energy commission was established in the United Nations in 1946. This Commission was charged with an attempt to work out an acceptable method of international control. The plan proposed by the United States, commonly known as the Baruch Plan, was not accepted. Several years of negotiation failed to bring agreement and the United Nations Atomic Energy Commission was finally dissolved in 1952.

During the period from the end of the Second World War to the end of the Korean War, the United States, the United Kingdom and the USSR devoted their efforts principally to the development of weapons and the build-up of stockpiles. The Russians exploded their first atomic bomb in the fall of 1949 and the British in 1952. Although the United States Atomic Energy Commission had been set up under civilian control in 1947, its civilian power program made relatively little progress in this period. Such international cooperation as did exist was largely in the military field although both the British and the Canadians had undertaken programs looking toward the development of civilian nuclear power.

On 26 May, 1953, the United States Atomic Energy Commission presented a statement of "Policy on Nuclear Power Development" to the Joint Congressional Committee. By this time a number of small research, or testing, reactors had been built and put into operation. These included the experimental breeder reactor which generated small amounts of electric power in December 1951. This reactor and several others were at the United States National Reactor Testing Station in Idaho, which had been established in 1949. There were also research or development reactors at the Argonne National Laboratory and elsewhere. A reactor training school had been established at Oak Ridge and a considerable effort had been made to disseminate information among industrial groups which might be interested in the future of nuclear power. Numerous study or research projects had been fostered in preparation for a serious effort to develop peacetime nuclear power.

In summary, one can take the year 1953 as marking the end of the preparatory period for nuclear power and the beginning of major effort. Such major effort was to include not only domestic power plants but the dissemination of information throughout the world and the gradual establishment of research reactors under bilateral arrangements for the exchange of information and materials.

THE ATOMS FOR PEACE PROGRAM

On 8 December 1953, President Eisenhower delivered an address before the General Assembly of the United Nations entitled "Atomic Power for Peace." This speech has become known as the Atoms for Peace Speech, and marked the beginning of the era of extensive international cooperation in the use of atomic energy. Basically, the speech reviewed the terrible dangers of a nuclear arms race, the great benefits to mankind inherent in the discovery of nuclear fission, and the desirability of both controlling the arms race and promoting the peaceful uses of atomic energy.

The speech was a notable success; particularly striking was the enthusiastic reception which it received all around the world. Evidently, by 1953, many governments and many peoples had become aware of the terrible dangers of nuclear weapons and welcomed with enthusiasm both a proposal to reduce these dangers and the spirit in which it was given.

Specifically, this speech led directly or indirectly to three major steps toward international cooperation. First, plans were begun for an international conference on the peaceful uses of atomic energy under the auspices of the United Nations. Second, steps were taken to establish an International Atomic Energy Agency to promote peaceful uses of atomic energy. Third, the United States Congress in the summer of 1954 revised the U.S. Atomic Energy Act drastically, to encourage the development of nuclear power in the United States and to permit the worldwide dissemination of information and the negotiation of agreements of cooperation between the United States and other countries for the development of the peaceful uses of atomic energy.

The First International Conference on the Peaceful Uses of Atomic Energy was convened by the United Nations in Geneva, 8-20 August 1955. This conference was unique in a number of respects. Seventy-three nations, plus eight specialized agencies of the United Nations, sent to the conference a total of 1 428 delegates. In addition to the regular delegates there were 1 334 official observers, principally from non-governmental organizations, academic institutions and industrial concerns. There were also present 902 representatives of the news media of the world. These numbers alone offer testimony to the impression that President Eisenhower's speech of December 1953 had made on the world.

But of course the President's speech and the calling of the conference simply highlighted the extraordinary situation in which the world's scientific and industrial community found itself. The discovery of nuclear fission in 1939 offered a new and vast source of energy. Industrial progress was dependent on the use of conventional fuels as a source of energy, and it was becoming apparent that the reserves of such fuels were not unlimited. In the sixteen years that had elapsed since the discovery of nuclear fission, normal channels of interchange of information had been interrupted by war, by subsequent political tensions, and by the secrecy imposed because of the military importance of nuclear weapons. Here at Geneva was the first opportunity in fifteen years for the scientists and engineers of many countries to meet together. Here was their first opportunity to discuss this great discovery, here great amounts of information developed in the various countries in a period of fifteen years were to be revealed for the first time.

One could hardly expect the misunderstandings and barriers of secrecy to be swept away by a single conference, but remarkable progress was made and this first Geneva meeting will certainly go down in history as a great step forward toward international cooperation from both a political and a scientific point of view.

The establishment of a new international organization is necessarily a slow business. Nevertheless, by October 1957 the International Atomic Energy Agency had been established with headquarters in Vienna and an initial membership of fifty nations. I shall return to a discussion of the Agency later.

In order to carry out the Atoms for Peace Program, the United States Atomic Energy Commission established a Division of International Affairs in 1955. By 1957 bilateral agreements had been made with more than twenty countries for cooperation in the peaceful uses of atomic energy. It is unnecessary to list these bilateral arrangements or similar arrangements made by the United Kingdom, the USSR, Canada and France. Arrangements made by the United States are presumably typical and cover a wide range. Where the other bilateral partner was already scientifically and industrially well-developed, scientific and technical information, designs for research reactors or such reactors themselves, could readily be put to use. In some cases only information was supplied; in others material or reactors themselves. In certain lesser developed countries small research reactors were set up to stimulate general scientific interest and education. The financial arrangements were of various kinds although usually involving some degree of subsidy.

One of the first countries to embark on an atomic energy program aimed solely at peaceful purposes was Canada. Cooperation between the United States and Canada has been continuous since the early days of the war. In the postwar years exchange of information between the two programs has grown constantly. Canada chose to concentrate its efforts to develop nuclear power on reactors using heavy water as a moderator or coolant, or both. Although the United States had built several heavy water reactors for the production of plutonium, the trend of interest among our power plant engineers was in the direction of other types of reactors. It became obvious that it would be mutually advantageous to the two countries to exchange information in the power reactor field and to let the Canadians take the lead in the development of heavy water reactors. A mutual understanding to this effect was formalized in 1960 and has continued to operate to the satisfaction of both countries.

Another example of international cooperation is remarkable for the number of countries participating. This is the so-called DRAGON Project for the development of a high-temperature gas-cooled reactor. This is a project of the Organization for European Economic Cooperation. It involves participation by eleven countries in Western Europe, plus a certain amount of cooperation by the United States.

More immediately aimed at the construction of nuclear power plants, the EURATOM group was formed in 1957 and agreement for cooperation with the United States was signed a year later. The membership of this group is identical with that of the Common Market and the Coal and Steel Community. Their initial plans for the construction of power plants were based on the over-optimistic ideas of cost prevailing at the time the group was formed. Later appraisals were more realistic and the program is now going forward with several powerplants in operation or under construction.

Shortly after the war Japan embarked on a vigorous program of nuclear power development. This was particularly appropriate because conventional fuels are costly in Japan and there is a solid background of scientific, engineering and industrial competence on which to build. The program initially consisted of a number of small research reactors but has now moved into the phase of construction of power reactors. Assistance from other countries comes in various forms through a series of bilateral arrangements, including one with the United Kingdom and one with the United States. A unique feature of the Japanese program is its insistence by action of parliament on the limitation to peaceful uses and on international inspection to guarantee that this limitation is effective.

The United States now has arrangements with thirty-five individual countries, covering more than sixty reactors or critical assemblies which it has furnished wholly or in part. The United States has supplemented its formal cooperative arrangements by setting up training schools at Oak Ridge and at the Argonne Laboratory which are open to students from foreign countries. These schools have been well-attended by men of appropriate previous education who have then returned to their native countries to help in establishing atomic energy programs and in operating research reactors or whatever facilities may be available.

As a final example of bilateral or multilateral cooperation and one of great importance I should cite the exchange of visits between leading figures in the atomic energy activities of the USSR and the United States. These visits began in 1959 and have continued under a series of different agreements until the present time. Not only has the information exchanged been mutually beneficial, but cordial personal relations have been established.

THE SECOND GENEVA CONFERENCE

All the types of international cooperation which I have been describing are still continuing. In addition there are of course many international scientific conferences arranged by various organizations. Since general international cooperation in the field of atomic energy really began with President Eisenhower's speech in 1953 and the First Geneva Conference in 1955, it seems appropriate to close this description of the kinds of international cooperation by mentioning the Second Geneva Conference which was held in September 1958. Like the First Conference, it was devoted to the peaceful uses of atomic energy and, again, covered a very wide range of topics. The success of the first conference in stimulating work in this field throughout the world is shown by the fact that the second conference, only three years later, was nearly double the size of the first in terms of participants and number of papers submitted.

It is probable that so large a conference will not occur again. Certainly the present conference, as you well know, is more limited in subject matter, size and exhibits. In a sense, the limited nature of the present conference recognizes that many aspects of the peaceful uses of atomic energy have been absorbed into the general corpus of scientific and engineering activity. The scientific and technical activities related to atomic energy are now so numerous and so widespread as to make it impracticable to cover them in detail in a single conference.

THE PRESENT CONFERENCE: SAFEGUARDING NUCLEAR POWER PLANTS

The central theme of the present conference is nuclear power. In spite of the close relation of nuclear reactors to nuclear physics, to materials technology, to chemical technology, and to engineering, there is one aspect of nuclear power which requires that it be treated separately from its component parts. We must recognize that nuclear power plants are usually producers of nuclear explosives. The proliferation of nuclear power plants means the proliferation of potential sources of weapons material, and therefore poses political problems of a quite different kind from those associated with the progress of science and technology in other fields.

I believe that all the Nuclear Powers have recognized the possibility and grave danger of the proliferation of nuclear weapons and are eager to prevent it. Certainly this has been a concern of the United States since it started making bilateral arrangements for the dissemination of information and materials. Every bilateral agreement that the United States has signed which involves any significant amount of nuclear material has provisions for safeguarding that material against diversion to military use. The Statute of the IAEA recognizes the necessity for a system of safeguards and instructs the Agency to set up such a system. Article II of the Statute describes the Agency's objectives as follows: "The Agency shall seek to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world. It shall insure so far as it is able that assistance provided by it or at its request or under its supervision or control is not used in such a way as to further any military purpose." Thus the Agency has a dual purpose. It must promote and it must restrain.

THE INTERNATIONAL ATOMIC ENERGY AGENCY

In earlier parts of this paper I have made several references to the IAEA. Originally suggested in President Eisenhower's 1953 speech, the Agency finally came into existence in 1957. Though it is independent of the United Nations organization, it is required to submit reports of its activities to the General Assembly of the United Nations and, when appropriate, to the Security Council. The main point of the relation of the Agency to the United Nations is that the Agency should not be concerned with political questions bearing on the maintenance of international peace and security, but should have a responsibility for calling to the attention of the United Nations any such questions which might arise from the Agency's activities. The Agency is controlled by a Board of Governors originally composed of the representatives of twenty-three nations, now enlarged to twenty-five, to give greater representation to the African nations.

One of the two principal objectives cited in the Statute as quoted above appeared to be of little importance in the early days of the Agency. There was not much point in safeguarding the materials in nuclear power plants if there were not any nuclear power plants. Nevertheless, the Agency undertook to set up a system of safeguards. Such a system, limited to reactors of less than 100 MW thermal power, was approved by the Board of Governors in January 1961. Most of the members recognized that such a system would be worse than useless unless it was really effective and that to be effective it must include some sort of inspection by officers of the Agency. Nevertheless, several member nations found such a system repugnant and voted against it. It is perhaps just as well that the demand for such a system did not come rapidly. The years between 1961 and 1964 provided an opportunity to put the limited system into practice on a few small low-powered reactors and to find that it is neither onerous nor offensive to national dignity. In this same period the peoples and governments of the world have gradually become more aware of the dangers of nuclear warfare and have become more willing to accept some form of international control.

Whatever the reason, the impressive fact is that the extension of the IAEA safeguards system to large power reactors was tentatively approved by the Board of Governors in June 1963 with only three abstentions and no negative votes, was approved by the General Conference in September 1963 with only a handful of negative votes and abstentions, and was finally approved by the Board of Governors in February 1964, unanimously.

THE PRESENT STATUS OF NUCLEAR POWER

Let me digress a moment to adduce evidence that nuclear power is about to become important around the world. In the fall of 1962, the United States Atomic Energy Commission released a study of the present and prospective costs of nuclear power. It was on the whole optimistic, even in terms of the United States where conventional power is cheaper than in most areas of the world. Since that time greatly reduced prices for the capital cost of such plants have been announced by United States industry indicating that prices are falling more rapidly than anticipated.

More direct evidence for the increasing importance of nuclear power is the recent announcement of plans for new power plants in Japan, India, the United States, the United Kingdom, western Europe and elsewhere.

A new development of potential importance is the idea of nuclear reactors for the dual purpose of desalting water and producing power. At present, such reactors appear to be economically feasible only in very large sizes, but studies are going forward both as to costs and possible sites.

NUCLEAR POWER: BENEFITS AND DANGERS

At the beginning of this paper I defined the conflict between the advantages of international scientific cooperation in a peaceful world and the potential hazards of such cooperation to nations fearful of war. Let me now restate this conflict in terms of nuclear power.

Nuclear power plants may be of enormous benefit to the peoples of the world in the next half century. Nuclear power plants of the types most likely to be practicable produce nuclear explosives. Although the techniques of converting such materials to weapons are intricate if we are concerned with efficiency, primitive atomic weapons could probably be made by many countries without assistance from the great Nuclear Powers.

The question before the world is simple though the answer to it may not be. Can the world enjoy the benefits of nuclear power without promoting the proliferation of nuclear weapons?

We in the United States believe this is possible. We believe that a system of safeguards can be set up which could prevent the proliferation of nuclear weapons. We believe this can be done without serious interference with the sovereignty of nations and without significant interference with the construction and operation of nuclear power plants. We believe that such a system is best administered by an international agency and can be effective if the world recognizes its necessity.

Our convictions are based on twenty years of experience with nuclear reactors, large and small, on ten years of experience with bilateral safeguards, on three years of experience with the safeguards of the International Atomic Energy Agency, and on exhaustive studies by technical and political experts.

The operation of a nuclear power plant under a safeguard system must meet three requirements. The first, to operate efficiently, is common to all industrial plants and is the responsibility of management. The second requirement, also common to many industrial plants, is to operate the plant safely for its workers and without polluting the environment. Responsibility for meeting this requirement is shared by management with government authorities either city, state or national, depending on the nature of the potential dangers. Regulations must be laid down and must be enforced by responsible officials using whatever system of review and inspection is agreed upon as necessary.

Both efficiency and safety are obviously important in nuclear power plants. Many of the procedures that promote safety also promote efficiency. Both technically and in terms of responsibility these requirements overlap.

The third requirement, to safeguard a power reactor against diversion to military use, involves techniques generally similar to those needed for safe and efficient operation. Regardless of the techniques necessary, there is one inherent and fundamental difference between this third requirement and the first two. A system of effective safeguards against diversion of nuclear material to military use involves much wider responsibility than ordinary safety and efficiency of operation, and therefore implies a wider authority than local, state or national government.

The whole world is involved, and the whole world must be assured that no material in any nuclear power plant is being diverted to bombs. Such assurance will be accepted only if it comes from a source outside the country where the nuclear power plant is located. That source must base its assurance on whatever review of inventories, study of reports and inspection of plants have been agreed upon as necessary.

It is the conviction of the United States that a safeguard system, to insure against diversion of nuclear material to military purposes, or to detect such a diversion should it occur, is best administered by an international agency.

It is also our belief that an international safeguard system is more likely to be effective if it is applied at every step of the series of processes involved, for example, isotopic enrichment, fuel fabrication, fuel use in a nuclear reactor and chemical reprocessing. We recognize that this may not be practicable, but we are sure that thorough inspection of records and of the physical plant at least at two stages is desirable. An ineffective system is worse than useless.

The IAEA has at present a safeguards system fully described in IAEA documents. It requires record keeping, reports, and inspection. By action of the Board of Governors it is now applicable to nuclear reactors of any power level. In the United States we have used this system for small reactors and have now asked that it be applied to one of our big power reactors. We have found the reports and inspections neither burdensome nor offensive. We recognize that the review of the system presently under way in the Agency is appropriate especially in terms of clarification of principles and procedures. We shall do our best to see that the revised system is clear and reasonable. We shall also do our best to assure that it is effective. Above all, we urge the other members of the Agency to do likewise.

We have no illusions. To set up a safeguard system is not enough. It must be generally accepted and generally applied. It may be only a small step toward arms control, but it is a significant one. Further steps must follow and be followed in turn by actual disarmament. Such further steps may be facilitated by the experience gained from the establishment of a system of control and inspection in the limited field of nuclear explosives produced by nuclear power plants.

CONCLUSION

The world moves haltingly along the path toward assured peace. The way leads through a jungle of inherited feuds, conflicting commercial interests, clashing political faiths and mutual distrust. One small segment of the world community, the segment represented at this conference, shares a common language and a common tradition of cooperation.

You are here to explore the means by which nuclear energy, one of the greatest discoveries of science, can be developed to benefit all nations. You are well aware that such a development can be dangerously perverted. I am urging you to do everything in your power to prevent that happening. It does not need to happen. It will happen if petty pursuit of personal ambition, or blind insistence on commercial advantage, or exaggerated sensitivity about national sovereignty prevent far-sighted and generous cooperation. It is my profound conviction that in the use of nuclear energy, the whole world is involved.

ABSTRACT - RÉSUMÉ - АННОТАЦИЯ - RESUMEN

A/193 Etats-Unis d'Amérique

Coopération internationale dans le domaine de l'énergie nucléaire

par H. D. Smyth

La découverte de la possibilité de libération de l'énergie nucléaire par une réaction neutronique en chaîne dans l'uranium marqua le point culminant de la recherche scientifique en coopération entre plusieurs nations. Ironiquement, cette découverte survint précisément au moment où le nuage noir de la guerre s'étendait sur le monde, rompant le courant normal des échanges d'informations au sein de la communauté mondiale de la science.

Les échanges internationaux d'informations sur l'énergie nucléaire furent rétablis lentement après la guerre à cause de l'effrayante puissance destructrice des armes nucléaires et à cause de l'atmosphère d'instabilité et de suspicion mutuelle. En 1945, les Etats-Unis commencèrent à libérer le plus possible d'informations en accord avec la sécurité militaire et, dans le cadre du plan Baruch, proposèrent un projet destiné au contrôle des armes nucléaires et au progrès des utilisations pacifiques de l'énergie nucléaire.

Le plan Baruch ne fut pas accepté, mais graduellement des échanges d'informations s'établirent grâce à des accords bilatéraux comprenant l'échange de visiteurs, grâce aux voies normales de publication, et grâce à des conférences internationales. Les plus complètes de ces conférences furent celles tenues à Genève en 1955 et en 1958. Les comptes rendus de ces conférences, qui furent publiés, constituent un monument notable à la coopération internationale.

Les principes de base d'un réacteur de centrale nucléaire sont très simples. Ceci peut expliquer l'optimisme du début concernant les possibilités immédiates d'obtention d'électricité d'origine nucléaire à bon marché. En fait, la réalisation de réacteurs de centrales nucléaires sûrs et pouvant entrer en compétition économique avec les autres sources d'énergie s'est montrée difficile. En conséquence, l'échange d'informations scientifiques, techniques et économiques a joué un rôle essentiel.

Il existe de nombreux accords bilatéraux ou multilatéraux pour la construction de centrales nucléaires. Du point de vue de la coopération, ces arrangements vont d'un extrême représenté par un pays recevant seulement des informations à l'autre extrême représenté par une livraison "presse-bouton" complète d'un réacteur de centrale, équipement auxiliaire, accords pour le traitement de combustibles épuisés et la garantie de la fourniture de combustible de rechange.

Les exemples d'accords coopératifs comprennent le projet "DRAGON" pour la mise au point d'un réacteur à haute température refroidi par un gaz. Le projet DRAGON est unique au point de vue du grand nombre de pays participants. Un autre exemple est l'accord bilatéral entre le Canada et les Etats-Unis, accord par lequel le Canada ouvre la voie dans l'étude des réacteurs à eau lourde avec la pleine coopération des Etats-Unis.

Le Groupe de l'EURATOM fut formé en 1957 dans le but plus immédiat de construire des centrales nucléaires et un accord de coopération avec les Etats-Unis fut signé un an plus tard. Le changement dans le programme de l'EURATOM depuis son établissement initial montre bien le glissement de l'optimisme exagéré du milieu des années cinquante au point de vue plus réaliste actuel.

Le Japon est en train de construire une série de réacteurs de tailles et de types divers dans le cadre de divers accords avec un certain nombre de pays.

Les Etats-Unis ont des accords avec plus de trente pays couvrant plus de soixante réacteurs ou "ensembles critiques" fournis entièrement ou en partie par les Etats-Unis et assujettis à des restrictions contre la déviation vers des utilisations militaires. La plupart de ceux-ci étant de petites dimensions, les restrictions ne seront pas très importantes en pratique mais sont très importantes du point de vue du principe.

Il existe de nombreux problèmes concernant la santé et la sécurité, la responsabilité en cas d'acci-

dents, l'élimination des déchets, etc., liés aux accords mentionnés. La garantie de non-utilisation militaire est d'importance primordiale. Beaucoup de ces problèmes concernent la communauté des nations toute entière et non pas seulement le pays où le réacteur est situé.

Pour cette raison, un contrôle international coopératif est essentiel au développement sûr des centrales nucléaires. Un tel contrôle peut et doit être exercé avec le soutien vigoureux de l'Agence internationale de l'énergie atomique.

A/193 США

Международное сотрудничество в области использования атомной энергии

Г. Д. Смит

Открытие того, что в результате цепной реакции в уране можно получить атомную энергию, было результатом совместных научных усилий многих стран. По иронии судьбы это открытие было сделано как раз в то время, когда мир был погружен в войну, прервавшую нормальный обмен информацией между учеными разных стран.

После войны международный обмен информацией по атомной энергии налаживался очень медленно как из-за колоссальной разрушительной силы атомной энергии, так и из-за напряженности международной обстановки и взаимного недоверия между государствами. В 1945 году США начали предавать гласности максимум информации, который можно было опубликовать в пределах обеспечения безопасности вооруженных сил страны. В то же время был предложен «план Баруха», который предусматривал систему контроля за атомным оружием и использование атомной энергии в мирных целях.

«План Баруха» не был принят, но все же обмен информацией постепенно начал расширяться путем обоюдных соглашений о взаимных визитах научных работников, нормальном обмене научной литературой и организации международных конференций. Главные из этих конференций состоялись в Женеве в 1955 и в 1958 годах. Изданные труды этих конференций являются важным вкладом в международное сотрудничество.

Основные принципы устройства ядерных энергетических реакторов очень просты. Этим объясняется ранний оптимизм в отношении быстрого получения дешевой ядерной энергии. В действительности оказалось, что создание ядерных энергетических реакторов, которые могли бы надежно и экономно конкурировать с другими источниками энергии, представляет собой очень трудную задачу. Поэтому дальнейший обмен научной, технической и экономической информацией является необходимым.

Существует целый ряд двусторонних и многосторонних соглашений по строительству ядерных энергетических реакторов. В одних случаях эти соглашения сводятся просто к получению страной-покупателем одной лишь информации по данному вопросу, а в других — предусматривается поставка готовых энергетических реакторов и вспомогательного оборудования, а также обеспечение переработки отработавшего топлива и гарантий по поставке нового топлива.

Примером коллективного договора о сотрудничестве в области атомной энергии может служить проект DRAGON — разработка высокотемпературного реактора с газовым охлаждением. Данный проект отличается от других тем, что в нем принимает участие целый ряд стран. Вторым примером является двустороннее соглашение между Канадой и США, по которому Канаде отведена ведущая роль в разработке реакторов на тяжелой воде при активной помощи со стороны США.

В 1957 году было создано Европейское сообщество по атомной энергии (Евратом) с целью непосредственного строительства энергетических реакторов, которое год спустя подписало договор о сотрудничестве с США. Изменение первоначальной программы Евратома указывает на переход от чрезмерного оптимизма, характерного для середины 50-х годов, к более реалистической позиции настоящего времени.

В настоящее время Япония строит ряд реакторов различных типов и мощностей в соответствии с соглашениями с разными странами.

Соединенные Штаты связаны более чем с тридцатью странами договорами на поставку (целиком или частично) свыше шестидесяти реакторов и критических сборок, причем эти договоры предусматривают обеспечение соответствующих гарантий против использования поставляемого ядерного оборудования и материалов для военных целей. Так как большинство этих реакторов имеют небольшую мощность, такие гарантии имеют скорее принципиальное, чем практическое, значение. В связи с заключением договоров по реакторам возникло много проблем, связанных с охраной здоровья и техникой безопасности, гарантиями на случай ядерной аварии, удалением радиоактивных отходов и т. д. Особенно важно предотвращение использования реакторов для военных целей. Многие из этих вопросов не только касаются стран, где построен реактор, но и имеют международное значение.

Поэтому для обеспечения безопасности развития атомной энергетики необходимо установление коллективного международного контроля. Такой контроль может и должен быть создан путем энергичной поддержки деятельности Международного агентства по атомной энергии.

A/193 Estados Unidos de América

Cooperación internacional en la energía nuclear

por H. D. Smyth

El descubrimiento de que la energía nuclear puede ser producida por una reacción neutrónica en cadena en el uranio fue la culminación de los trabajos de investigación llevados a cabo con la cooperación de muchas naciones. Irónicamente, este descubrimiento ocurrió justamente cuando la amenaza de guerra envolvía la tierra, haciendo imposible el intercambio de información en el mundo de la ciencia.

El intercambio internacional de información acerca de la energía nuclear se desenvolvió de una manera lenta después de la guerra, debido al espantoso poder destructivo de las armas nucleares y a la atmósfera de inseguridad y sospecha que prevaleció durante los años de la posguerra. En 1945 los Estados Unidos empezaron a suministrar el máximo de información que su seguridad militar permitía, y en el plan Baruch presentó un proyecto destinado al control de las armas nucleares y al desenvolvimiento de los usos pacíficos de la energía nuclear.

El plan Baruch no fue aceptado, pero la información ha sido diseminada gradualmente a través de tratados bilaterales, incluyendo el intercambio de visitantes, a través de vías normales de publicación y a través de conferencias internacionales. De estas conferencias, las que cubrieron el mayor número de temas fueron las que se celebraron en Ginebra en 1955 y en 1958. Las Actas de estas conferencias son un monumento notable a la cooperación internacional.

Los principios en que se basa un reactor nuclear son muy simples. Esta simplicidad puede haber sido la causa del optimismo que prevaleció al principio acerca de las perspectivas inmediatas de energía nuclear a bajo costo. En realidad, el desarrollo de reactores nucleares confiables y que pudieran competir económicamente con otras fuentes de energía ha sido una tarea dificultosa. Por consiguiente, el intercambio de información científica, técnica y económica ha sido esencial.

Hay muchos tratados bilaterales y multilaterales relacionados con la construcción de plantas nucleares. Estos tratados van desde el caso en el que un país obtiene solamente información hasta el caso opuesto, en el que se suministra de golpe un reactor, su equipo auxiliar, acuerdos para el tratamiento del combustible gastado y garantía de abastecimiento de combustible nuevo.

Un ejemplo de tratado de cooperación es el proyecto DRAGON para el desarrollo de un reactor de alta temperatura, refrigerado por gas. Una característica única del proyecto DRAGON es el gran número de países que participan. Otro ejemplo es el tratado bilateral entre los Estados Unidos y Canadá, por el cual el Canadá va a la cabeza en el desarrollo de reactores de agua pesada con la cooperación plena de los Estados Unidos.

Más inmediatamente encaminado a la construcción de plantas nucleares, el grupo Euratom se formó en 1957, y el año siguiente se firmó un tratado de cooperación con los Estados Unidos. El cambio en los planes del Euratom, desde su formación, es un ejemplo de la transformación del optimismo exagerado de la mitad del decenio de 1950-1960 a la posición más realista de hoy en día.

El Japón está construyendo una serie de reactores de diferentes tipos y tamaños bajo diferentes tratados con varios países.

Los Estados Unidos tienen acuerdos con más de treinta países que cubren más de sesenta reactores o plantas críticas que han sido suministrados totalmente o en parte por los Estados Unidos y que están sujetos a garantías frente a su utilización para fines militares. Puesto que la mayoría de estos reactores o plantas críticas son pequeños, esta garantía no es importante en la práctica, pero es extremadamente importante en principio.

En conexión con los acuerdos mencionados hay muchos problemas relacionados con la salud y seguridad, seguro contra accidentes, manejo de residuos, etc. Un problema importante es la vigilancia para que estas instalaciones no se usen con fines militares. Muchos de estos problemas conciernen a la comunidad total de las naciones, no solamente al país donde el reactor está instalado.

Por esta razón, la cooperación en el control internacional es esencial para un desenvolvimiento seguro de las plantas nucleares. Tal control puede y debe ser ejercido por medio de un vigoroso apoyo al Organismo Internacional de Energía Atómica.

Международное сотрудничество в области атомной энергии

И. Д. Морохов, В. С. Кандарицкий, Ю. В. Архангельский*

Время, прошедшее между Второй и Третьей международными конференциями по мирному использованию атомной энергии, характеризуется значительным прогрессом в применении энергии атома для блага человека. Достижения бурно развивающейся атомной науки и техники, все большее овладение атомной энергией и внедрение ее почти во все отрасли науки и экономики развитых стран сделали возможным практическое использование ее и в странах, которые сравнительно недавно вступили на путь научного и экономического развития. С расширением применения атомной энергии укрепилось и расширилось международное сотрудничество в этой важной области.

За истекшие после Второй Женевской конференции 6 лет в нашей стране неуклонно прилагались большие усилия к тому, чтобы всемерно развивать международное сотрудничество и налаживать контакты ученых в деле мирного использования ядерной энергии.

ОБМЕН ВЗАИМНЫМИ ВИЗИТАМИ

В научно-исследовательских институтах СССР, занимающихся важными проблемами ядерной физики и атомной техники, за последнее время побывали руководители атомной промышленности и выдающиеся ученые ряда стран. В соответствии с заключенными соглашениями были проведены взаимные визиты научных делегаций СССР, социалистических стран, США, Англии, Италии, Франции и Дании.

Тесные контакты осуществлялись с учеными социалистических стран. Советские научные и исследовательские организации, где действуют атомные реакторы, ускорители и другие ядерные установки, посетили видные руководители, ученые и инженеры из ЧССР, РНР, ВНР, ГДР, ПНР, НРБ и других стран. Эти визиты послужили дальнейшему укреплению и расширению научных связей советских ученых с учеными данных стран.

Гостями Советского Союза были: верховный комиссар по атомной энергии Франции с группой специалистов; председатель Управления по атомной энергии Великобритании; председатель Комиссии по атомной энергии США с группой ученых в 1959 и 1963 гг.; делегация Комиссии по атомной энергии Канады; председатель Комиссии по атомной энергии Финляндии; председатель Комиссии по атомной энергии Дании; председатель Комиссии по атомной энергии Афганистана; заместитель председателя Комиссии по атомной энергии Республики Гана с группой ученых и другие официальные лица.

В 1959 г. группа советских ученых, возглавляемая председателем Государственного комитета по использованию атомной энергии СССР, посетила Соединенные Штаты Америки и Францию. В 1960 г. советская делегация ученых посетила Англию. В 1962 г. с ответным визитом в Швецию и Норвегию выезжала делегация во главе с первым заместителем председателя Государственного комитета по использованию атомной энергии СССР, а в 1963 г.— в Канаду. В 1962 г. для обсуждения вопросов по физике реакторов и реакторам на быстрых нейтронах в Англию выезжала делегация, возглавляемая заместителем председателя Госкомитета.

В 1963 г. делегации советских ученых-атомников во главе с председателем Государственного комитета по использованию атомной энергии СССР посетили Соединенные Штаты и Польскую Народную Республику.

Советский Союз обменивался также научными работниками с длительным пребыванием их (до одного года) в научных учреждениях ряда стран.

ОБМЕН НАУЧНО-ТЕХНИЧЕСКОЙ ИНФОРМАЦИЕЙ

Советский Союз, придавая большое значение расширению научных контактов и распространению научно-технической информации, публикует ежегодно до 4000 статей по атомной тематике как в общетехнических, так и в специальных журналах. В СССР существует специальное издательство по атомной тематике — Атомиздат, поддерживающее широкий международный книгообмен.

Общеизвестна инициатива Советского Союза по рассекречиванию термоядерных исследо-

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* Государственный комитет по использованию атомной энергии СССР, Москва.

ваний. Ограничения на открытую публикацию этих работ были сняты во всем мире впервые после подробного доклада академика И. В. Курчатова о советских работах своим английским коллегам в Харуэлле в 1956 г. Ко Второй международной конференции в Женеве в 1958 г. кроме докладов о термоядерных исследованиях, выполненных в СССР, был подготовлен четырехтомник работ по этой тематике. Труды Женевских конференций, являющихся крупным вкладом в развитие международного сотрудничества, регулярно издаются в Советском Союзе и пользуются заслуженным успехом.

Наряду с личными контактами Советский Союз проводит широкий обмен научной информацией с социалистическими странами. По двусторонним соглашениям организован также обмен научной и технической информацией с США, Великобританией и другими государствами.

Советские ученые и специалисты за прошедший период принимали самое деятельное участие в международных и национальных конференциях, симпозиумах и совещаниях, выступали на них с научными докладами и лекциями, участвовали в различных дискуссиях, расширяя и укрепляя тем самым научные связи и международное сотрудничество с учеными различных стран мира.

Для популяризации идей применения энергии атома в мирных целях Государственный комитет по использованию атомной энергии СССР проводит огромную работу по показу научно-технических выставок, иллюстрирующих ту пользу, которую может получить человечество от ядерной энергии. Эти выставки демонстрировались многократно как в СССР, так и в 39 странах Европы, Азии, Африки, Латинской Америки, а также в США. Советские выставки посетило более 22 миллионов человек.

ДВУСТОРОННИЕ МЕЖПРАВИТЕЛЬСТВЕННЫЕ СОГЛАШЕНИЯ

Начиная с 1955 г. СССР оказывает научную и материально-техническую помощь по мирному использованию атомной энергии другим государствам как проведением исследований, так и путем поставки оборудования и технической документации. За это время Советский Союз заключил 30 двусторонних межправительственных соглашений и протоколов с 15 странами: Народной Республикой Болгарией, Венгерской Народной Республикой, Польской Народной Республикой, Германской Демократической Республикой, Румынской Народной Республикой, Чехословацкой Социалистической Республикой, Китайской Народной Республикой, Корейской Народно-Демократической Республикой, Социалистической Федеративной Республикой Югославией, Объединенной Арабской Республикой, Республикой Ирак, Республикой Индонезия, Республикой Гана, Республикой Индия и Афганистаном.

Указанные соглашения предусматривают следующие обязательства со стороны СССР:

оказание технической помощи в сооружении исследовательских атомных реакторов, ускорителей, радиохимических, изотопных и физических лабораторий, на базе которых создаются национальные научно-исследовательские атомные центры;

подготовку национальных кадров по вопросам эксплуатации атомных установок и проведения на них экспериментальных работ;

оказание технической помощи в строительстве атомных исследовательских, экспериментальных и энергетических реакторов;

совместную разработку отдельных научных проблем, приборов, оборудования и защитной техники;

совместное рассмотрение и обсуждение планов научных и исследовательских работ по использованию атомной энергии в мирных целях;

обмен опытом по производству радиоактивных изотопов и излучателей и методам их применения.

Советские научные, конструкторские и проектные организации разработали и спроектировали для создаваемых в других странах с помощью СССР научно-исследовательских центров пять типов исследовательских атомных реакторов — тяжеловодный (ТВР), водо-водяной (ВВР), реактор погружного типа (ИРТ), учебно-исследовательский реактор на 50 и 100 *квт*; ускоритель элементарных частиц на 25 *Мэв* с физической лабораторией; электростатический генератор; радиохимическую (изотопную) лабораторию; подкритическую сборку для учебных целей; бетатрон на 30 *Мэв*; мощную кобальтовую установку.

Из Советского Союза в указанные страны для сооружения атомных установок поставлено большое количество сложного уникального оборудования, приборов и специальных материалов. Особенностью этих поставок является то, что Советский Союз осуществляет их на основе обычных сделок купли-продажи без предъявления каких-либо политических, экономических и иных условий. Это в полной мере относится и к поставкам для проведения научно-исследовательских работ расщепляющихся материалов, а также комплектов тепловыделяющих элементов для атомных исследовательских реакторов.

Для оказания помощи в строительстве, монтаже, наладке и пуске в эксплуатацию поставленного оборудования было командировано в указанные выше страны свыше 700 высококвалифицированных советских специалистов.

С 1957 г. с помощью Советского Союза сооружены и пущены в эксплуатацию 9 атомных реакторов, 6 циклотронов, 7 радиохимических и физических лабораторий, один электростатический генератор и подкритическая сборка, на базе которых в Румынии, Чехословакии, Польше, Венгрии, Болгарии, ГДР, КНР, Югославии и ОАР созданы национальные научно-исследовательские атомные центры.

Создаются также атомные центры в КНДР, Ираке, Индонезии, Гане, где будут сооружены 13 атомных установок, в том числе: реакторы, радиохимические и физические лаборатории, ускорители, мощная кобальтовая установка, подкритическая сборка и различные вспомогательные сооружения. Этим странам переданы разработанные советскими проектными организациями комплексные рабочие проекты, на основе которых в этих странах проводится строительство научно-исследовательских атомных центров. Графиками строительства предусмотрены следующие сроки пуска исследовательских реакторов: в Ираке, в КНДР и в Гане — в 1965 г., в Индонезии — в 1966 г. и ввода в эксплуатацию радиохимических изотопных лабораторий: в Ираке и КНДР — в 1965 г., в Гане — в 1966 г.

По проектам, представленным СССР, осуществляется также строительство вспомогательных зданий и сооружений в этих центрах, в том числе: станций захоронения и дезактивации радиоактивных отходов, специальных прачечных, санитарных пропускников.

В сентябре 1963 г. между СССР и Афганистаном было подписано соглашение о сотрудничестве, которым предусмотрено оказание технического содействия в строительстве подкритической сборки, в организации физической лаборатории, а также в подготовке афганских специалистов для работы в области использования атомной энергии в мирных целях. Сооружение подкритической сборки начнется в 1964 г. и будет закончено в первом полугодии 1965 г.

За последние годы с рядом стран подписаны новые соглашения, которые предусматривают не только оказание технической помощи в проектировании и строительстве атомных установок и объектов, но и главным образом сотрудничество путем совместного решения широкого круга научных проблем в области применения и использования атомной энергии в мирных целях. Такие соглашения заключены с Венгерской Народной Республикой, Чехословацкой Социалистической Республикой, Социалистической Федеративной Республикой Югославией, Румынской Народной Республикой, Германской Демократической Республикой и Польской Народной Республикой.

В соответствии с новыми соглашениями сотрудничество с социалистическими странами осуществляется путем проведения совместных научных исследований, подготовки национальных кадров по согласованным планам и программам командирования советских специалистов в эти страны для проведения консультаций, совместной работы по отдельным научным проблемам и по разработке экспериментальных установок, проведения консультаций специалистам указанных стран в Советском Союзе, передачи советской технической документации, поставок оборудования и экспертизы проектов.

Советские ученые и ученые социалистических стран обмениваются опытом эксплуатации исследовательских реакторов, результатами выполненных на этих установках работ на совместных рабочих совещаниях и конференциях, рассматривают и координируют планы научных работ и обсуждают актуальные научные проблемы.

Советские ученые и специалисты принимали участие в обсуждении перспективных планов развития атомной науки и техники в ГДР, ЧССР, ПНР, ВНР, РНР. Они рассматривали и давали консультации по проектам строительства в этих странах новых атомных реакторов и подкритических сборок.

Например, при консультации советских ученых и специалистов польские ученые и специалисты занимаются подготовкой к реконструкции действующего реактора типа ВВР-С, которую намечено провести в два этапа. На первом этапе, осуществляемом совместно со специалистами ЧССР, предусмотрено повышение мощности реактора до 4000—4500 *квт* путем увеличения скорости теплоносителя в активной зоне, как было сделано при реконструкции советского реактора ВВР-2. Этот этап должен быть закончен в 1964 г.

Второй этап реконструкции намечено выполнить на основе разработок специалистов ЧССР. Предусматривается полная переделка активной зоны реактора и переход на новые трубчатые твэлы типа твэлов советского реактора ВВР-М с 36%-ным обогащением ураном-235. При осуществлении этого этапа, запланированного на 1966 г., мощность реактора будет доведена до 10 000 *квт*, что обеспечит значительное повышение плотности нейтронного потока. Естественно, что второй этап реконструкции ВВР-С потребует существенных дополнений и изменений технологического оборудования. Новые твэлы будут поставлены Советским Союзом.

В соответствии с пожеланием Комиссии по атомной энергии ОАР в Каирском центре по атомной энергии в течение ряда лет арабскими и советскими учеными проводятся совместные научно-исследовательские работы на атомном реакторе и на других установках этого центра. По некоторым проведенным совместно советскими и арабскими специалистами научным работам были сделаны публикации в арабской и советской печати и печати других стран.

В Каирском центре по атомной энергии сложился хороший коллектив научных сотрудников, состоящий главным образом из молодых физиков. Советские ученые прочитали здесь более 300 лекций по различным проблемам физики. Систематически проводится практикум по радиоэлектронике и по радиохимии изотопов.

Для материально-технического обеспечения научных и экспериментальных работ в ОАР из Советского Союза поставлено значительное количество оборудования, аппаратуры, специальных и расщепляющихся материалов.

МЕЖДУНАРОДНОЕ СОТРУДНИЧЕСТВО В ОИЯИ

Ярким примером научного сотрудничества между социалистическими странами является учреждение международной организации — Объединенного института ядерных исследований в Дубне. Советское правительство еще в 1956 г. передало в дар этому исследовательскому центру два уникальных ускорителя: синхроциклотрон на 680 *Мэв* и синхрофазотрон на 10 *Гэв*. С того времени дружный международный коллектив ОИЯИ построил новые ядерные установки: импульсный реактор на быстрых нейтронах, циклотрон многозарядных ионов. Созданы новые лаборатории, построены механические мастерские и другие сооружения. В настоящее время в этом институте кроме советских ученых работает несколько сот ученых, приехавших в Дубну из других стран — членов ОИЯИ. Публикуемые ОИЯИ работы рассылаются во все крупные научные центры Европы, Азии, Африки, США, Латинской Америки.

В странах — участницах ОИЯИ проводятся актуальные научные работы на исследовательских реакторах. В связи с этим поставлен вопрос о планировании работ, рациональном выборе направлений исследований, координации совместных научных работ. Дальнейшим расширением научного сотрудничества между странами — участницами ОИЯИ явилось создание секции по ядерной физике низких энергий при Ученом совете института. Задачами секции являются выработка научных рекомендаций по отдельным вопросам ядерной физики низких энергий, рассмотрение планов работы и отчетов о совместных исследованиях, обмен информацией о научных и методических разработках путем проведения конференций, рабочих совещаний и т. п.

По физике и технике исследовательских реакторов было проведено несколько конференций и совещаний.

В 1960 г. в Центральном институте ядерной физики в Дрездене (ГДР) состоялась конференция по вопросам эксплуатации и использования исследовательских реакторов. На конференции присутствовало около 150 ученых и инженеров из девяти стран. Работа проходила в нескольких секциях, где рассматривался опыт, накопленный странами-участницами по эксплуатации исследовательских реакторов, расширению их экспериментальных возможностей и использованию для проведения научных работ. Секции ядерной физики и физики твердого тела обсуждали результаты первых научных исследований, выполненных на этих реакторах. Конференция выдвинула ряд научных и технических проблем, которые нужно решить в ближайшее время, причем некоторым странам, исходя из имеющегося у них опыта и сложившейся специализации, было предложено взять на себя решение отдельных вопросов.

В ноябре 1961 г. в Бухаресте (РНР) состоялось совещание по физике и технике исследовательских реакторов. В нем участвовало 80 специалистов из девяти стран. Было представлено 68 докладов по следующим основным вопросам.

1. Опыт эксплуатации исследовательских реакторов, использование и расширение их экспериментальных возможностей.

2. Теоретическая и экспериментальная физика и техника реакторов:

а) термализация нейтронов;

б) развитие и применение метода реакторного осциллятора для измерений эффективных сечений захвата нейтронов различными веществами и изучения кинетических параметров реакторов;

в) применение пульсирующих нейтронных источников для изучения физических параметров замедлителей;

г) применение анализа флуктуации нейтронного потока для изучения динамических характеристик решеток;

д) изучение поведения реакторов в переходных режимах;

е) изучение пространственного распределения спектра нейтронов и гамма-излучения.

3. Расчеты, создание и применение подкритических и критических сборок и реакторов нулевой мощности.

4. Теоретические и экспериментальные вопросы, связанные с методикой измерений нейтронных потоков и гамма-полей.

Обсуждение докладов проводилось на пленарных заседаниях и в отдельных секциях и группах.

На совещании были приняты рекомендации по усовершенствованию активной зоны реакторов и экспериментальных каналов; по разработке вспомогательных устройств с целью расширить экспериментальные возможности для проведения научных и прикладных работ; по постройке и применению критических сборок в целях разгрузки реакторов от работ, требующих малых мощностей; по повышению мощности реакторов ВВР-С и по направлениям работ на исследовательских реакторах.

Следующая конференция по физике и технике реакторов состоялась в апреле 1963 г. в Праге (ЧССР). В ней приняли участие 89 специалистов из девяти стран. Работа проводилась в двух секциях: технической и физической. Были рассмотрены следующие вопросы.

В технической секции:

а) опыт эксплуатации исследовательских реакторов;

б) усовершенствование технологических схем, систем управления и контроля реакторов;

в) реакторные петли;

г) конструкции и системы управления критических сборок;

д) техника радиационной безопасности.

В физической секции:

а) теория реакторов;

б) критические эксперименты;

в) повышение мощности действующих исследовательских реакторов;

г) реакторные осцилляторы, измерение констант и нейтронных потоков;

д) физические эксперименты на нейтронных пучках;

е) нейтронные спектры.

На конференции было рассмотрено 115 докладов, из них на пленарных заседаниях было заслушано 6 докладов, в которых излагались вопросы повышения мощности реакторов ВВР-С и ИРТ, опыта эксплуатации ВВР-М, исследования характеристик импульсного реактора ИБР на быстрых нейтронах.

Большое количество докладов было посвящено созданию критических сборок, а также некоторым результатам экспериментов на них; вопросам регулирования и защиты реакторов, теории реакторов. Несколько докладов касались действующих петлевых установок на исследовательских реакторах.

Конференция разработала рекомендации по сотрудничеству в области реакторной техники.

На конференциях и рабочих совещаниях обсуждаются не только результаты уже выполненных работ, но и рассматриваются планы на будущее, в том числе планы совместных исследований, вопросы кооперации по проектированию и изготовлению уникальной аппаратуры.

В настоящее время созданные с помощью Советского Союза центры реакторных исследований в социалистических странах стали полноценными научными организациями, вносящими значительный вклад в мировую науку и обеспечивающими запросы народного хозяйства своих государств.

МЕЖДУНАРОДНОЕ СОТРУДНИЧЕСТВО ПО ЯДЕРНОЙ ЭНЕРГЕТИКЕ

Технико-экономические вопросы атомной энергетики имеют большое значение для всех стран социалистического содружества, поэтому перспективам развития этого вида энергетики уделяется большое внимание. На специальном совещании ученых и специалистов социалистических стран были рассмотрены и обсуждены некоторые вопросы, связанные с развитием ядерной энергетики.

Атомная энергетика требует тщательного, научно обоснованного перспективного планирования. Развитие ее должно увязываться с развитием научно-технической базы, созданием специализированных проектно-конструкторских организаций, привлечением машиностроительных заводов к изготовлению оборудования, решением вопросов переработки ядерного топлива и с решением такой важнейшей проблемы, как удаление радиоактивных отходов.

Достаточно точные сравнительные технико-экономические показатели атомных электростанций можно получить только на основе широкого опыта их промышленного применения. Реальный путь решения этой проблемы состоит в разработке, строительстве и всестороннем анализе работы опытно-промышленных атомных электростанций различных типов.

Плановый характер социалистической экономики позволяет проводить анализ не изолированно, а в комплексе, с учетом возможных и необходимых темпов развития энергетики и всех необходимых для обеспечения развития производств, включая предприятия топливного цикла и заводы по производству реакторного оборудования.

Только на основе такого анализа можно оценить стоимость установленного киловатта мощности АЭС и стоимость киловатт-часа электрической энергии, выбрать техническое направление и темп роста мощностей атомных электростанций, а также провести общий технико-экономический анализ отраслей хозяйства, связанных с развитием ядерной энергетики.

Советский Союз оказывает техническую помощь Чехословацкой Социалистической Республике и Германской Демократической Республике в строительстве атомных электростанций мощностью: в ЧССР — 150 тыс. *квт* с реактором корпусного типа на природном уране, тяжелой воде и с газовым теплоносителем, в ГДР — 70 тыс. *квт* с реактором на обогащенном уране и с обычной водой в качестве замедлителя и теплоносителя.

Советские, чехословацкие и немецкие специалисты совместно решают сложные технические вопросы, связанные с проектированием, строительством и изготовлением оборудования для атомных электростанций. Совместно проводится широкий круг экспериментальных и научных исследований, решаются инженерно-технические вопросы, связанные со строительством атомных электростанций.

Строительство атомных электростанций в СССР, ЧССР и ГДР даст возможность после накопления достаточного опыта их эксплуатации выбрать наиболее технически совершенные и экономически выгодные типы реакторов, которые были бы наиболее надежными и конкурентоспособными в сравнении с другими типами энергетических установок.

СОТРУДНИЧЕСТВО ПО ПОДГОТОВКЕ КАДРОВ

Большую помощь СССР оказывает в подготовке национальных кадров. На 1 января 1964 г. в Советском Союзе подготовлено 1680 иностранных специалистов, в том числе:

эксплуатационного персонала для реакторов и циклотронов, а также физиков-исследователей и радиохимиков	930
специалистов по применению радиоактивных изотопов и излучений:	
в промышленности	370
в медицине, биологии и сельском хозяйстве	380

Подготовка специалистов проводится по специально разработанной программе, изданной на русском и английском языках.

МЕЖДУНАРОДНОЕ СОТРУДНИЧЕСТВО В МАГАТЭ

Советский Союз принимает активное участие в работе Международного агентства по атомной энергии, в проводящихся этой организацией конференциях, симпозиумах, семинарах и совещаниях по различным проблемам атомной науки и техники и аспектам их развития.

Так, в 1960 г. советские ученые и специалисты приняли участие в конференции по малым и средним энергетическим реакторам и в симпозиуме по исследованиям в области физики при помощи нейтронов, получаемых в реакторах.

Советские эксперты работали на совещании по выработке наставления по безопасной эксплуатации критических сборок и исследовательских реакторов, закончившемся принятием руководства по эксплуатации таких установок, а также на совещании по ответственности за использование атомных судов, положившем начало выработке соответствующей конвенции.

В 1961 г. советские представители участвовали в симпозиумах по разработке программ использования исследовательских реакторов и по опытным энергетическим реакторам, а также в семинаре по физике реакторов на быстрых и промежуточных нейтронах. По этим вопросам было представлено 19 советских докладов.

Делегация Советского Союза приняла активное участие и выступила с двумя докладами на симпозиуме по безопасности реакторов и методам оценки опасности, состоявшемся в 1962 г. в Вене. В том же году на совещании по проекту долгосрочного плана работ по атомной энергетике советский эксперт внес ряд предложений, способствовавших составлению конкретного плана МАГАТЭ в этой области.

В 1963 г. представители СССР приняли участие во всех мероприятиях Агентства, имевших целью обсуждение вопросов разработки и эксплуатации реакторов. Ученые и специалисты представляли Советский Союз на конференциях по опыту эксплуатации энергетических реакторов и по технологии новых ядерных материалов, включая неметаллические тепловыделяющие элементы, в симпозиумах по экспоненциальным и критическим экспериментам и по проблемам физики и выбора материалов для регулирующих стержней реакторов. На этих форумах они выступили с 20 докладами.

Советские эксперты обменивались мнениями и опытом с иностранными специалистами на совещаниях по тяжеловодным решеткам, по химическим исследованиям на исследовательских реакторах, по выработке гарантий для реакторов мощностью выше 100 *Мвт*, по экономическим проблемам включения атомных электростанций в энергетические системы и на семинаре для административного персонала в области атомной энергии.

СОТРУДНИЧЕСТВО И МИРНАЯ ПОЛИТИКА СССР

Советский Союз, верный ленинским принципам внешней политики — политики мира, дружбы и широкого сотрудничества со всеми странами, накопил большой опыт в области мирного использования атомной энергии во всех отраслях народного хозяйства, выступал и выступает за широкое развитие международного сотрудничества в этой области.

Осуществляя политику мира, Советское правительство, советский народ и народы социалистического содружества со всеми народами мира с большим удовлетворением и одобрением встретили подписание Московского договора о запрещении испытаний ядерного оружия в атмосфере, в космическом пространстве и под водой как первый шаг к успешному разрешению проблемы всеобщего и полного разоружения. Советские люди горды тем, что именно в Москве был подписан Договор, положивший начало концу радиоактивного заражения Земли.

Новым шагом в направлении разоружения является решение Советского правительства о сокращении производства расщепляющихся материалов для военных целей и направлении большего количества расщепляющихся материалов для использования в мирных целях — на атомных электростанциях, в промышленности, сельском хозяйстве, в медицине, в осуществлении крупных научно-технических проектов.

Великое завоевание человеческого разума — покорение атома — должно быть использовано на благо и только на благо людей; атомная энергия — могучее средство научно-технического прогресса человечества — должна использоваться только для мирных целей.

ABSTRACT - RÉSUMÉ - АННОТАЦИЯ - RESUMEN

A/295 USSR

International co-operation in the field of atomic energy

By I. D. Morokhov *et al.*

Widespread interest in the problems of the peaceful uses of atomic energy as a powerful means of scientific and technical progress is now evidenced in an ever-increasing number of countries. The achievements scored in recent years in this rapidly developing field of science and technology and the utilization of atomic power in almost all branches have enabled various practical applications of this power in countries with different levels of scientific and economic development and have promoted and expanded international co-operation.

Planning of research work in the field of nuclear physics, mastery of reactor engineering, training of personnel and of many young scientists with initiative is what is necessary to enable a number of new countries to place atomic science at the service of human progress.

The years which have passed since the Second United Nations International Conference on the Peaceful Uses of Atomic Energy have witnessed a marked expansion of international ties and scientific and technical co-operation between Soviet scientists and scientific establishments and the scientists and scientific establishments of various countries.

International scientific and technical co-operation of the USSR with other countries in the field of the peaceful uses of atomic energy extends virtually to all branches of science — from the building of atomic power plants and research reactors to the training of technical and scientific personnel, the exchange of scientific and technical information and the setting up of "Atoms for Peace" exhibitions.

The Soviet Union has concluded new agreements and expanded scientific and technical exchanges with twenty-two foreign countries.

The first agreements on the problems of the utilization of atomic power were concluded by the USSR with all socialist countries. These agreements provided for the rendering of assistance in setting up large research centres equipped with modern facilities including experimental reactors and modern physics and radiochemical laboratories and in training personnel for these countries in the USSR. The second stage of these agreements related to co-operation between the countries in the further development of joint scientific research in nuclear physics and radiochemistry, in the use of isotopes for national economy, in the field of atomic power generation and in the development of new reactors. What is new in these agreements is that they envisage not only the rendering of assistance but also the carrying out of joint research both on a bilateral basis and within the framework of the Council of Mutual Economic Assistance. In the new agreements, such as those signed with the Korean People's Democratic Republic, Ghana, Indonesia and Iraq, the USSR undertakes to build, in these countries, research reactors, physics and radiochemical laboratories, and to train national personnel to work in these centres.

The Joint Institute of Nuclear Research which was set up in the town of Dubna on the "open door" principle is functioning successfully, its international associations are widening and its equipment and facilities are growing. The Joint Institute of Nuclear Research widely practices joint studies with the scientists from other countries.

Soviet experts and scientists take an active part in international congresses, conferences and symposia, a number of such conferences and symposia being held in the Soviet Union.

Guided by Lenin's principles of foreign policy — the policy of peace, friendship and co-operation with all countries — and having accumulated vast experience in international co-operation in the field of the peaceful utilization of atomic energy, the Soviet Union calls for the further development of scientific and technical co-operation in this field. Following the policy of peace, the Soviet people and the peoples of the socialist countries warmly welcomed the signing of the Moscow Treaty, banning nuclear tests in the atmosphere, in cosmic space and under water, as the first step towards the successful solution of the problem of general and complete disarmament.

A/295 URSS

Collaboration internationale dans le domaine de l'énergie atomique

par I. D. Morokhov *et al.*

Un nombre croissant de pays manifestent un grand intérêt pour l'utilisation pacifique de l'énergie nucléaire, en tant que facteur puissant du progrès scientifique et technique. Les réalisations récentes de la science et de la technique, qui se sont développées prodigieusement, l'utilisation croissante de l'énergie atomique dans presque tous les domaines, qui a permis une série d'applications pratiques dans des pays plus ou moins développés du point de vue scientifique et économique, ont renforcé et développé la collaboration internationale.

La réalisation méthodique d'essais en matière de physique nucléaire, la mise au point de la technologie des réacteurs, la formation de spécialistes et l'apparition de toute une pléiade de jeunes savants pleins d'initiative permettront à une nouvelle série de pays de mettre la science nucléaire au service du progrès.

Depuis la deuxième Conférence internationale des Nations Unies sur l'utilisation de l'énergie atomique à des fins pacifiques, les relations internationales et la collaboration scienfique et technique entre savants et organismes scientifiques de l'URSS et savants et organismes scientifiques d'une série d'autres pays se sont considérablement accrues.

La collaboration scientifique et technique internationale dans l'utilisation pacifique de l'énergie atomique porte sur toutes les branches, depuis la création d'installations productrices d'énergie d'origine atomique et de réacteurs de recherche jusqu'à la formation de spécialistes et de cadres scientifiques, l'échange d'informations scientifiques et techniques, et l'organisation des expositions « Atome pour la paix ».

L'Union soviétique a conclu de nouveaux accords et a développé ses échanges dans le cadre de la collaboration scientifique et technique avec 22 pays.

Les premiers accords concernant l'utilisation de l'énergie atomique ont été conclus entre l'Union soviétique et tous les pays socialistes. Ils concernaient l'octroi d'une aide pour la création de grands centres scientifiques et techniques, équipés d'appareils modernes, y compris des réacteurs expérimentaux et des laboratoires de physique et de radiochimie modernes, ainsi que la formation de spécialistes en URSS. Le second stade de ces accords prévoit la collaboration des pays en vue du développement futur d'études scientifiques communes en physique nucléaire et radiochimie, sur l'utilisation d'isotopes dans l'économie nationale, dans l'énergétique atomique et pour la création de nouveaux réacteurs. La nouveauté de ces accords consiste non seulement en l'aide octroyée, mais aussi en la poursuite de travaux de recherche scientifique communs, sur le plan bilatéral et dans le cadre du Conseil d'aide économique mutuelle. Par exemple, les nouveaux accords avec la République populaire démocratique de Corée, le Ghana, l'Indonésie et l'Irak prévoient la construction dans ces pays, avec l'aide de l'Union soviétique, de réacteurs de recherche, de laboratoires de physique et de radiochimie, ainsi que la formation de cadres nationaux pour ces centres.

L'Institut unifié de recherches nucléaires, à Doubna, fondé sur le principe des « portes ouvertes », se développe avec succès et accroît son équipement technique. Il réalise avec des savants étrangers des recherches scientifiques communes à grande échelle.

Les spécialistes et savants soviétiques participent activement aux conférences internationales, aux congrès et symposiums, dont une série a également eu lieu en URSS.

L'Union soviétique, guidée par les principes léninistes en matière de politique extérieure — politique de paix, d'amitié et de coopération avec tous les pays —, acquiert beaucoup d'expérience en matière de coopération internationale pour l'utilisation pacifique de l'énergie atomique, et elle envisage d'augmenter encore la collaboration scientifique et technique dans ce domaine.

Dans le cadre de cette politique de paix, le peuple soviétique et les peuples des pays socialistes ont chaleureusement approuvé la signature du traité de Moscou sur l'interdiction des essais d'armes nucléaires dans l'atmosphère, dans l'espace et sous l'eau, en tant que premier pas vers la solution du problème du désarmement général et complet.

A/295 URSS

La colaboración internacional en el campo de la energía atómica

por I. D. Morokhov *et al.*

El gran interés hacia la utilización pacífica de la energía atómica como medio poderoso para el progreso científico-técnico se manifiesta cada vez en mayor número de países. Los adelantos de los últimos años en este campo de la ciencia y de la técnica, que está en rápido desarrollo, y la adaptación del empleo de la energía atómica a casi todas sus ramas, lo cual hace posible sus aplicaciones prácticas en países con diversos grados de desarrollo científico y económico, todavía han reforzado y ampliado más la colaboración internacional.

La realización planificada de las investigaciones en el campo de la física nuclear, la puesta a punto de la técnica de los reactores, la instrucción de especialistas y la preparación de toda una pléyade de científicos jóvenes de iniciativa, son las condiciones que permitirán a una serie de países poner la ciencia atómica al servicio del progreso.

En el tiempo que ha transcurrido desde la segunda Conferencia Internacional de las Naciones Unidas sobre la utilización de la energía atómica con fines pacíficos, se han ampliado significativamente los lazos y la colaboración científico-técnica de los hombres de ciencia soviéticos y los organismos científicos de la URSS con los hombres de ciencia y los organismos científicos de otros países del mundo.

La colaboración científico-técnica de la URSS con otros países para la utilización pacífica de la energía atómica abarca, en realidad, todas las ramas y direcciones posibles en este campo: desde la construcción de centrales nucleoeléctricas y reactores de investigación hasta la preparación de especialistas y cuadros de científicos, intercambio de información científico-técnica y organización de las exposiciones "Atomos para la paz".

La Unión Soviética tiene acuerdos y mantiene amplio intercambio en el campo de la colaboración científico-técnica con 22 países.

Los primeros acuerdos, relativos a la utilización de la energía atómica, fueron firmados por la Unión Soviética y todos los países socialistas. Estos acuerdos fueron los de ayuda para la creación de grandes centros de investigación científica equipados con medios modernos, entre ellos un reactor experimental y laboratorios físicos y radioquímicos modernos, y la preparación de especialistas, para ellos, en la URSS. La segunda etapa de estos acuerdos prevé la colaboración de los distintos países en el progresivo desarrollo de las investigaciones científicas conjuntas en el campo de la física nuclear y de la radioquímica, en la utilización de isótopos en la economía nacional y en el campo de la energía atómica, para la construcción de nuevos reactores. La novedad de estos acuerdos es que no sólo establecen la prestación de una ayuda, sino también la realización de trabajos comunes de investigación científica, tanto sobre una base bilateral como dentro del marco de Consejo de ayuda mutua económica. Por ejemplo, en los nuevos acuerdos con la República Popular Democrática de Corea, Ghana, Indonesia e Irak, se prevé la construcción, en estos países, con ayuda de la Unión Soviética, de reactores de investigación y laboratorios físicos y radioquímicos, y la preparación de cuadros nacionales de científicos para que trabajen en dichos centros.

Funciona con éxito y amplía sus lazos internacionales, el Instituto Internacional de Investigaciones Nucleares de Dubna, organizado de acuerdo con el principio de "puerta abierta", y que está fortaleciendo su base material y técnica. Son muchos los trabajos de investigación conjuntos de este Instituto con científicos de otros países.

Los especialistas y los científicos soviéticos toman parte activa en las conferencias, simposios y congresos internacionales. Muchas conferencias y simposios de esta clase se han celebrado en la URSS.

La Unión Soviética, que se rige por los principios de política exterior de Lenin: política de paz, de amistad y colaboración con todos los países, ha acumulado gran experiencia en la colaboración internacional en el campo de la utilización pacífica de la energía atómica, y emprende un mayor desarrollo de la colaboración científico-técnica en este campo. Poniendo en práctica una política de paz, el pueblo soviético y los pueblos de los países de la amistad socialista, con todos los países del mundo, firmaron con gran aceptación el pacto de Moscú para la supresión de los experimentos de armas nucleares en la atmósfera, en el espacio cósmico y bajo el agua, como un primer paso para el éxito subsiguiente de la resolución del problema del desarme total universal.

Investigations on site selection for the first UAR nuclear power station

By M. A. El-Guebeily, K. E. A. Effat, K. A. Mahmoud, M. F. El-Fouly, A. Ayoub, M. E. Aly and M. Obeid *

The UAR Electricity Authorities are undertaking a vast program of electrification of the country [1], which includes the installation of the High Aswan Dam Power Station (2 100 MW) and many conventional thermal stations. The total installed capacity will reach 4 000 MW in 1970 compared with 400 MW in 1952, corresponding to an increase in the total generated energy from 1 000 to 11 000 GWh with the generated energy *per capita* rising in the same period from 47 to 350 kWh. The detailed studies made in this connection indicate that these projects will satisfy the electrical energy requirements of the country until the year 1972, after which an average additional 150-200 MW(e) will be installed annually. In spite of the fact that nuclear power, in the present conditions of the UAR, is neither imposed by an economic urgency, nor expected to compete favourably at the anticipated sizes—up to 200 MW(e)—with conventional thermal power, the decision has been taken to install the first nuclear power station for integration into the general electric 220 kV grid system by 1969. The object of this project, in addition to the production of electricity, is to introduce nuclear power technology and experience, and to train personnel in the various disciplines required to face the needs of an expanding nuclear power program starting from 1972. For this project, various technical, economic and site investigations have been undertaken.

The present report deals only with the main problems involved in the selection of a suitable site and outlines the principal lines of investigations which were carried out for the comparative evaluation of the various possible sites. These problems arose from the facts that:

(*a*) Being the first project of its kind in the UAR, safety aspects had to be particularly emphasized; and that

(*b*) The reactor type not being defined the selected site should satisfy the main requirements for various types of power reactors.

ORGANIZATION

The site selection studies have passed through three main distinct stages—namely, the initial survey stage, the detailed technical investigation and evaluation stage, then the international consultation and final conclusion stage. These stages are diagrammatically represented in Fig. 1. During all these three stages the work has been organized by the Siting Committee composed of senior staff members of the UAR Atomic Energy Establishment.

The initial survey stage of the site studies was concluded by a recommendation that the three most promising sites for detailed investigations were the Burg El-Arab, Inshas and Wadi Hof areas. At a later stage, it was decided to add a further two sites, namely the Fayoum and El-Tahrir areas, as next in priority, in order to widen the scope of the detailed evaluation studies for the sake of completeness with respect to the first nuclear power station, and for the possible use of this data for future nuclear power projects.

In the detailed technical investigation and evaluation stage, the Committee organized various technical study groups composed of qualified experts from specialized national institutes and organizations to carry out the detailed studies concerning the above mentioned sites. Periodic meetings were organized between the Committee and these study groups to discuss the technical data required for comparative evaluation. This stage was concluded by the preparation of comparative evaluation reports on the five sites.

In the third stage of international consultations, the UAR Atomic Energy Establishment invited an IAEA panel of international experts to meet in Cairo in May 1963 for discussions and consultation on site selection. In addition, the consulting engineers, Kennedy and Donkin, were requested to prepare a detailed report on the siting of the nuclear power station. All technical reports of the study groups and the Committee have been presented to the IAEA panel and to the consulting engineers.

The final decision on the site shall be made on basis of the comparative evaluation reports of the Committee [2-4], the IAEA panel report [5] and the consulting engineers report [6].

Initial general survey

In order to simplify the studies on site selection and to restrict the detailed investigations to the

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* Atomic Energy Establishment, UAR.

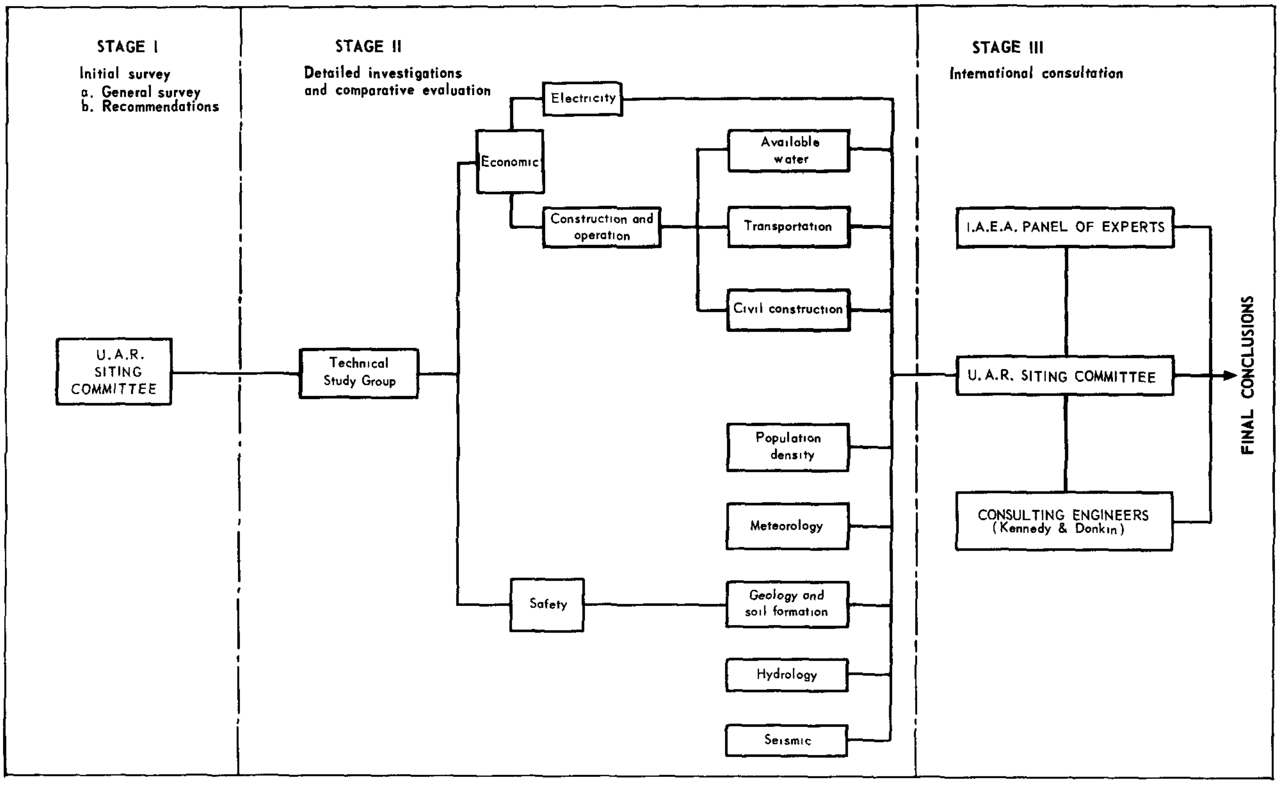

Figure 1. Organization chart for site studies

minimum number of best possible sites, studies were started by a preliminary general survey of the different possible sites in various regions of the UAR. This survey aimed at excluding areas and locations which appeared from the available general technical data to be either rejectionable or less favourable from the safety or economic viewpoint. Twelve different sites from different regions were examined; these were: Cairo, Alexandria, Damanhour, Talkha, El-Tahrir, Inshas, 40 km NE of Cairo, Ismailia, Port Said, Burg El-Arab, Wady Hof and Fayoum. Fig. 2 shows the geographical location of these sites.

This survey led to the conclusion that there was no area or site which could be considered as perfect from all aspects and had full priority over the others. Consequently, the main problem was to balance the various priorities and to ensure that the sites to be chosen for detailed investigation should not contradict any major aspect concerning the electrical, safety or constructional and operational requirements. In the light of these considerations and the available technical data, the following areas were excluded:

(*a*) Southern Egypt, to the Fayoum area, because of the cheap hydroelectric power which will be available from the High Aswan Dam Project;

(*b*) The Suez Canal area (Port Said and Ismailia) for reasons of navigation safety and because of the proximity of the National Oil Field which reduces transportation costs of fuel for conventional power station;

(*c*) Big cities (Cairo and Alexandria) because of the high population density and the high concentration of industrial, commercial and cultural centres;

(*d*) The Delta region (Talkha and Damanhour) to avoid possible risks to the population and agriculture, which are mainly concentrated in this region;

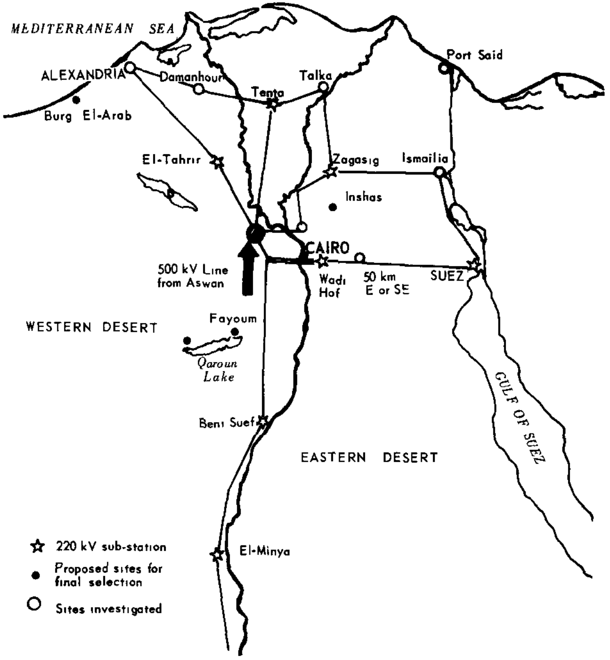

Figure 2. Possible site locations and the 220 kV grid in lower Egypt

(*e*) Some desert regions, which are favourable from the safety point of view (50 km SE of Cairo), but do not fulfil the main requirements such as the availability of the required amounts of water necessary for condenser cooling, make-up, etc.

The general survey concluded with the recommendation to concentrate further investigations on three areas to which the two areas next in priority were added at a later stage for the reasons indicated earlier. These five areas were:

(*a*) Inshas on the Ismailia Canal 40 km NE of Cairo;

(*b*) Burg El-Arab on the Mediterranean coast about 30 km W of Alexandria;

(*c*) Wady Hof on the River Nile about 20 km S of Cairo;

(*d*) Fayoum on Lake Quaroun about 80 km SW of Cairo;

(*e*) El-Tahrir on one of the canals near to and branching from the Rozetta branch of the River Nile about 60 km NW of Cairo.

TECHNICAL REPORTS AND CRITERIA FOR SITE EVALUATION

Certain general criteria have been adopted for site evaluation. These criteria were taken as the main guide for the detailed technical data required to be included in the technical reports prepared by the various study groups. These technical reports (about thirty) covered the main fields of: electric power generation, transmission and distribution in the UAR [1, 7], population density distribution [8, 9], meteorological information [10, 11], geology [12-17], soil formation [18], hydrology [19-24], hydrographic information [25-27], seismic considerations [28, 29], water requirements [30, 31], transportation requirements [32, 33], civil constructional considerations [34] and water temperatures [35].

The main criteria adopted for comparative evaluation are given in the following sections.

Electrical considerations

In this connection due consideration has been given to the short- and long-term policies of electric power development, to the future establishment of the general 220 kV electrical grid system, to the future generation of cheap hydroelectric power from the Aswan High Dam and to the distribution of load centres in the various areas. Furthermore, the cost incurred in connecting the nuclear power station to the 220 kV grid and in supplying the site with the required electric power for the construction and testing periods, as well as the transmission losses, have also been considered in the analysis.

Safety considerations

These include:

(a) *Population density.* The main criteria for population density studies were based on considerations of the distance of a given site from highly populated areas and of the population density distribution around each site, for which the site rating treatment of F. R. Farmer (*The Evaluation of Power Reactor Sites*) was taken as basis.

(b) *Meteorology.* The main criteria were based on the following concepts: (i) radioactive contamination of the atmosphere may arise from any of a wide variety of accidents or incidents starting from a small release up to a maximum credible accident and (ii) the fundamental basis of evaluation is the restriction of arrival of hazardous levels to any living environment. Therefore, the meteorological evaluation included analysis of wind speed and direction as well as the frequency of occurrence of miscellaneous weather phenomena such as mists, rainfall, calm, light variable winds, temperature inversions, sand storms, sand rising, gales and thunderstorms. Some of these phenomena favour the spread of any radioactive release to the atmosphere while others favour its localisation around the site.

(c) *Geology.* The criteria for the geological data include their implications in the following aspects: (i) safety aspects involving the decontamination by soils and clay minerals of radioactive waste and accidental releases, hydrology and seismic effects and (ii) civil considerations concerning the soil bearing capacity.

(d) *Hydrology.* The basic criterion in this connection is the role the hydrological conditions of every site would play in eliminating or minimising the spread of hazardous radioactive contamination to people directly or indirectly through water to the food chain or otherwise. Consequently, particular stress was given to the analytical evaluation of the following hydrological factors: (i) the present picture of the water table and the expected changes due to future projects; (ii) the direction of flow, the velocity of the ground water and the hydraulic properties of the ground water; (iii) types and varieties of materials crossed by the ground water in its flow and (iv) hydrographic parameters for coastal sites, particularly sea water currents and their directions and some related ecological problems such as fish migration, sponge beds, etc.

(e) *Seismic effects.* The UAR being generally a quiet country from the seismic point of view, the sites were evaluated in this respect with regard to their proximity to internal seismic sources and to the local microseismic effects which are important for civil constructions.

Constructional and operational requirements

These include:

(a) *Water requirements.* The criterion applied is the availability and the cost of providing the station with the required amounts of fresh or salty water for cooling the turbine condensers and fresh water for the make up of the reactor and the steam and accessory circuits, facilities, general utilities, etc.

(b) *Transportation requirements.* The adopted criterion is the comparative cost evaluation of transportation to different sites. In all modes of transportation special trailers, wagons or tugs have to be available. In addition, for railway and road transportation special measures regarding bridge reinforcement may be necessary in some cases. Extra measures may also need to be taken in the case of road transportation, to remove obstacles or to adapt certain parts of roads to suit the extra loads and dimensions. Harbour facilities of main ports such as stationary and floating cranes have also to be considered.

(c) *Civil construction considerations.* The criteria for evaluation, involve the cost incurred due to the following: (i) the availability of constructional materials such as cements, concrete aggregates, steel bars and bricks and (ii) the soil bearing capacity required for heavy structures.

(d) *The availability of skilled labour* in the area and the proximity to industrial and scientific centres which are important for the rapid realisation and low cost of the project.

COMPARATIVE EVALUATION

In the light of the above mentioned criteria, comparative evaluation of the five chosen sites has been carried out and is outlined below.

From the point of view of the electrical considerations, the four areas of Burg El-Arab, Inshas, El-Tahrir and Wady Hof are quite suitable, being near to important load centres, sufficiently far from the cheap hydroelectric power of the High Dam (see Fig. 2) and having low or acceptable costs for connection to the 220 kV grid and for supply with the required electric power during the construction and installation period. The Fayoum area, although not rejected yet, is the least favourable in this respect, since it offers smaller possibilities of local load development and because of the much higher expenses involved in transmitting the generated power to Cairo and in supplying the area with power in the construction and testing stage.

From the safety standpoint, Burg El-Arab stands out as the best area, having a Class 1 population density distribution and being characterised by favourable meteorological, hydrological, soil fixation properties and seismic conditions. The Fayoum site west of Lake Quaroun is comparable with Burg El-Arab, with the only drawback that the Fayoum area proved to be the epicentre for intermediately destructive earthquakes; however, they are quite rare and could be faced by the appropriate measures in construction and design. East of the lake, the conditions are similar with an added disadvantage in meteorological conditions, since about 70% of the prevailing winds are directed towards the Fayoum agricultural province. The Inshas area, although less favourable than Burg El-Arab, satisfies the safety requirements to a reasonable degree. It is characterised by Class 2 sites, and Class 1 sites could be found (see Fig. 3) but would involve additional costs. The meteorological, soil and seismic conditions are comparable with Burg El-Arab while the hydrological conditions are acceptable though less favourable. As to the Wady Hof and El-Tahrir areas, they present serious objections from the safety point of view. Although Class 2 sites could be found in these areas, the hydrological data present serious objections and make these two areas unacceptable, at least for the first nuclear power station. These data indicate that in the Wady Hof area, the ground water forms a continuous water body with the Nile water and it flows towards the Nile during eight months of the year (see Fig. 4). The presence of this area just south of Cairo (population of 3.5 million) and the Delta (80% of the cultivated land in the country) may represent a serious hazard in case of a major accident. Similarly in the El-Tahrir area, the ground water also forms a continuous body with the Nile and Delta ground water, appreciable amounts (35×10^6 m^3) flowing towards the Delta during four months, representing about one-tenth of the ground water used for irrigation in the central Delta. Furthermore, in the El-Tahrir area, about 33% of the prevailing winds are directed towards the Delta.

Concerning the constructional and operational requirements of the nuclear power station, they can be satisfied in the various areas at a variety of costs. Condenser cooling water is available from the Nile, Lake Quaroun or the Mediterranean with additional expenses for the intake system in some sites. The required amounts of fresh water for make up or other purposes are obtainable from the Nile and its main canals, with the necessity of long pipeline connections in certain cases. Transportation facilities are or could be made available in all cases for all kinds of equipment including those having the biggest weights or dimensions. Additional roads would be required which vary from one site to another. The bearing capacity of the soil varies from 2 kg/cm^2 in the sandy areas to 20 kg/cm^2 in the limestone areas and technical solutions for foundations could be found in all cases. Building materials could be supplied to all five areas. Similarly, qualified personnel and skilled labour could be made available for the project at all the sites. In general, the El-Tahrir area would be the least expensive in these respects and Fayoum West would be the most expensive, while the other sites would be intermediate in cost.

On the basis of the above considerations, although Wady Hof and El-Tahrir areas are quite attractive from the economic point of view, they have been rejected as sites for the first nuclear power stations

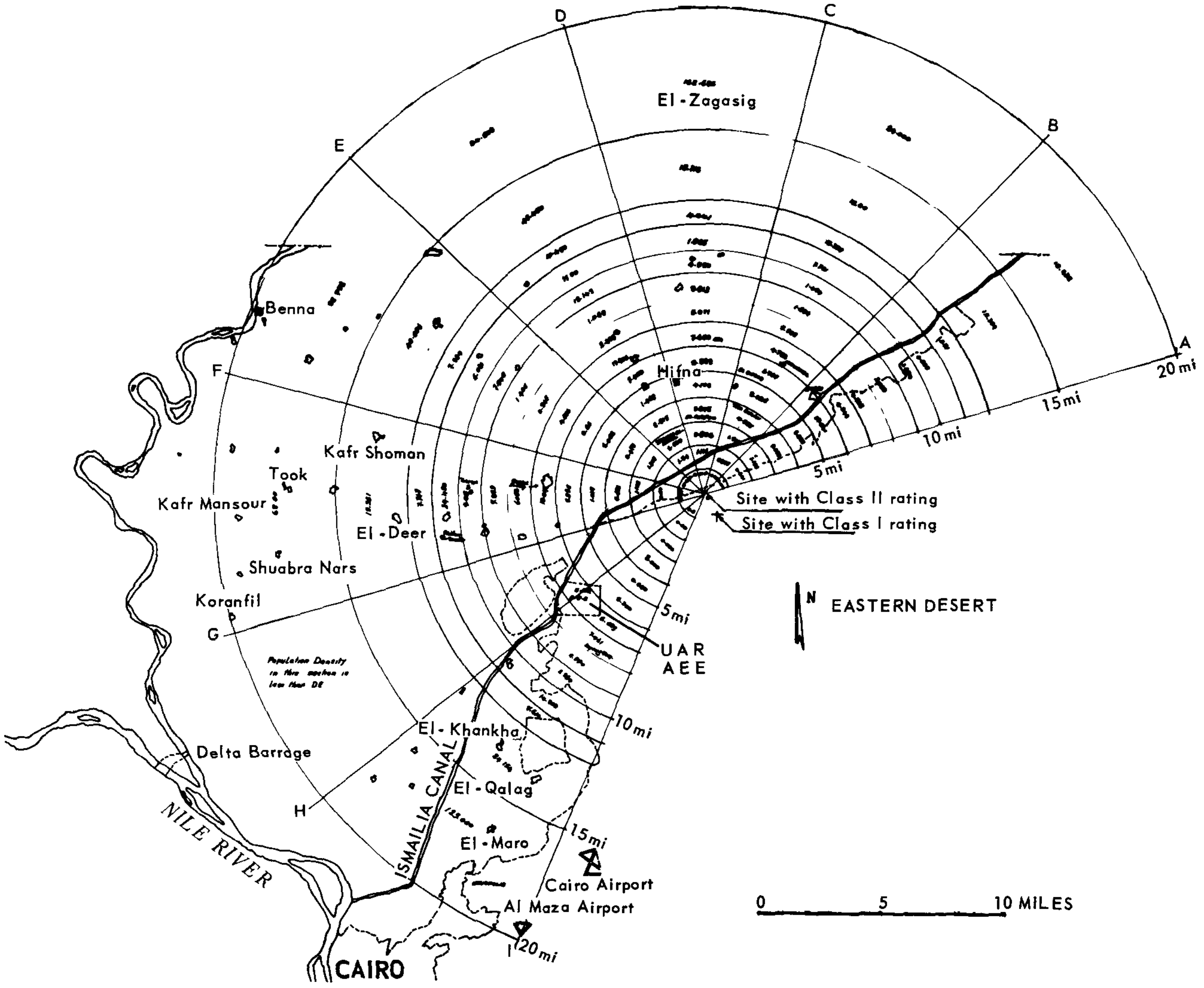

Figure 3. Population density around Inshas site

on safety grounds, due to the seriousness of the hydrological objections which are of special importance in a country like the UAR where agriculture represents an important factor in the national economy and is based on irrigation from the Nile and the ground water. Three areas have therefore been left for the final choice, namely, Burg El-Arab, Inshas and Fayoum.

Burg El-Arab is the safest site. It is economically suitable and would incur acceptable expenses. The installation of the first nuclear power station in this site would promote industrial and scientific developments in the Alexandria area.

Inshas is also an acceptable site from the safety standpoint. Economically, it is comparable with the Burg El-Arab site, involving expenses of the same order. The choice of this site would be favoured from the point of view of promoting nuclear power technology in the UAR, due to its proximity to the Atomic Energy Establishment and to the industrial and scientific centres at Cairo.

Fayoum is comparable with Burg El-Arab from the safety point of view, especially the western site. It is economically the least favourable of the three areas, the eastern site being in this respect more

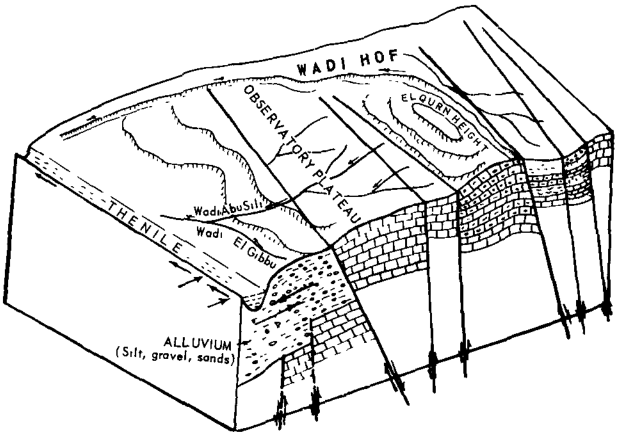

Figure 4. Block diagram showing drainage structure and water movements for the Wadi Hof area

advantageous than the western site. The choice of this area would support the general policy of decentralization and the creation of major industrial and cultural centres outside the Cairo and Alexandria areas.

At the time of writing this paper, the final selection of the site for the first UAR nuclear power station is under consideration, taking into account the balance of the relative merits and drawbacks of the proposed three areas.

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In fact, without the devoted efforts and the sincere contributions of all those mentioned in this acknowledgement and of many others, it would have been impossible to carry out this work.

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ABSTRACT - RÉSUMÉ - АННОТАЦИЯ - RESUMEN

A/840 République arabe unie

Etudes sur le choix du site pour la première centrale nucléaire de la RAU

par M. A. El-Guebeily *et al.*

Le mémoire expose les principaux problèmes rencontrés dans le choix d'un site convenable pour la première centrale nucléaire de la RAU ainsi que les principales études qui ont été entreprises en vue de l'évaluation comparative des différents sites. La puissance prévue pour la centrale est de 100 à 200 MW(e), et elle sera intégrée dans le réseau général à 220 kV.

Les problèmes essentiels du choix du site pour cette centrale résultent des faits suivants: i) s'agissant du premier projet de centrale nucléaire de la RAU, la sécurité doit recevoir une considération particulière; ii) le type du réacteur n'étant pas encore défini, le site à choisir doit satisfaire les besoins principaux de différents types de réacteurs.

Les études pour le choix du site ont été effectuées par le Comité du site de la RAU pendant les deux dernières années et les résultats de ces études ont été présentés, pour consultation, au groupe d'experts de l'AIEA réuni au Caire en mai 1963. En plus, d'autres études ont été faites sur le choix du site depuis mai 1963 par les ingénieurs conseils Kennedy et Donkin, nommés consultants pour ce projet.

Les études ont comporté initialement une revue générale, qui a conduit à exclure certaines régions pour des raisons évidentes de sécurité ou d'économie. Ces régions sont l'Egypte du Sud à cause du bon marché de l'énergie hydro-électrique fournie par le haut barrage d'Assouan, la zone du canal de Suez pour la sécurité de la navigation, les grandes villes pour la densité élevée de la population, la région du Delta pour la sécurité de la population et de l'agriculture et quelques régions désertiques pour le manque d'eau de refroidissement, etc.

Les études de site ont donc été concentrées sur les cinq régions suivantes:

i) Inshas, sur le canal d'Ismaïlia, à environ 40 km au nord-est du Caire;
ii) Burg El-Arab, sur la Méditerranée, à environ 30 km au sud-ouest d'Alexandrie;
iii) Wady Hof, sur le Nil, à environ 20 km au sud du Caire;
iv) Fayoum, sur le lac Quaroun, à environ 80 km au sud-ouest du Caire;
v) El-Tahrir, sur un canal se branchant sur le bras Rosette du Nil, à environ 60 km au nord-ouest du Caire.

Ces régions ont été soumises à une analyse et une évaluation détaillées du point de vue des aspects suivants:

i) Les facteurs relatifs à l'électricité, comprenant la demande d'électricité, la distance de la centrale hydro-électrique du haut barrage, le coût de connexion au réseau de 220 kV et le coût de fourniture d'énergie électrique nécessaire pour la construction.

ii) Les facteurs de sécurité, comprenant la densité de la population, la météorologie, l'hydrologie, les propriétés de fixation du sol et les phénomènes sismiques.

iii) Les besoins en matière de construction et d'exploitation, comprenant l'approvisionnement en eau, les facilités de transport, les considérations de génie civil et la disponibilité de personnel technique compétent.

Les différents facteurs mentionnés ci-dessus ont fait l'objet de rapports techniques détaillés présentés par des experts qualifiés représentant des instituts spécialisés du pays. Les données contenues dans ces rapports ont été utilisées comme base pour l'évaluation comparée des différents sites. A la lumière de ces évaluations, trois régions sont considérées comme convenables pour une centrale nucléaire: Burg El-Arab, Inshas et Fayoum. Cependant, certaines différences existent entre ces régions du point de vue des aspects sécurité et économie. Au moment de la rédaction du mémoire, le choix final du site est à l'examen, compte tenu des avantages et inconvénients relatifs des trois sites proposés.

A/840 OAP

Исследования по выбору площадки для строительства первой атомной электростанции Объединенной Арабской Республики

М. А. Эль-Гебейли *et al.*

В данном докладе рассматриваются основные проблемы, связанные с выбором подходящей площадки для строительства первой атомной электростанции Объединенной Арабской Республики, и дается обзор основных исследований, проведенных с целью осуществления сравнительной оценки различных площадок. Предполагается, что атомная станция будет иметь электрическую мощность от 100 до 200 *Мвт* и давать электроэнергию в общую энергосистему напряжением 220 *квт*.

Основные проблемы выбора площадки для данной атомной электростанции связаны со следующими факторами: а) поскольку для ОАР это первый проект подобного рода, то особое внимание должно быть уделено вопросам безопасности и б) поскольку тип реактора для электростанции пока еще не определен, выбранная площадка должна удовлетворять главным требованиям, предъявляемым к различным типам энергетических реакторов.

В течение последних двух лет Комитет по выбору строительных площадок ОАР проводил исследования по оценке площадок для первой атомной электростанции, и полученные результаты были представлены для рассмотрения экспертному комитету Международного агентства по атомной энергии, который заседал в Каире в мае 1963 года. Кроме того, фирмами «Консалтинг энджинирз Кеннеди» и «Донкин», назначенными в качестве консультантов проекта строительства атомной электростанции, с мая 1963 года проводятся дальнейшие исследования по выбору строительной площадки.

Первоначально работы по выбору строительных площадок включали проведение общего предварительного изучения, в результате которого ряд районов был исключен по экономическим соображениям или по причинам безопасности. К таким районам относятся: южная часть Египта ввиду наличия там дешевой гидроэлектроэнергии, обеспечиваемой проектом Высотной плотины; зона Суэцкого канала по причине обеспечения безопасности навигации; крупные города из-за высокой плотности населения, район дельты Нила по причине обеспечения безопасности для населения и развития сельского хозяйства, а также некоторые пустынные районы из-за недостатка воды для охлаждения.

Поэтому исследования строительных площадок были сконцентрированы на пяти районах:

1. Иншас, расположенный в районе Исмаильского канала, приблизительно в 40 *км* к северо-востоку от Каира;

2. Бург Эль-Араб, расположенный на берегу Средиземного моря, приблизительно в 30 *км* к западу от Александрии;

3. Вади Хоф на реке Нил, приблизительно в 20 *км* к югу от Каира;

4. Фаиум на озере Куарун, приблизительно в 80 *км* к юго-западу от Каира;

5. Эль-Тахрир, расположенный на одном из каналов, идущих от реки Розетты, являющейся рукавом Нила, находится приблизительно в 60 *км* к северо-западу от Каира.

Детальный анализ и оценка этих районов осуществлялись с точки зрения следующих аспектов:

1. Потребностей в электроэнергии, включая нагрузку, расстояние от источников электроэнергии Высотной плотины, стоимость подсоединения к общей системе энергоснабжения напряжением 220 *квт* и стоимость подачи электроэнергии в период строительства.

2. Требований обеспечения радиационной безопасности, включая плотность населения, метеорологические условия, вопросы гидрологии, фиксирующие свойства почвы и сейсмические характеристики.

3. Строительных и эксплуатационных требований, включая наличие водных ресурсов, средств транспорта, соображения гражданского строительства и наличие квалифицированной рабочей силы.

Различные факторы, входящие в вышеупомянутые аспекты, являются предметом обсуждения в детальных технических отчетах, представляемых квалифицированными экспертами специализированных институтов страны. Данные, содержащиеся в этих технических отчетах, легли в основу сравнительной оценки различных строительных площадок. В свете таких оценок три района были признаны пригодными для строительства атомной электростанции, а именно: Бург Эль-Араб, Иншас и Фаиум. Между этими районами существуют, конечно, некоторые различия с точки зрения безопасности и экономики. К моменту написания данного доклада вопрос об окончательном выборе строительной площадки для первой атомной электростанции ОАР находится в стадии рассмотрения с учетом относительных достоинств и недостатков трех предполагаемых районов строительства.

A/840 República Arabe Unida

Investigación sobre la selección del emplazamiento de la primera central nuclear de potencia de la RAU

por M. A. El-Guebeily *et al.*

Este informe trata de los problemas más importantes relativos a la selección de un emplazamiento apropiado para la primera central nuclear de potencia de la RAU, y esboza las principales investigaciones efectuadas para la evaluación comparativa de los diversos emplazamientos. La potencia prevista de la central es de 100 a 200 MW(e), y será integrada en la red eléctrica general de 220 kV.

Los principales problemas que aparecen en el emplazamiento de esta central son debidos a: i) ser el primer proyecto de esta clase en la RAU, donde las cuestiones de seguridad tienen que ser acentuadas de un modo particular, y a que ii) al no haber escogido aún el tipo de reactor, el emplazamiento elegido debe satisfacer los principales requisitos de los diversos tipos de reactores de potencia.

Los estudios para la evaluación del emplazamiento han sido llevados a cabo durante los dos últimos años por el Comité de Emplazamientos de la RAU, y los resultados de estos estudios han sido sometidos al informe de un grupo de expertos de la OIEA que se reunió en El Cairo en mayo de 1963. Además, la firma de ingenieros asesores Kennedy and Donkin, que fue nombrada asesora de este proyecto de energía nuclear, ha llevado a cabo desde mayo de 1963 estudios posteriores sobre la selección del emplazamiento.

Las investigaciones sobre el emplazamiento comprendían, al principio, un examen general preliminar que dio lugar a la exclusión de ciertas regiones, debidas a razones obvias de economía o seguridad. Estas eran: el Egipto Meridional, por la potencia hidroelétrica barata obtenida en la Presa de Asuán; la zona del Canal de Suez, por la seguridad de la navegación; las grandes ciudades, por su gran densidad de población, la región del Delta del Nilo, por la seguridad de la agricultura y de la población, algunas regiones desiertas, por falta de agua para refrigeración, etc.

Por lo tanto, los estudios de emplazamiento se han concentrado en cinco regiones, o sea:

i) Inshas en el Canal de Ismailía, a unos 40 km al NE de El Cairo;

ii) Burg El-Arab, en la costa mediterránea, a unos 30 km al O de Alejandría;

iii) Wady Hof, en el Río Nilo, a unos 20 km al S de El Cairo;

iv) Fayoum, en el lago Quaroon, a unos 80 km al SO de El Cairo;

v) El-Tahrir, en uno de los canales que parten del cercano Roseta, afluente del río Nilo, a unos 60 km al NO de El Cairo.

Se ha efectuado el análisis detallado y la evaluación de estas regiones desde los siguientes puntos de vista:

i) Las necesidades eléctricas, incluyendo los factores de carga, la distancia a la central eléctrica de la Presa de Asuán, el coste de la conexión a la red de 220 kV y el coste del suministro de energía eléctrica durante la construcción;

ii) Los requisitos de seguridad contra la radiación, incluyendo la densidad de población, la meteorología, la hidrografía, las características de estabilidad del suelo y los fenómenos sísmicos;

iii) Los requisitos de construcción y funcionamiento que incluyen la disponibilidad de agua, las facilidades de transporte, las consideraciones sobre la construcción de la infraestructura y la disponibilidad de personal competente y experto.

Los diversos factores incluidos en los aspectos mencionados arriba han sido objeto de informes técnicos detallados, efectuados por expertos competentes que representan institutos especializados del país. Los datos incluidos en estos informes técnicos han sido tomados como base para la evaluación comparativa de los diferentes emplazamientos. En vista de estas evaluaciones, se han considerado aptas para la construcción de una central nuclear, tres zonas, a saber: Burg El-Arab, Inshas y Fayoum. No obstante, entre ellas existen ciertas diferencias desde el punto de vista de seguridad y de economía. En el momento en que se escribe este trabajo aún está en estudio, teniendo en cuenta el balance de méritos y desventajas relativos de los tres lugares propuestos, la selección final del emplazamiento de la primera central nuclear de potencia de la RAU.

The NPY Project, a co-operative research programme in reactor physics between Norway, Poland, Yugoslavia and IAEA

By V. O. Eriksen,* N. Raišić,** F. Żelazny*** and B. Semenov****

An agreement has been signed by Norway, Poland, Yugoslavia and the International Atomic Energy Agency in Vienna on co-operation in the field of reactor physics. This project, the NPY Project, is just one of a large number of international co-operative efforts which are being undertaken in various branches of science and technology, but it deserves particular attention because of the special character of the co-operation and the catalyzing role played by the IAEA.

The present report describes the motivation for starting this project and outlines the objectives of the Co-operative Programme together with a short description of the organizational features of the Project and of the various tasks undertaken in implementing its aims.

GENERAL MOTIVATION FOR CO-OPERATIVE EFFORTS IN REACTOR PHYSICS

Reactor physics is a field which is well suited for international co-operation both because of its fundamental character and because it is less bound by commercial strings than other fields of nuclear technology. The mass of scientific information and its rate of development make it almost mandatory for physicists to get together to review the pace of progress, review the status of various branches of the field, try to avoid unnecessary duplication of efforts and recommend future actions.

The need for co-operative efforts among different regional groups of countries has already found practical ways of establishing various bodies for securing the necessary international exchange of information. Whatever the individual national motivation is, there are some aspects which are quite general and deserve closer attention.

Development of nuclear power reactors is a formidable task and very expensive. In fact, only a few of the larger countries can afford full coverage of all aspects of their nuclear development programmes through national efforts. The smaller countries should realize that the concentration of their nuclear development efforts on a limited number of key tasks is a prerequisite for the most efficient implementation of their nuclear power programme. Complementary fields must be deliberately left uncovered in their own development work and reliance placed upon access to the information obtained through contacts established with other countries.

Accepting this philosophy, it would then appear natural that groups of countries which could together cover essential parts of nuclear development work would find a Co-operative Programme on selected tasks to be of mutual benefit. Since one of the objectives of the IAEA is to encourage and promote such international co-operation, the NPY Project has been organized with the active participation of this organization.

MOTIVATION OF THE NPY PROJECT

The NPY Project between Norway, Poland and Yugoslavia is a relatively modest undertaking and its scope is limited to reactor physics. It establishes co-operation between three countries which have found that they have national programmes in reactor physics sufficiently overlapping and complementary to benefit from a co-operative effort.

It is therefore the primary motivation for the NPY Project to establish co-operative research in reactor physics on an advanced scientific level and of a scope which certainly would be beyond the possibilities of any of the individual countries. The Co-operative Programme is to be developed through a harmonization and co-ordination of the aims of those parts of the national programmes made available for the Project.

It is believed that the Co-operative Programme can contribute substantially both to the general progress of reactor physics and to the needs of the national power reactor development programmes.

Since the NPY Project hardly has any parallel elsewhere, it might in a way be considered an experiment of its own.

In addition to the main consideration for establishing the Co-operative Programme, there are a number of other reasons for co-operation.

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A practical motivation for the NPY Project has been that the parties will have access to a larger pool of special equipment than would be available to a country working independently. This includes large computing facilities and critical and subcritical assemblies. Efficient utilization of such equipment and a helpful service between laboratories concerned should effect a considerable saving in costs.

Exchange of personnel between laboratories will give staff members a greater stimulus and a wider background of experience than they would obtain by working in the comparative isolation of an independent laboratory.

Mutual criticism of each other's physics programmes could also give refreshing stimuli for the future work.

From the point of view of the Agency such a programme would allow more of the Agency's research activity to be based upon co-ordination of selected fractions of existing national programmes, rather than on research of its own. The NPY Project is one practical way of doing this.

THE CO-OPERATIVE PROGRAMME

The essence of the NPY Project is the establishment of a Co-operative Programme to be conducted in the various national laboratories. The main objectives of this Co-operative Programme are the development and testing of theoretical models and methods used in lattice calculations and in interpretation of experimental data. Further, the parties co-operate in the development of experimental techniques and test their applicability in various fields of reactor physics.

The actual work has been concentrated on a number of tasks. The choice of the tasks reflects the joint interests of the three parties and is an illustration of the fact that co-operation is directed to specific problems with well defined aims.

The first tasks of the Co-operative Programme agreed to are:

Task 1: Establishment of a consistent set of nuclear data

The purpose of Task 1 is to ensure that theoretical models and calculation techniques can be compared without the discrepancies caused by the use of different sets of nuclear data. A common set of nuclear data has therefore been prepared and accepted as a basis for comparative calculations.

Task 2: Calculation of thermal neutron distributions and reaction rates in lattice cells and comparison with experiments

The object of Task 2 is to review critically the present methods used for the calculation of thermal neutron distributions and reaction rates in lattice cells. The three laboratories presently use different methods and together they are able to present a choice of theoretical models, and the corresponding experimental programmes provide a wide variety of test cases for the theories. In another paper to this Conference a preliminary report of the work included under Task 2 is given [1].

A good comparison of the relative merits of the theories is obtained since each party is using its calculational models on each other's experiments.

Task 3: Resonance absorption effects

The object of this task is to study generally resonance absorption effects. Emphasis has been put on resonance absorption effects in closely packed water moderated lattices. Two different experimental techniques are being studied. A radiochemical separation technique has been developed in Norway and has been used extensively while the use of a reactor oscillator technique is under preparation in Poland and Yugoslavia. The results obtained using both techniques will be compared and evaluated.

Task 4: Buckling measurements and interpretations

The object of this task is to review methods being used for measurements of material bucklings, to investigate the validity of the concept of the buckling as such and to provide an experimental programme for testing of the theoretical models.

The NPY-Project has at its disposal four critical facilities, namely, NORA in Norway, ANNA and MARYLA in Poland and the RB reactor in Yugoslavia. An extensive series of critical experiments is being carried out with these reactors [2,3,4,5]. Development of experimental techniques like the substitution technique is being undertaken in Yugoslavia. A different kind of substitution technique is being applied in Norway. The results will be exchanged and jointly analyzed.

Task 5: Study of void-reactivity effects

The purpose of this task is to study methods for evaluation of void-reactivity coefficients for boiling water power reactors. This is a task where only one of the parties (Norway) is actively working. The other parties will be kept informed.

Task 6: Neutron thermalization and slowing down

This task is closely related to Task 2, but includes more fundamental studies of neutron space-energy spectra and development of experimental techniques for such investigations. First results related to this task are included in other papers presented to this Conference [1, 6].

Task 7: Pulsed neutron techniques and determination of microscopic lattice parameters

Task 7 involves a study on the determination of microscopic and diffusion parameters by means of pulsed neutron techniques (impulsator, fast chopper) and application of different theoretical models for their interpretation (eigenfunction expansion method).

Task 8: Reactor kinetics studies

Problems studied under Task 8 are related to the question of reactor stability. Emphasis is put on the interpretation of reactor noise experiments and on the study of spatial dependence of reactivity-power transfer functions.

Task 9: Development of a nuclear design code

The objective of Task 9 is to develop a nuclear design code to be used in optimization studies of nuclear power plants. It is too early to conclude to what extent development of such a design code can be subject to co-operative effort because of diversified individual national interests. Large proportions of such a design code are, however, of general applicability and could be dealt with under Task 9.

It is felt that a development job like Task 9 would be ideally suited as a framing task for the Co-operative Programme, since new tasks could be selected according to how they contribute, directly or indirectly, to the buildup of the design code.

IMPLEMENTATION OF THE CO-OPERATIVE PROGRAMME

Exchange of staff, services and equipment

The actual practical measure taken for the implementation of the Co-operative Programme includes exchange of staff for various specific tasks for shorter or longer periods. The purpose of such a visit could be to study a technique in which the visited establishment is active, or to carry out specific research for which the permanent facilities of the establishment visited are better suited to the task than those of the home institute. Carrying out calculations on computing facilities available at the establishment visited is an example of this. The laboratories will thus provide services for each other.

Special provisions are made in the Agreement for the exchange of personnel, materials, equipment and services. The IAEA makes a number of fellowships available for the Project.

Seminars on various task problems

The necessary contacts between the staff members of the co-operating institutions are established through the organization of seminars or panel meetings. One seminar on resonance absorption effects has been held in Belgrade with a lecturer from outside the three countries provided by the Agency, and one on reactor kinetics at Kjeller. Seminars on other subjects are planned.

The purpose of these seminars is to exchange experience and information, present the status in the field, plan further work and work out proposals for possible joint publications of the results.

International Advanced Summer School in Reactor Physics

An International Advanced Summer School in Reactor Physics will be organized this year (September 1964) in Zakopane, Poland, within the framework of the NPY Project and with IAEA as a co-sponsor. The course is open for participants outside the Project. The lectures will be kept on a high scientific level. Scientists from Sweden, USA, the United Kingdom and USSR have been invited to give lectures at the School.

ORGANIZATION OF THE NPY PROJECT

The Co-operative Programme is worked out and supervised by a Joint Committee consisting of one representative from each of the three countries and two members from the Agency. The Joint Committee meets at least twice a year. Each of the parties also appoints a Programme Supervisor, who is responsible for the implementation of the national contribution to the Co-operative Programme.

The Joint Committee shall provide the scientific guidance of the Co-operative Programme by establishing the research programme and assign portions of it to each of the parties within such budgetary limits as the Government concerned may establish.

As a rule, each of the parties cover their own expenditures on the Co-operative Programme and the Joint Committee can only *recommend* actions to be taken by the parties.

CONCLUSION

There has already been close contact between the nuclear laboratories of Norway, Poland and Yugoslavia for a number of years. The NPY Project implies an extension and accentuation of this cooperation in reactor physics.

It is, however, too early to judge the importance and usefulness of an undertaking like the NPY Project. The outcome of the Project will ultimately give an answer to this. The authors consider that the Project starts out with a Co-operative Programme whose objectives are of sufficiently general interest and specific enough to make it a worth-while effort and it is believed that work originated in smaller groups will gain in scientific value if considered in a wider context. The value of the Co-operative Programme is therefore expected to be higher than the sum of its individual contributions if carried out independently. The performance of work under the various tasks will take this duly into account.

The importance of IAEA as a catalyzer for this Project is greatly acknowledged.

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ABSTRACT - RÉSUMÉ - АННОТАЦИЯ - RESUMEN

A/596 Norvège

Le projet NPY — Un programme de recherche en physique des réacteurs entrepris en coopération entre la Norvège, la Pologne, la Yougoslavie et l'AIEA

par V. O. Eriksen *et al.*

On attend de nombreux avantages de la coordination des programmes de recherches de différentes institutions nationales dans le domaine de la physique des réacteurs, les problèmes d'intérêt commun étant abordés de concert. Le projet NPY, entrepris par la Norvège, la Pologne et la Yougoslavie, avec l'aide de l'AIEA, vise à explorer les avantages d'un effort commun dans le domaine de la physique des réacteurs.

Les principaux buts du projet NPY sont d'établir entre les signataires une coopération dans la mise au point de techniques expérimentales en physique des réacteurs, de vérifier et contrôler les possibilités d'application ainsi que l'exactitude et la validité de ces techniques et de mettre au point aussi des méthodes et modèles théoriques pour le calcul des réseaux et l'interprétation des données expérimentales et de vérifier l'étendue de leur validité.

Le mémoire donne un aperçu des tâches entreprises en commun.

A/596 Норвегия

Проект НПЮ. Программа сотрудничества в области научно-исследовательских работ по физике реакторов между Норвегией — Польшей — Югославией и МАГАТЭ

В. О. Эриксен *et al.*

(Доклад представлен Институтом атомной энергии, Норвегия)

Предполагается, что координация программ научно-исследовательских работ по физике реакторов, проводимых различными национальными учреждениями, может дать значительные преимущества, что позволит сконцентрировать усилия на решении проблем, представляющих общий интерес. Проект НПЮ сотрудничества между Норвегией — Польшей — Югославией и МАГАТЭ в качестве «катализатора» является попыткой извлечь преимущества из совместных усилий в работах по физике реакторов.

Основными задачами проекта НПЮ являются следующие: сотрудничество договорившихся сторон в разработке экспериментальных методов по физике реакторов, проверка и испытание их на применимость, обоснованность, точность и дальнейшее развитие теоретических моделей и методов, используемых при расчетах решетки, при интерпретации экспериментальных данных, и проверка степени их справедливости.

В докладе приведен краткий обзор объединенных работ.

A/596 Noruega

El proyecto NPY, programa cooperativo de investigaciones en física de reactores concertado entre Noruega, Polonia, Yugoslavia y el OIEA

por V. O. Eriksen *et al.*

Es de esperar que una coordinación de los programas de investigación de instituciones científicas de diferentes países, que permitiría abordar armónicamente los problemas de interés común, brinde múltiples ventajas. El proyecto NPY, concertado entre Noruega, Polonia y Yugoslavia, y en el que el OIEA actúa, por así decir, como catalizador, representa un intento de evaluar prácticamente los beneficios de la cooperación en materia de física de los reactores.

La finalidad de proyecto NPY consiste en que los signatarios colaboren en el desarrollo de las técnicas experimentales de la física de reactores, en el ensayo y la verificación de su campo de aplicación, de sus límites de validez y de su grado de precisión, así como en el desarrollo de los modelos y métodos teóricos utilizados en el cálculo de los reticulados, en la interpretación de los datos experimentales y en la comprobación de su validez.

Se presenta una reseña de las tareas emprendidas en común.

The DRAGON Project

By C. A. Rennie, G. E. Lockett and R. E. Reynolds*

The OECD High Temperature Gas Cooled Reactor Project (DRAGON) is a joint undertaking, under the sponsorship of the European Nuclear Energy Agency, in which twelve countries have joined together to investigate the high temperature gas-cooled reactor system. The project is therefore an exercise in international co-operation as well as a scientific and technical investigation into a novel reactor system. A committee was set up in 1958 to examine the most fruitful and practical methods of collaboration among OEEC countries in the field of experimental and prototype reactors, and its work resulted in the DRAGON Agreement of March 1959 [1], signed by representatives of Austria, Denmark, Euratom, Norway, Sweden, Switzerland and the United Kingdom. This Agreement, which provided for five years' work from 1 April 1959, at an estimated cost of £13.6 million, was to include research in connexion with high temperature reactors and the design, construction and operation of a reactor experiment [1-4]. By the Revised Agreement of November 1962 [4], the signatories agreed to extend the period for a further three years to 31 March 1967, and to continue and broaden the original programme. The project now has the additional aim of providing the signatories with information leading to the design of an economic, land-based, gas-cooled, carbon-moderated, high temperature reactor. The estimated total cost of the revised programme for the eight-year period is £25 million.

FORMATION

The United Kingdom Atomic Energy Authority had begun to examine the high temperature reactor system in 1956, and agreed to make available to the proposed project both the information which it had gained and the team of about fifty currently employed on the work. It was also agreed that the project should be sited at the UKAEA Establishment at Winfrith, Dorset, where facilities such as offices, workshops and site services could be provided on a repayment basis. An immediate start on the project's work could have been delayed, however, if it had been necessary for the project to be constituted as a new international body with its own legal entity. This was avoided by an agreement that the United Kingdom Atomic Energy Authority should execute all legal acts arising in connexion with the project on behalf of the signatories.

FINANCE

The project's funds are provided by the signatories on an agreed scale, whereby Euratom will pay £11.5 million, and the United Kingdom Atomic Energy Authority £10.2 million out of the total of £25 million. The balance of £3.3 million will be paid by the other signatories in agreed proportions.

MANAGEMENT

Over-all control of the project is exercised by a Board of Management which consists of representatives from all the signatories and from the European Nuclear Energy Agency, and which determines the programme of work and the budget for each year. The Board is assisted by a General Purposes Committee, comprised of senior technical specialists representing signatories, which is charged with the supervision of the carrying out of the programme and with the approval of all important contracts. The detailed conduct of the project is entrusted to the Chief Executive, who, together with other senior staff, is appointed by the Board. The arrangement whereby the UKAEA acts as the legal agent of the project does not in any way affect the control of the project's affairs by the signatories and this arrangement has been found to be an entirely workable solution to a difficult problem.

ORGANIZATION AND STAFFING

Since it has no separate legal existence, the project itself cannot employ staff but receives them on secondment from their parent organizations, paying for their services at standard reimbursement rates. During the period of secondment, the allegiance of the staff is entirely to the project. The staff are subject to the directions of the Chief Executive, may not disclose their work outside the project except with his permission, and must assign all the results of their work, including any patents, to the project. Secondment is normally for two years but is subject to extension by agreement. Extra ancillary staff

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* OECD High Temperature Reactor Project, Winfrith, Dorset, England ; this project is one of the joint undertakings of the European Nuclear Energy Agency. All the authors were seconded by the United Kingdom Atomic Energy Authority.

required for short-term work are usually obtained by contract with local firms. This system has facilitated flexibility in staffing a comparatively short-term project. It has also enabled the international character of the organization to be emphasized by selection of staff from all the countries taking part. Only minor difficulties have been experienced in the assembling of the team and in the working relations between individuals with very different backgrounds. This system enjoys the advantage that new people with new ideas can join in the work, but also suffers from the disadvantage of having a higher turnover rate in staff.

The nucleus of staff provided by the UKAEA was rapidly built up to about two hundred professional and technical staff, of whom about half came from the United Kingdom and half from the other participating countries. In addition, about fifty ancillary staff were obtained under contract and there were about fifty administrative staff mostly from the United Kingdom. Initially, the project was organized into an Engineering Division and a Research and Development Division of about equal size, with an Administrative Division of about fifty. As the reactor design and construction neared completion, the Engineering Division was reduced in strength but new staff joined to assist in the work on assessment studies for large power-plants. The project now has three technical divisions, Physics, Materials and Chemistry, and Engineering, each of which will play its own part in the continuing tasks on research and the use of the reactor experiment, and will also take part in the assessment work.

PROGRAMME

One of the main tasks placed upon the project in 1959 was the design, construction and operation of the reactor experiment and the engineering work is described in more detail in another paper for this Conference [5]. It was agreed that the reactor should be designed in such a way as to enable it to be used as a major tool in the over-all programme for the development of a high temperature reactor system. For this reason it was decided that the design work should be centred at Winfrith and undertaken by the international staff of the project. With the object of spreading the manufacture of the components widely throughout the signatory countries, and so that advantage could be taken of the specialist facilities available in those countries, it was further decided that a larger number of medium-sized contracts should be placed, rather than a smaller number of large contracts. The project team has, therefore, had to be responsible for the design of the reactor in considerable detail and for co-ordinating the work of all the contractors. In the event, some one hundred important contracts for reactor plant were placed, as well as several hundred contracts for smaller items. Having assumed this major responsibility, the project made arrangements with the Engineering Group of the United Kingdom Atomic Energy Authority for them to undertake the design and procurement of the more conventional items of plant, to carry out the design and construction of the building and civil engineering work, to provide the required inspection and progress services for all plant, and to be responsible for the erection and testing of the plant which had been designed and purchased by the project.

The second task of the project was the research and development programme which involved support both for the reactor experiment in providing design information and testing principles adopted in design, and a broader general investigation of the problems of high temperature reactors. This work is described in more detail in another paper for this Conference [6]. It was realised that to achieve our objectives within the project's life it was necessary to have the full participation of research establishments, industry, and other organisations throughout the Signatory countries. The project's own research was limited, therefore, to the tasks necessary for the co-ordination of a broad programme, and to the tasks which could be executed more satisfactorily and economically at Winfrith. The remainder of the work was carried out under contract, the project being fortunate in having access to the scientific and technical resources and experience available throughout twelve countries. Considerable effort has had to be put into co-ordinating the work but the project has found that the co-operation and mutual stimulation between different contractors and between contractors and project staff have contributed much to our work.

OBJECTIVES

The high temperature reactor seeks to exploit three advantages which the system has with the object of reducing the cost of nuclear power. The first of these is to achieve a sufficiently high reactor gas outlet temperature that the most modern design of steam turbine plant can be used. The high gas outlet temperatures also lead to smaller sizes of heat exchanger. The second advantage is to achieve a high power density in the core as this reduces the size of the reactor pressure vessel and biological shield. A reduction in size also enables higher pressures to be used which reduce the pumping power required to circulate the coolant. The third advantage is to use a ceramic-type fuel element which can withstand a high burn-up in the reactor with a consequent long life. This could mean that fuel changing need only be carried out when the plant was shut down for routine maintenance and provision for on-load refuelling would not be necessary. The use of a ceramic-type fuel in which the fissile material, the fertile material and the moderator are mixed together also eases the problem of heat removal from the fuel.

The use of unclad fuel with graphite as moderator requires an inert gas such as helium to be used as the coolant. Because helium is expensive and because some fission product activity will be released into the coolant, it is necessary to achieve a high degree of leak tightness in the primary circuit of the reactor. Further, since parts of the graphite moderator will be at high temperatures, any impurities in the helium coolant will react with the graphite giving rise to problems of carbon transfer. In order to reduce these effects, it is necessary to purify the helium continuously.

Initially, it was felt that the best approach to the fuel problem would be to have a fuel element which emitted as many fission products as possible and to remove these from the coolant circuit by means of a fission product trapping system. In this way, the maximum reactivity benefit could be obtained by removing neutron poisons from the fuel, at the expense of a complicated purification plant. However, work has shown that it is not easy to get many of the important fission products out of the fuel even at the high temperature at which it operates, so that little benefit is obtained in this way.

Meanwhile, there were important developments in making coated particle fuels which retained the fission products in the fuel. In these coated particle fuels the fissile and fertile materials are made into small spherical particles and each particle is then coated individually with pyrolytic carbon. These coated particles are then formed into compacts with more carbon so that the fuel consists of a matrix of carbon or graphite with the coated particles embedded in it. Experimental work has shown that these coated particle fuel compacts have good fission product retention properties and work is now going on to try and establish the operating limits at which such fuels can be used. One possibility would be to use these fuels in a reactor where the fuel compacts are cooled directly by the main coolant. The DRAGON Reactor Experiment was based on the concept of a purged fuel element as, at the time, it was thought that this principle was essential. However, the reactor experiment should be suitable for testing both purged and unpurged fuel elements.

REACTOR DESCRIPTION [1-4]

Some of the more important parameters of the reactor experiment are given in Table 1, and Fig. 1 gives a general view of the reactor experiment and the reactor building. In the main pressure vessel containing the primary helium cooling circuit, the hot outlet gas is routed so that it is always isolated from the vessel walls by the cooler inlet gas. Fuel elements are mounted at their lower ends on mounting spikes, each making connections to the fission product purging line. The upper ends of the fuel elements are mutually in contact, and kept together by the effect of the pressure drop of the coolant across the reactor core. A shield plug is situated in the neck of the pressure vessel and an extension of the vessel above this point forms a lower temperature region housing the charge machine and control rod winding heads. The various mechanical drives are contained in their own pressure enclosures at the end of extension pipes in accessible positions.

Table 1. DRAGON reactor experiment: general data

Thermal output	20 MW
Helium coolant pressure	20 atm (294 lb/in^2)
Inlet coolant temperature	350°C (662°F)
Outlet coolant temperature	750°C (1382°F)
Mean power density of core	14 MW/m^3
Cooling channel voidage	13%
Mean surface heat flux over core	24 W/cm^2
Core length	160 cm (5 ft 3 in)
Core diameter	107 cm (3 ft 6 in)
Fuel element length	254 cm (8 ft 4 in)
Fuel rods on 6.35 cm (2.5 in) triangular pitch	259
Fuel elements, each consisting of a cluster of seven fuel rods	37
Reflector length	244 cm (8 ft ½ in)
Reflector diameter	289 cm (9 ft 6 in)
Number of control rods in reflector	24
Diameter of control rod pitch circle	123 cm (4 ft ½ in)
Pressure vessel diameter around core	350 cm (11 ft 6 in)
Pressure vessel thickness around core	5 cm (2 in)

HEAT REMOVAL SYSTEM

A schematic arrangement of the various heat removal circuits is shown in Fig. 2. There are six primary heat exchangers mounted on six connecting ducts and a gas bearing primary coolant circulator is attached to each heat exchanger shell. A by-pass through the centre of each heat exchanger is closed by a valve which can be opened as necessary in order to control the core inlet temperature under various reactor load conditions. The same valve can be raised beyond its normal control range so that a given circuit can be isolated if it is required to work with less than six heat exchangers. Circulator speeds are controlled by varying the supply frequency from a variable frequency generating set. Each primary heat exchanger transfers its heat to a secondary circuit loop of the forced circulation boiling type. Water is partly evaporated in the primary heat exchangers and the steam/water mixture is carried to the secondary heat exchangers where it is condensed and recirculated by canned rotor pumps. Shutdown heat can be transferred by natural circulation.

A single tertiary circuit, of the pressurised water type, is used to carry the heat from the six secondary heat exchangers to a finned-tube, forced-draught, air-cooler bank outside the reactor building. In addition there is an emergency tertiary circuit connected to each secondary heat exchanger comprising a natural circulation boiling water loop in which

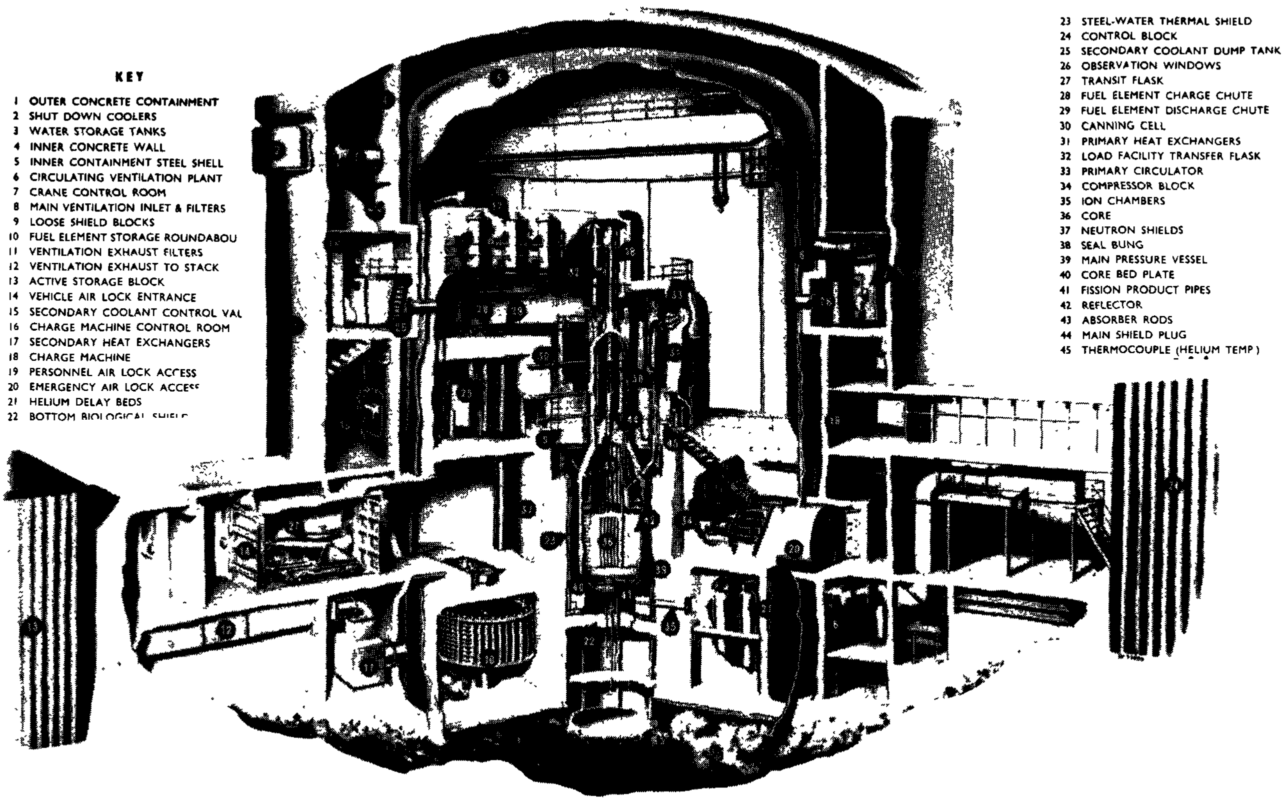


Figure 1. General arrangement of DRAGON reactor

steam is condensed in air radiators mounted at high level outside the reactor building. The emergency circuit is always in operation and the rating is such that shutdown heat can be dissipated in case of power failure.

HELIUM PURIFICATION PLANT

After leaving the fuel elements, the purge flow passes through the mounting spikes into a common flow path and through a pre-cooler mounted on the reactor vessel before entering a group of fission product delay beds. To check that fuel elements are neither broken nor unseated, a branch capillary from each spike unit is used for indication and this also permits sampling of the purge gas from any individual fuel element.

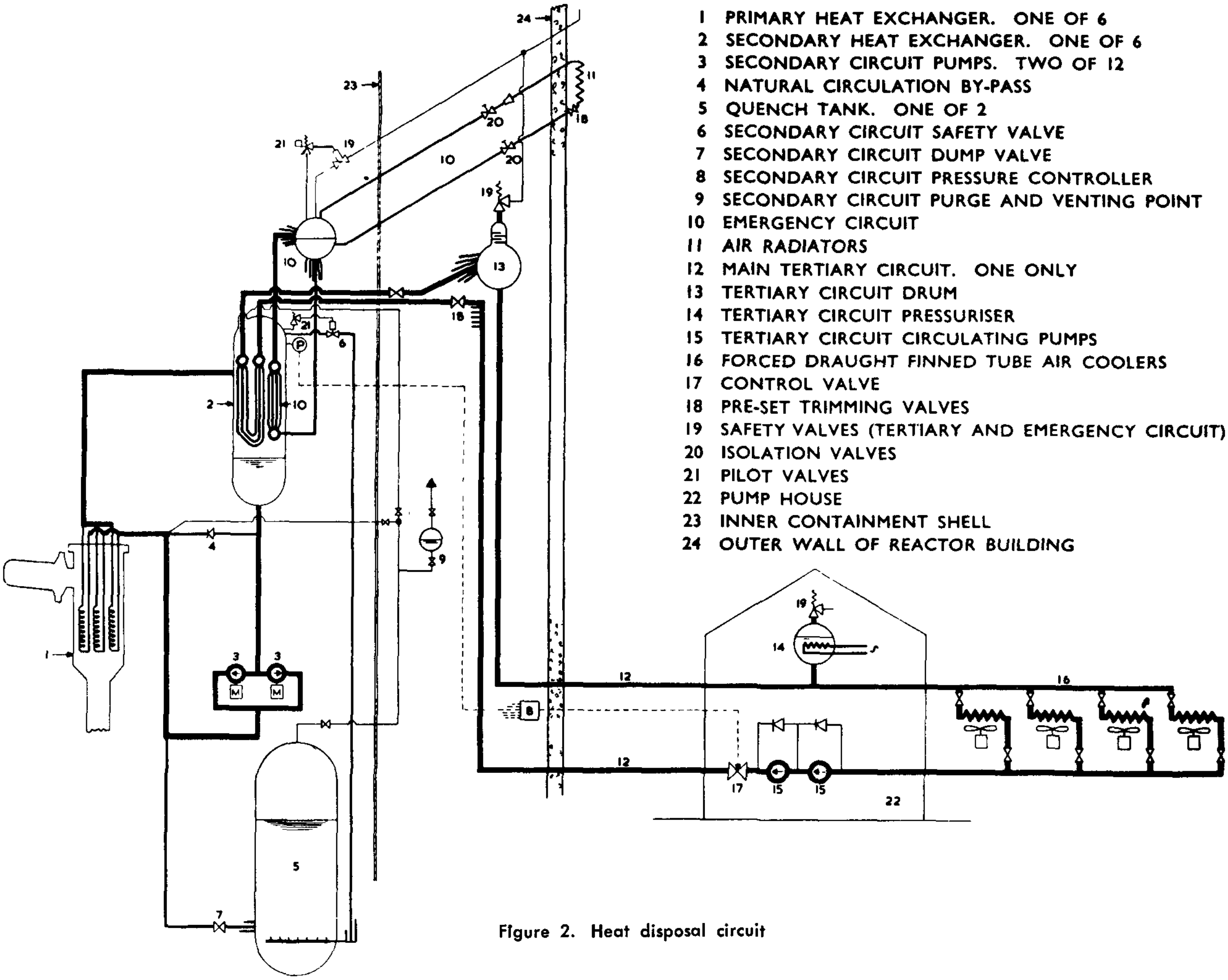
The delay beds which follow the pre-cooler consist of a series of water-cooled charcoal traps which delay fission products sufficiently for their activity and heat generation to decay to acceptable levels. The helium purification system which follows the delay beds is fed from a pipe manifold to allow various routing possibilities. Any of three similar plants may be used and each consists of a high temperature section followed by a low temperature section, the selected plant receiving the purge flow after leaving the delay beds. The two remaining plants are available for either regeneration or stand-by.

In the high temperature section the gas is heated and fed through copper oxide beds in which hydrogen and carbon monoxide are oxidised. The gas is then cooled and passed to the low temperature process where it passes through a freezer heat exchanger to trap out ice and carbon dioxide as solid deposits. The gas then passes through a liquid nitrogen-cooled charcoal trap to remove xenon and krypton before returning through a regenerative route where it is warmed up to room temperature by heat from the incoming dirty gas before being fed back through a circulator to the reactor.

REACTOR BUILDINGS

A general indication of the reactor building is also given in Fig. 1. An inner steel shell, to provide primary containment, surrounds the reactor and encloses units of plant which are closely associated with the primary circuit. These plant units include secondary heat exchangers, charge/discharge machinery, hot fuel element storage and fission product and gas purification plant. All these areas are appropriately shielded to allow entry for certain operations such as fuel element changing but it is normally not necessary to enter the containment shell. The steel shell is surrounded by an outer building of sealed concrete construction. Air is admitted to the outer building and exhausted to a stack through valves which can be closed in the event of an incident.

A separate reactor control building containing the main control room is situated adjacent to the



1 PRIMARY HEAT EXCHANGER. ONE OF 6
2 SECONDARY HEAT EXCHANGER. ONE OF 6
3 SECONDARY CIRCUIT PUMPS. TWO OF 12
4 NATURAL CIRCULATION BY-PASS
5 QUENCH TANK. ONE OF 2
6 SECONDARY CIRCUIT SAFETY VALVE
7 SECONDARY CIRCUIT DUMP VALVE
8 SECONDARY CIRCUIT PRESSURE CONTROLLER
9 SECONDARY CIRCUIT PURGE AND VENTING POINT
10 EMERGENCY CIRCUIT
11 AIR RADIATORS
12 MAIN TERTIARY CIRCUIT. ONE ONLY
13 TERTIARY CIRCUIT DRUM
14 TERTIARY CIRCUIT PRESSURISER
15 TERTIARY CIRCUIT CIRCULATING PUMPS
16 FORCED DRAUGHT FINNED TUBE AIR COOLERS
17 CONTROL VALVE
18 PRE-SET TRIMMING VALVES
19 SAFETY VALVES (TERTIARY AND EMERGENCY CIRCUIT)
20 ISOLATION VALVES
21 PILOT VALVES
22 PUMP HOUSE
23 INNER CONTAINMENT SHELL
24 OUTER WALL OF REACTOR BUILDING

Figure 2. Heat disposal circuit

reactor building and a services building is provided to house general plant such as stand-by diesel generators, batteries, variable frequency generating sets and other electrical machines. A storage building is provided for fuel elements, loading flasks and other items of a potentially active character. This building also contains changing rooms and a laboratory for the analysis of gas, water or other samples from the reactor. Attached to this building is the fuel element production laboratory in which the fuel inserts are made and the complete fuel elements assembled.

OPERATION

The DRAGON Reactor Experiment achieved criticality during the summer of 1964 and should be operating at power early in 1965. During the remaining period up to March 1967, the two main objectives of the project will be to make the best possible use of the Reactor Experiment and to carry out a programme of assessment studies. In addition to obtaining information on the behaviour of the various components of the reactor and obtaining confirmation of the design principles on which it is based, the Reactor Experiment will be used as a test bed for the improved reactor fuels which are being developed by the project. This programme of fuel element development work should give sufficient information to enable reliable cost estimates to be made for the different fuel cycles which are possible in a large power reactor system.

ASSESSMENT STUDIES

The assessment study work will be concentrated on the design of a land-based, gas-cooled, carbon-moderated, high temperature reactor with an electrical output of at least 500 MW. Two preliminary design studies have already been purchased by the Project. The first of these was carried out by the United Kingdom Atomic Energy Authority some three years ago and was based on the original concept for the DRAGON Reactor Experiment, that is, the use of purged fuel elements. This study gave quite encouraging capital cost estimates and, at the same time, it showed that there should be very real possibilities of achieving low fuel cycle costs.

A further preliminary design study was commissioned from a Joint Group comprising AGIP Nucleare of Italy and Indatom of France. As a result of the research and development work carried out on coated particle fuel the Joint Group was asked to assume, as a starting point for this later study, that a fuel element could be developed which could be directly cooled by the main helium coolant and would not need a fuel element purging system. This assumption meant a considerable simplification in the reactor concept and the Joint Group was asked to make a preliminary assessment of the design and the cost on this basis, developing their study from the outline schemes prepared by the Project.

Although both studies must at the moment be regarded as preliminary, it is of interest to note that while the earlier purged fuel element study gave a cost of about £75 per installed kilowatt, the later unpurged fuel element study gave a cost of about £50 per installed kilowatt. In each case, these cost figures exclude the site work which would normally be carried out by the customer and so correspond to preliminary estimates of the tender price. The fuel costs might be slightly higher in the latter case, but the effect of the reduction in capital cost would far outweigh any increase in fuel cost. At the moment the Project is engaged on further research and development work to try and prove the assumptions which have been made for this latter study, and it will then carry out a more detailed design study using the information which becomes available. There is every hope that the later estimates of cost will be near the figure of £50 per installed kilowatt.

The difference in capital cost between the two studies is not entirely due to the change in concept from purged to unpurged fuel. The UKAEA study was based on a 1 000 MW (thermal) non-integrated design using a steel pressure vessel with multiple charging standpipes and a pressurised charge machine of a similar type to that used for existing natural uranium reactors. A containment shell surrounds the reactor area and an outer building surrounds this shell as in the DRAGON Reactor Experiment. In general, the fuel elements and their mounting spikes follow closely the DRAGON Reactor concept.

The Joint Group study is for a 1 250 MW (thermal) design and in addition to the change from purged to unpurged fuel, the design has been based on the use of a pre-stressed concrete pressure vessel. The assumed fuel performance, together with the safety precautions in the vessel and penetration design, allow the reactor to be housed in a normal industrial-type building. The higher coolant pressure which can be accommodated by the concrete pressure vessel allows useful reductions to be made in heat exchanger size and in coolant pumping power requirements. The simplification of the helium coolant processing plant to a by-pass system on the main coolant flow also reduces the cost. Further gains are made by carrying out only fuel changing during annual maintenance periods when the reactor is shut down and depressurized, as this simplifies the charging machine requirements.

COLLABORATION WITH USAEC

The Project has a Collaboration Agreement with the United States Atomic Energy Commission, under which information emanating from the Project is made available to the USAEC in exchange for information arising from the USAEC programme on high temperature gas-cooled reactors. This Agreement is being extended and broadened to include much of the additional work under the Revised DRAGON Project Agreement and much of the work which the USAEC is doing in this field in addition to the Peach Bottom Reactor Project.

INFORMATION

The results of the Project's work are distributed to the signatories of the project by means of individual reports and regular summary reports. These documents are the property of the signatories who have the right to disclose the information as they wish to persons and undertakings established in their own territories, but disclosure to others is permissible only with the agreement of all the signatories. The reports are supplemented by conferences and symposia at which the signatories, the project's contractors and the project's staff are represented, the information provided at these meetings again being given on a confidential basis. More general descriptions of the project's work are given in the Annual Reports [1-4] which are published, and detailed results in some areas of work are published from time to time in the literature.

INTERNATIONAL ASPECTS

The international character of the project which is reflected in its constitution and system of management, has been emphasised in its staffing arrangements, in the policies which have been adopted for the execution of its tasks, and in its arrangements for the placing of contracts. As an international organisation the project has enabled the participating countries, some of whom could not easily mount so large an effort individually, to take an active and detailed part in a major investigation of an important reactor system. It has also enabled the project to benefit from the knowledge and specialist facilities available throughout a large part of Europe. Experience has shown that co-operation between individuals, firms and other organisations in a number of countries can be established to mutual benefit, and that the co-ordination of the efforts of many and widespread contractors in both research programmes and in complex engineering tasks can be achieved. The creation of an integrated scientific, technical and administrative staff with clearly defined objectives, within a fixed time scale and within a fixed budget, has engendered the necessary feeling of unity of purpose and concern for the early achievement of the tasks on an economical basis.

Finally, the system of staffing has enabled people of the kind required for the task in hand to be made available on a temporary basis and for the composition of the team to be varied as necessary although, inevitably, some difficulties have arisen through staff changes at inconvenient times.

The project has now completed five years of its appointed eight year life, and its form of organisation is considered to be well adapted for the tasks required of it. As the prospect of an economic power plant grows nearer it could well be that the differing interests of industry in a number of countries would involve major difficulties for a joint undertaking. However, for a project in a comparable stage of development to that of the high temperature reactor system a similar collaboration arrangement to that covered by the DRAGON Project Agreement would seem to offer many advantages and few disadvantages.

CONCLUSION

The overall programme of research and development, and in particular the work on fuel elements, is proceeding well and giving valuable results. Preparations are now being made for using the reactor experiment to confirm our earlier work and to obtain further results under realistic operating conditions. Some preliminary assessment studies of the cost of electricity from large high temperature power reactors have been made. The detailed figures for the cost per kilowatt hour which have emerged from these studies are not given in this paper as there are at present too many uncertainties and assumptions in them to justify publication, even though they are very encouraging. The Project will continue its work on assessment studies and this further work, together with actual operating experience on the reactor experiment, should enable most of the present uncertainties and assumptions to be resolved.

The reactor experiment has reached the stage of criticality and preparations are well advanced for operation at power early in 1965. No insuperable difficulties have been encountered in our development of this reactor system over the past five years. Solution of many of the problems which loomed large in the early days has proved to be less troublesome than had been expected, and we are now satisfied that the engineering techniques which have been developed will be adequate for future large power reactors. There is good ground on which to base our hope that the detailed design study which the project will carry out will confirm the very encouraging figures for cost per unit of electricity obtained in our preliminary studies.

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ABSTRACT - RÉSUMÉ - АННОТАЦИЯ - RESUMEN

A/121 Royaume-Uni

Le Projet DRAGON

par C. A. Rennie *et al.*

Le Projet DRAGON est une entreprise commune de douze pays européens, créée sous les auspices de l'Agence européenne pour l'énergie nucléaire de l'Organisation de coopération et de développement économiques; son but est d'entreprendre un programme de recherche et de mise au point dans le domaine des réacteurs à haute température modérés au graphite et refroidis à l'hélium. L'histoire du Projet est d'abord décrite, ainsi que les points principaux de l'Accord initial conclu en mars 1959 pour une période de travaux de cinq ans à partir d'avril 1959 et de l'Accord revisé de novembre 1962, couvrant une période de huit ans jusqu'en mars 1967.

Les tâches de l'entreprise, son organisation et les principes suivis pour l'exécution de ces tâches sont résumées; l'état actuel des travaux est exposé.

Les aspects internationaux du Projet sont évoqués et leur influence sur la marche des travaux est discutée. Les avantages et inconvénients inhérents à la forme d'organisation de l'entreprise sont passés en revue.

Les buts et objectifs du programme de recherche et de mise au point entrepris sont résumés. Ces travaux ont d'abord visé à obtenir des réponses aux problèmes spécifiques qui se posaient pour la mise au point du projet de réacteur expérimental, puis, dans toute la mesure possible, ils ont été étendus à des problèmes plus généraux intéressant les réacteurs à haute température. Un des aspects les plus importants des travaux de recherche et de mise au point de l'entreprise a été et demeure l'étude des éléments combustibles pour ces réacteurs.

Une description du réacteur expérimental en construction à Winfrith est donnée, portant en particulier

sur les éléments du réacteur expérimental pouvant servir à résoudre les problèmes relatifs aux futurs réacteurs à haute température.

Enfin, un aperçu des études entreprises concernant les grands réacteurs à haute température est donné. Les hypothèses sur lesquelles ces études sont basées sont indiquées et les mesures prises pour vérifier ces hypothèses sont décrites.

A/121 Соединенное Королевство

Проект реактора DRAGON

К. А. Ренни *et al.*

Строительство реактора DRAGON является совместным проектом двенадцати европейских стран под руководством Европейского агентства по ядерной энергии Организации экономического сотрудничества и развития. Проект направлен на выполнение программы работ по созданию высокотемпературных реакторов с графитовым замедлителем и гелиевым теплоносителем. Впервые описана история разработки проекта и наиболее важных условий первоначального соглашения от марта 1959 года, рассчитанного на пять лет начиная с апреля 1959 года, и пересмотренного соглашения от ноября 1962 года, рассчитанного на восемь лет вплоть до марта 1967 года. Рассматриваются задачи проекта, организационные меры и план, принятые для осуществления этих задач, а также приводится отчет о состоянии работ по этому проекту в настоящее время.

В докладе обсуждаются международные аспекты проекта и их влияние на его осуществление, а также сравнительные преимущества и недостатки формы организации работ, предусмотренных проектом.

Дается краткий обзор целей программы научно-исследовательских и опытно-конструкторских работ, выполняемых в соответствии с проектом. Первоначально в этих работах предусматривалось решение специфических проблем, возникающих на стадии проектирования экспериментального реактора, но затем они были расширены, где это возможно, с целью разрешения более общих проблем, связанных с высокотемпературными реакторами. Одним из самых важных научно-исследовательских и опытно-конструкторских направлений было и остается изучение тепловыделяющих элементов для реакторов такого типа.

В докладе дается описание экспериментального реактора, строящегося в Уинфрите, причем особое внимание уделяется тем характеристикам этого реактора, которые должны помочь в решении проблем будущих высокотемпературных реакторов.

В заключение сообщается об исследованиях, проделанных в соответствии с проектом в направлении создания крупных высокотемпературных реакторов. Рассматриваются те предложения, на которых основываются работы, и меры, предпринимаемые для подтверждения этих предположений или отказа от них.

A/121 **Reino Unido**

El proyecto DRAGON

por C. A. Rennie *et al.*

El proyecto DRAGON es un proyecto común de doce países europeos, patrocinados por el Organismo Europeo de Energía Nuclear de la Organización de Cooperación y Fomento Económicos, para la realización de un programa de trabajo en el campo de los reactores de temperatura elevada, moderados por grafito y refrigerados por helio. Se describe en primer lugar la historia del proyecto, juntamente con las disposiciones más importantes del Convenio original de marzo de 1957 para ordenación del trabajo durante un período de cinco años a partir de abril de 1959 y el convenio revisado de noviembre de 1962 que abarca un período de ocho años, hasta marzo de 1967.

Se resumen las tareas del proyecto, así como la organización y programas para su ejecución, y se informa sobre el estado actual de las actividades.

Se examinan los aspectos internacionales, y se discuten sus efectos sobre los trabajos del proyecto. Se mencionan las ventajas y desventajas relativas del sistema de organización.

Se da un resumen de las directrices del programa de investigación y del trabajo de desarrollo realizado. La actividad inicial se dirigió hacia la solución de problemas específicos que se plantearon durante la etapa de proyecto de la experiencia crítica, pero se han extendido, en lo posible, a aspectos más generales en reactores de alta temperatura. Un aspecto muy importante de la investigación ha sido, y es, el estudio de los combustibles de estos reactores.

Se ofrece una descripción del reactor experimental que se encuentra en construcción en Winfrith, insistiendo particularmente sobre los aspectos que pudieran ser útiles para resolver problemas de los futuros reactores de alta temperatura.

Finalmente, se da cuenta de la contribución del proyecto al diseño de reactores grandes de temperatura alta. Se especifican las hipótesis en que se basa el estudio, y se indican las medidas que se están tomando para demostrarlas o desecharlas.

Review of research and development work for the DRAGON Project*

By L. R. Shepherd,** H. de Bruijn,*** K. O. Hintermann**** and R. A. U. Huddle**

The original concept of the high temperature gas-cooled reactor which has formed a basis for the OECD DRAGON Project was presented in a paper at the previous Geneva Conference [1]. The present paper is one of three which deal with the general objectives and organisation of the project [2], the engineering problems in the design and construction of the DRAGON Reactor Experiment [3], and in this report, the programme of research and development which has been carried out.

The dual objective of the research and development programme has been the general investigation of problems inherent in high temperature gas-cooled reactors, and the particular problems that are associated with the 20 MW Reactor Experiment which has been constructed at Winfrith. The Reactor Experiment itself has a major role in the general research programme, which is directed primarily towards the eventual application of high temperature reactors to large electricity generating stations. This role embraces reactor physics, engineering and coolant chemistry problems and, in particular, the testing under reactor conditions of fuel elements and their constituent materials.

In a report of the present length it is impossible to cover all aspects of the work carried out by the Research and Development Division of the DRAGON Project. No attempt has been made to include engineering studies on special components such as gas-bearing circulators, on dry and lubricated bearings operated in pure helium and on the special demountable seals, valves and welds which have had to conform to a standard of leak tightness hitherto unprecedented in high pressure equipment. No reference is made in this paper to the work that was carried out in the field of heat transfer, the assessment of the safety of the Reactor Experiment, or to the miscellaneous but very important developments in high temperature techniques and measurements.

In the ensuing sections, the aspects of the work which have been examined include only a part of the reactor physics investigations, graphite and fuel element development, and studies on the chemical problems associated with the coolant. Even these features are examined only in outline, and the discussion of them confined to a few selected topics which are considered to be of major significance. In particular, the discussions have been directed primarily to those problems which concern the Reactor Experiment.

REACTOR PHYSICS OF THE DRAGON REACTOR EXPERIMENT

U-Th cycle in power reactors

One of the main purposes of the DRAGON Reactor Experiment is to test fuel elements suitable for large power reactors. In doing so it has been considered important to simulate, as closely as possible, in the test elements, the composition that might be anticipated in the elements of a power reactor. Preliminary theoretical investigations have been made on the uranium-thorium fuel cycle in order to establish the likely range of core compositions as well as the conditions and duration of exposure in the reactor.

It has been assumed, initially, that the cost of fuel reprocessing and refabrication will be sufficiently high to create a need for having a high burn-up, in terms of fissions per initial fissile atom (*fifa*), and a correspondingly long duration of exposure in the reactor. Fig. 1 illustrates the interdependence between burn-up and core composition obtained from a typical set of calculations. Each point on this diagram represents a particular average composition of a core, at any time, for a 1 000 MW(th) reactor, which is run with continuous fuel recharging. Results suggest that the fuel compositions which would be of greatest interest would involve thorium to uranium atomic ratios of $N = 10$ or above, and that the fuel should be exposed sufficiently long in the reactor to give a burn-up of *fifa* > 1.5.

The first core of the DRAGON Reactor Experiment

Certain difficulties have been encountered in finding a means for testing fuel elements of representative power reactor composition in the 20 MW Reactor Experiment. These arise from the disparity in the expected size of core of a large power reactor

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* OECD High Temperature Reactor Project, Winfrith, Dorset, England; this project is one of the Joint Undertakings of the European Nuclear Energy Agency.

** Seconded by the United Kingdom Atomic Energy Authority.

*** Seconded by the Reaktor Centrum Nederland.

**** Seconded by the Swiss Federal Institute for Reactor Research.

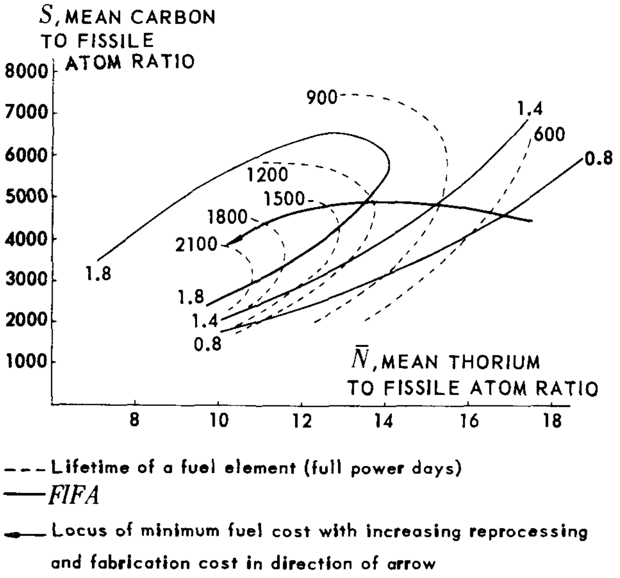

Figure 1. *Fifa*-values and life time for continuously charged-discharged 1 050 MW(th) reactors of different compositions: power density 11.6 MW/m^3

and that of the Reactor Experiment. The core of the latter consists of 37 fuel elements in a hexagonal lattice, each being a cluster of 7 identical fuel rods (Fig. 2), 244 cm long, the centre 160 cm forming the fuel bearing part leaving 40 cm at each end for the bottom and top reflector. The equivalent core radius is 53.6 cm, the radial reflector thickness 91 cm. Each fuel rod contains 54 g of uranium-235 in a total uranium-235 loading of 14 kg.

The reactor is controlled by 24 control rods, inserted in vertical holes within the radial reflector 10 cm from the core reflector boundary.

Due to the small size of the core, the leakage losses are considerable. The hot depleted and poisoned core, just critical, with control rods withdrawn, loses 32% of the neutrons by leakage. As a result, the over-all thorium to uranium-235 ratio (N-value) for the DRAGON core must be considerably lower than in large power reactors where leakage losses are around 2% for a 1 000 MW(th) system.

The over-all N-value for the first charge is about 3 compared with 10 or more for a power reactor. Consequently, the mean conversion ratio is very low and the lifetime short. In order to provide a useful test facility in spite of the above-mentioned drawback, the core will be loaded with two types of fuel elements. The seven centre elements will be representative of a power reactor with an N-value of 15. The remaining 30 elements will contain no thorium at all using zirconium instead to dilute the uranium-235 in the particles. These outer elements will serve merely as driver elements and must be replaced by fresh ones every 180 full power days. In this way the centre elements can be irradiated for several years, accumulating *fifa* comparable to that required in a power reactor.

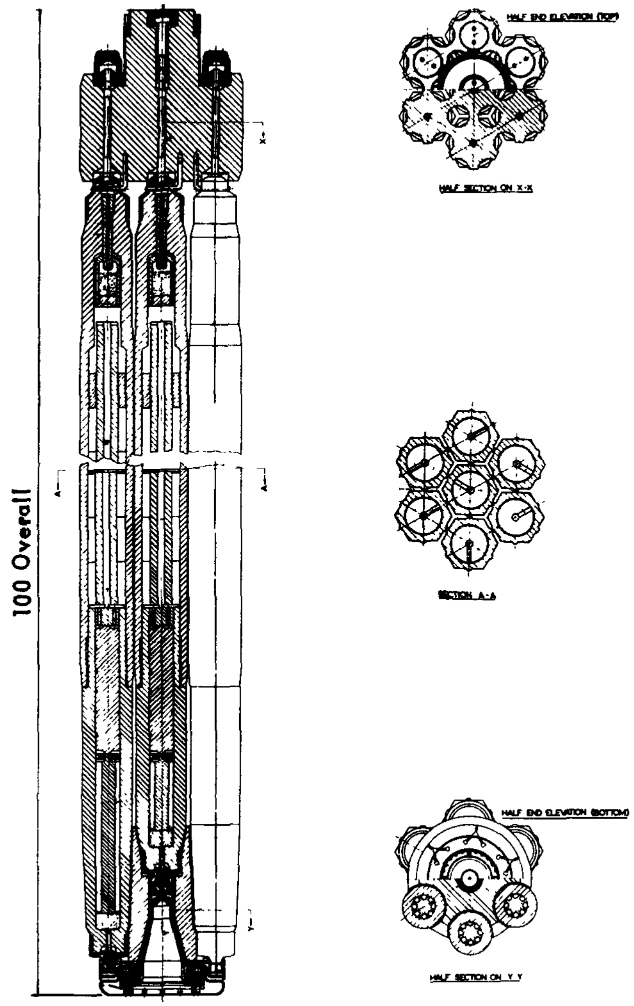

Figure 2. First charge fuel elements (section)

The effective multiplication constant k_{eff}

Calculation procedures were developed using basic data only to determine k_{eff} of the Reactor Experiment. The accuracy of the calculation methods was checked with experiments on the ZENITH zero power reactor [4] at the Atomic Energy Establishment, Winfrith.

The calculation starts with a 43-group computation of the neutron spectrum for the two core zones and the reflectors. With these spectra group, cross-sections for six-group criticality calculations with a two-dimensional R-Z-description of the reactor geometry were evaluated. These calculations yielded the k_{eff} and the flux distribution in a few groups. From the latter, energy dependent leakage coefficients for the different reactor zones were calculated and fed back into the spectrum calculations, the same sequence of calculations being repeated. Experience showed that running through this loop twice gave good convergence.

The spectrum calculations utilised free gas scattering kernels above a moderator temperature of 1 200°K and a crystalline kernel below that temperature. Because of the very diluted fuel cartridges only slight flux depressions (less than 2% for 2 200 m/s neutrons) are observed. This is taken care of in the form of energy dependent disadvantage factors, calculated with an S_4 approximation for the transport equations.

Extrapolation lengths for control rods were calculated with the method of Kushneriuk and McKay [5]. The distortion in spectrum caused by the control rods were treated by the same iteration procedure outlined above.

The effective resonance cross-sections for thorium were calculated according to Adler, Hinman and Nordheim [6] and checked with Monte Carlo calculations, which yielded almost equal results.

Fig. 3 shows the neutron spectra for the central and outer regions of the core in the cold (300 °K) state. The epithermal part of an infinite region spectrum without resonance absorption would be horizontal. The marked deviation from this shape demonstrated the strong influence of the net leakage of neutrons due to the smallness of the system, and by thorium resonance captures in the inner region.*

The variation of k_{eff} with burn-up is shown in Fig. 4, which shows also the recovery of reactivity on reloading the driver element zone. The temperature coefficient of k_{eff}, evaluated from the calculations is

$\alpha k_{\mathrm{eff}} = -5.76 \times 10^{-5}\ (°\ \mathrm{C})^{-1}$. The contributions to the temperature coefficient are:

40% due to increased in-leakage;

35% due to spectrum changes (decrease of ηf);

25% due to increase of the resonance absorption of the central seven elements (decrease of p).

The high degree of under-moderation (initial fuel to moderator atom ratio is 1:3 000) causes a thermal flux and power peak at the core reflector edge which demonstrates the necessity of a multigroup calculation in combination with a multizone spectrum calculation to be able to cope with the rapidly varying spectrum.

Fig. 5 gives the uranium-233 and uranium-235 contents, the conversion ratio and *fifa* values of the test elements in the central position as a function of burn-up. The comparatively slow burn-out of the fuel is reflected by the rather high but only slowly increasing conversion ratio.

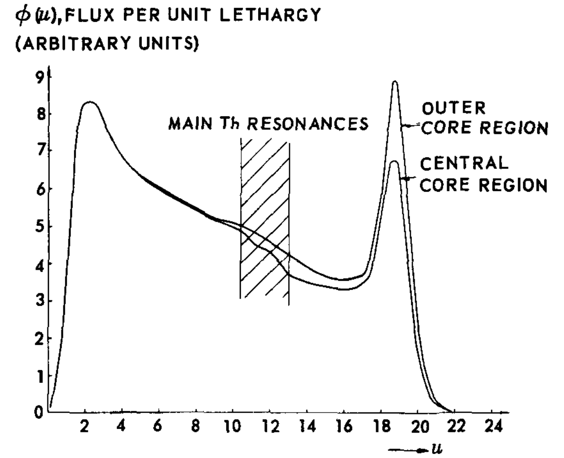

Figure 3. Comparison of neutron spectra in central and outer core region. Fluxes are normalised at $u = 4$ and $u = 0$ at $E = 10^7$ eV. Moderator temperature 300 °K

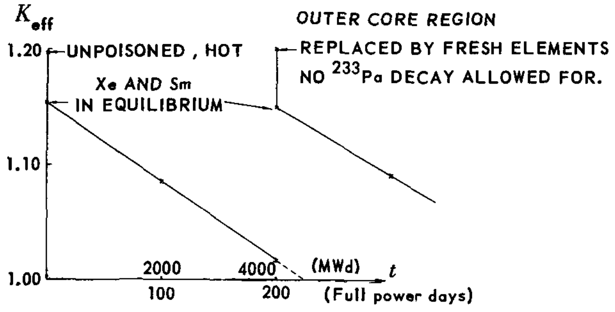

Figure 4. k_{eff} versus time for first DRAGON charge

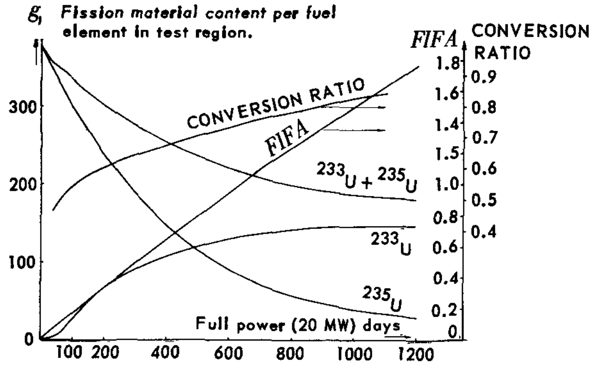

Figure 5. DRAGON first loading — properties of test region; fissile material content, *fifa* and conversion ratio against irradiation time at full power

FUEL ELEMENT DEVELOPMENT

Graphite fuel tube materials

The original concept of the DRAGON Reactor Experiment was evolved before the possibility of fission product retaining fuel had been investigated, and the possibility of copious fission product emission had to be taken into account. This led to the adoption of the purged fuel element (Fig. 2) and the development of special graphite tubes having appropriate pore characteristics to make the purge effective. Initially, the problem was considered in relation to commercially available graphite, and the only material that appeared to be suitable was the Morgan Crucible Company's EY9 rendered more impermeable by impregnation with an appropriate

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* The spectra on Fig. 3 are normalized at $u = 4$ to provide the same fission source for both spectra. The much higher thermal flux in the outer region originates from the in-leakage of thermal neutrons being slowed down in the reflector. The central core zone spectrum is very near to that of an infinite medium spectrum.

high carbon yield resin. The furfuryl alcohol impregnation process developed by the Royal Aircraft Establishment, Farnborough, was adapted for this purpose. Subsequently, the DRAGON Project proceeded with its own development of a graphite having a relatively low over-all permeability (of the order of 10^{-2} to 10^{-3} cm^2/s) [7]. To this end, laboratory experiments were carried out on the Harwell Experimental Graphite Plant and at Compagnie Pechiney's plant at Chedde, Haute-Savoie, to determine the relationship between the compositional variables, fabrication procedures and the final pore size distribution and to produce specimen materials.

The use of carbon black as a major constituent of all compositions was necessary to give the required pore characteristics. Unfortunately, it was found that this constituent enhanced the shrinkage of the graphite under irradiation at high temperatures. Because of this and difficulties inherent in manufacture, the development of graphite involving carbon black was abandoned, though the furfuryl alcohol impregrated Morgan graphite will still be used in the first DRAGON core.

In the initial concept of the fuel element, the object had been to develop an almost impermeable graphite fuel tube, purged by permitting a small flow of helium to enter the top of the element and pass down to an extract at the bottom. The alternative was to use a more permeable graphite which allowed the purge flow to enter through the pores and to limit the back diffusion of fission products by having an appropriate pore size distribution. For this purpose a new graphite has been developed by the Project in collaboration with its contractors, AERE and Compagnie Pechiney, leading to the pilot scale production at Chedde, of a material designated G.5 having a basic composition approximating to two-thirds 60 mesh graphite powder, and one-third micronised graphite powder. Experiments on this base material have shown that by employing two pitch impregnations the desired pore characteristics can be achieved; a reduction of B_0 from 7×10^{-11} cm^2 to 6×10^{-12} cm^2 and K_0 from 9×10^{-6} cm^2/s to 7×10^{-7} cm^2/s, in terms of the coefficients of the Carman Equation [8] in a typical specimen, indicating the effect of the impregnation. Fig. 6 shows a typical pore size distribution.

Although laboratory experiments have confirmed the theoretical predictions, the effectiveness of the back-sweeping principle in G.5 fuel tubes cannot be proved until the fuel elements are in service in the reactor. However, the degree of irradiation shrinkage of the carbon black materials was such as to give cause for concern regarding their integrity, and in this respect the G.5 material and its derivatives are markedly superior.*

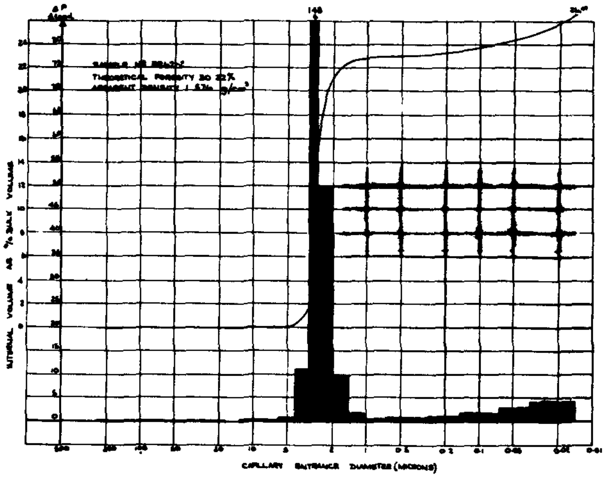

Figure 6. G.5 graphite pore size distribution (Compagnie Péchiney, Chedde, France)

Fission product retention

The purpose of the purged fuel element is to transfer fission products as directly as possible from the fuel material to a trapping system. It was hoped, initially, that the evolution of these fission products from the fuel bodies would be so rapid and nearly complete that an effective de-poisoning of the system could be achieved, leading to a significant increase in the attainable burn-up of each fuel charge. In the event, in-pile loop experiments (*q.v.*) with so-called fission product emitting fuels, did not confirm the possibility of effective de-poisoning, and any possible advantage of emitting fuel disappeared.

From 1957 onwards, exploratory experiments had been carried out by AERE and later by the DRAGON Project to investigate the feasibility of retaining fission products at their source, utilising the principle of the coated particle. Parallel work in the USA during 1960 yielded promising results and the DRAGON effort to produce effective coated particle fuel was accelerated in close collaboration with its contractors, notably: RAE Farnborough, England; SGAE Seibersdorf, Austria; Metallwerk Plansee, Reutte, Tyrol; CEN Mol, Belgium. The programme has included the development of process to fabricate fuel particles consisting of mixed uranium-thorium dicarbides as well as uranium-zirconium monocarbide particles (for the 'driver-elements'); the coating of these particles with pyrocarbon and silicon carbide and the consolidation of the coated particles into graphite fuel bodies. The investigations have led to the choice of the powder metallurgy agglomeration process for fuel particle fabrication, the fluidised bed process for pyrocarbon or silicon carbide coating, and the resin bonded matrix principle for consolidation.

The powder metallurgy agglomeration technique has many advantages, having a high yield and a

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* Irradiation tests on specimens heated to 650 °, 900 ° and 1 200 ° C are carried out in the High Flux Reactor at RCN Petten in the Netherlands.

degree of flexibility of composition essential in the early stages of development. The work on coating was divided into laboratory scale experiments for investigating the major parameters involved in the coating process as well as for the preparation of irradiation specimens and the development of production equipment for working with charges up to a kilogram. A summary of this work to May 1963 has already been given by one of the authors [9].

Parallel with the development of fabrication techniques, a programme to determine the behaviour of the consolidated fuel particles under irradiation has been undertaken using three types of irradiation test facilities:

The high power density capsule (HPD) involves a cylindrical specimen approximately 12 mm diameter, 10 mm long, having a small central hole for temperature measurement. Twelve such specimens are irradiated in the rig, the temperature of each specimen being controlled by its fissile content and by the design of each specimen carrier. Irradiation is carried out in a hollow fuel element within the core of DR3 at Risø, Denmark. Specimens have been irradiated at temperatures up to 1 750 °C.

Full scale "proving" capsule. This utilises fuel specimens of similar dimensions to the components of the fuel cartridges for the Reactor Experiment. Irradiation is carried out in the core of DIORIT at Würenlingen, Switzerland.

The purged capsule. In this experiment, specimens similar to those employed in the HPD rig are irradiated in the R2 reactor at Studsvik, Sweden and a small purge flow is maintained over the specimen which carries any gaseous or volatile fission products emitted from the fuel into a monitoring system. By such means a knowledge of the fission product emission is obtained during the actual irradiation. Temperature is controlled by fuel composition and by varying the proportions of helium and neon in the purge gas.

The PLUTO Loop (AERE Harwell). This experiment is basically a single fuel rod of the DRAGON Reactor Experiment developing around 30 kW of heat which is removed by flowing helium at 10 atmospheres pressure. It includes a number of features of the primary circuit of the Reactor Experiment, including the purge system. The specimen is geometrically similar to a full size fuel rod except that the active length of fuel is reduced by 40%. The PLUTO Loop is not primarily a fuel testing facility, its main purpose being to investigate problems concerning the coolant, particularly purification, carbon transport and the problems associated with fission product emission and control.

The early results of the irradiation experiments showed that the coated particles failed by a process resulting in removal of the carbon from the interior of the coating, a so-called "spearhead" penetrating to the surface [10]. The mechanism of spearhead attack is not yet fully understood, but a major factor may be shrinkage of the inner low density pyrocarbon coating. In general the situation can be summarised as follows:

(*a*) The attack is a maximum in the range 1 000 ° to 1 400 °C, becoming negligible at temperatures above 1 600 °C;

(*b*) The presence of excess carbon in the fuel particle reduces the severity of attack;

(*c*) The penetration of the spearhead can be limited by a discontinuity in the coating, the most effective procedure to produce a discontinuity being to stop the coating process at some stage, cool, expose the particles to air, then subsequently resume coating;

(*d*) Silicon carbide coatings do not appear to be subject to spearhead attack;

(*e*) The consolidation of the particles may have some influence.

The irradiation programme has so far been mainly directed towards understanding and eliminating spearhead attack. Typical examples of specimens illustrating the nature of the attack are shown in Fig. 7.

Measurements carried out during irradiation in the PLUTO Loop and the Studsvik facility are concerned primarily with the emission of rare gas isotopes. Most of the other fission products have to be determined by post-irradiation radio-chemical measurements. It has been found that barium and strontium diffuse readily through pyrocarbon coatings, and these metal fission products, as well as caesium, can be relatively mobile in migrating through and out of the fuel elements. Silicon carbide coatings around the fuel particles appear to be particularly effective in preventing the escape of these species.

It has been found that even if the pyrocarbon coatings fail, some degree of fission product retention is maintained, e.g., the rate of emission over birth rate (R/B) for a long-lived gas such as xenon-133 may still be as low as 10^{-2}. In unbroken coated particles the emission appears to be determined mainly by the contamination of the coatings by fissile material which occurs during the manufacturing process. With some multiple (silicon carbide plus pyrocarbon) coated particles irradiated at temperatures of 1 400 °C and above, values of R/B as low as 10^{-5}-10^{-6} have been observed with long-lived gaseous fission products. Measurements on Studsvik loops, which are also in agreement with results that have been obtained in America, e.g., at ORNL, indicate, within the limits of experimental error, that R/B for gaseous fission products varies with the half-life of the isotope concerned — a result which would be expected from a diffusion process. AERE Harwell, SGAE Seibersdorf, CCR Ispra and CEA Saclay have collaborated in the diffusion studies.

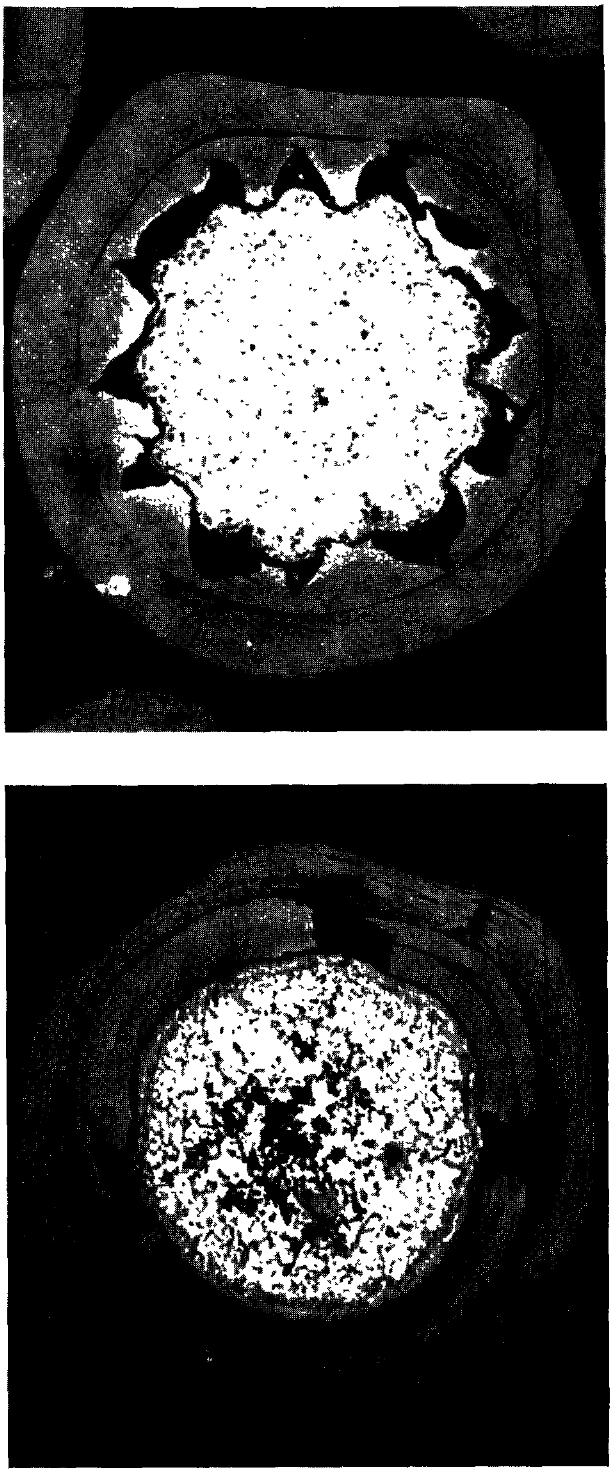

Figure 7. Coated particle fuel after irradiation

Fuel element production

A major aspect of the DRAGON fuel programme has been the development and setting up of facilities to produce and assemble the fuel elements for the Reactor Experiment. The initial production, covering the requirements of the first charge, consists of thirty driver elements with zirconium-uranium ($N = 5$) fuel coated with pyrocarbon, and ten test elements of thorium-uranium ($N = 15$) fuel having silicon carbide/pyrocarbon coatings. The processes used can be summarised as follows.

After characterization, the appropriate powders are fabricated into spheres, using either a rotary sieving technique in the case of the zirconium fuel and a planetary sieving technique for the thorium fuel. These spheroids are reacted and sintered at temperatures up to 2 300 °C to form the fissile-fertile particle. After coating in a fluidised bed the particles are mixed with a resin bonded graphite powder and pressed into annular fuel inserts. The inserts are heat treated to decompose the resin and finally degassed at 1 800 °C. The finished inserts are assembled into previously degassed fuel tubes, the final process being the assembly of the completed rods into a fuel element cluster as shown in Fig. 2.

CHEMICAL PROBLEMS OF THE COOLANT

Graphite corrosion and carbon deposition

The presence in the helium of chemically active gaseous impurities cannot be avoided. Oxidizing impurities such as carbon dioxide and water may lead directly to corrosion of graphite, while other impurities, e.g., carbon monoxide and hydrogen, may be converted in certain areas of the primary circuit into oxidizing species by carbon deposition reactions. These impurities attack the exposed hot graphite core and give rise to carbon transport from the core to other regions of the primary circuit of the reactor. In this process a number of variables are involved including temperatures, types and concentrations of reactants, influence of catalysts, helium flow rates, fast neutron fluxes and gamma radiation intensities and, since graphite is a porous medium, diffusion coefficients in the pores of the material.

To investigate the effects of such a large range of variables, a series of loops and laboratory rigs in which all variables are well defined have been constructed and developed. These include one large in-pile facility for investigating the possible influence of gamma radiation and fast neutrons in the BR2 reactor at Mol.

Fig. 8 illustrates a test rig for large sized electrically heated graphite samples operating at 1 atm helium pressure at well defined graphite temperatures between 850° and 1 500 °C. Water and carbon dioxide are the reactants, at concentration levels between 20 and 2 000 vpm and a helium flow rate up to 300 *l*/min, corresponding to a Reynolds' number of 3 000, is achievable.

Gas analysis and a carbon-14 labelling method have been applied to make it possible to follow corrosion rates during burn-off. A similar test loop operating at high pressure in order to simulate more closely the flow conditions expected in a gas-cooled

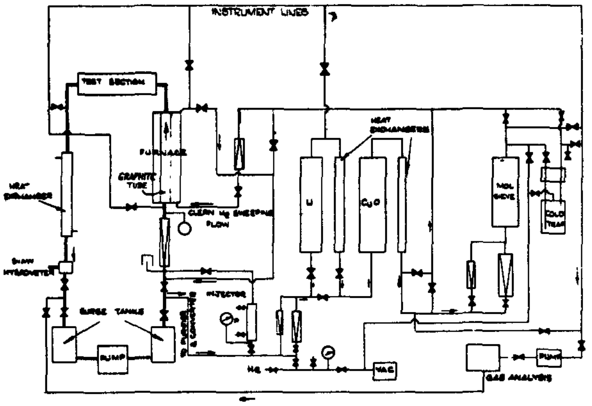

Figure 8. Carbon transport loop (1 atm helium)

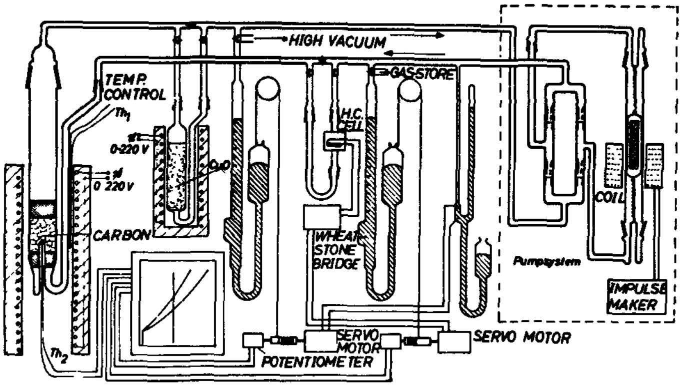

Figure 9. Münster differential reactor

reactor has also been employed. In Fig. 9 a diagram is given of a differential reactor used in the Institute of Physical Chemistry at the University of Münster for obtaining basic information on the pure chemical reactivity of the graphites of interest, the order of reaction, the proper activation energies and the rate decreasing influence of reaction products.

The equipment used for examining the influence of reactor irradiation on the corrosion rate consists in principle of a closed loop with two branches, one going through the BR2 core and one by-passing the reactor. Apart from the neutron and gamma flux the samples in both branches are under exactly the same conditions (temperature, gas composition, gas flow rate) (Fig. 10).

Results of experiments with the various loops have shown that the resin-impregnated graphites are chemically more reactive than the non-impregnated. Chemical purity of the graphite is important, e.g., vanadium and certain other impurities locally distributed can give rise to severe pitting corrosion.

Work at the Central Institute for Industrial Research, Oslo, has revealed that certain fission product metals can have a considerable catalytic influence on the reaction of graphite with water vapour, e.g., catalytic factors of 1 000 and more have been established with small amounts of barium (0.05% by weight). On the other hand, it has been observed that correspondingly small quantities of silica or alumina can inhibit this catalytic activity. Iron is also an important catalyst for the reaction between graphite and water vapour to an extent that depends both on the oxidation state in which iron is present, and on the water vapour and hydrogen concentration in the helium.

In order to calculate the corrosion rate of graphite in different areas of the reactor core, it is essential to have proper information on the graphite-water and graphite-carbon dioxide reaction and also on the order of the reactions as far as reactants and reaction products are concerned. These basic data were obtained with the differential reactor mentioned above. It was observed that the Hinshelwood equation could be used for the interpretation of the data. The data on the reaction rates obtained with the high pressure loop have given information on the transition temperatures from pure chemical reaction to in-pore diffusion control, e.g., 950 ° to 1 050 °C for CO_2 in a typical specimen of resin impregnated fuel tube graphite, and of the transition to the so-called mass transfer controlled regime, e.g., 750 °C for O_2 and 1 100 ° to 1 200 °C for CO_2 and H_2O in helium at 20 atm.

In parallel with the work on graphite corrosion, investigations on the rates of carbon deposition on various metallic surfaces have been carried out for the Project at AERE Harwell and SERAI Brussels. This work is still in an early stage.

All the results mentioned above have been obtained with the out-of-pile rigs. However, the experiments in BR2 show the need for caution in applying the data obtained with out-of-pile experiments in assessing the carbon transport problem in a reactor. An appreciable influence of irradiation has been observed due to the transfer of gamma radiation energy via the helium atoms to reactant molecules like carbon dioxide, leading to increased reaction rates particularly at the lower graphite surface temperatures (below 1 000 °C).

Helium processing

An assessment based on the results of the various experiments leads to the specification of certain maximum levels of impurity concentration in the reactor coolant. The investigation of processes by which the helium may be treated in order to achieve and maintain the necessary degree of purity, has formed an important part of the DRAGON programme. In the Reactor Experiment, the purification of the primary circuit helium is combined with the removal of fission products in the fuel element purge, the successive stages of the combined process being as follows:

(*a*) Removal of volatile fission product metals and delay of halogens in a trap at the bottom of each fuel element;

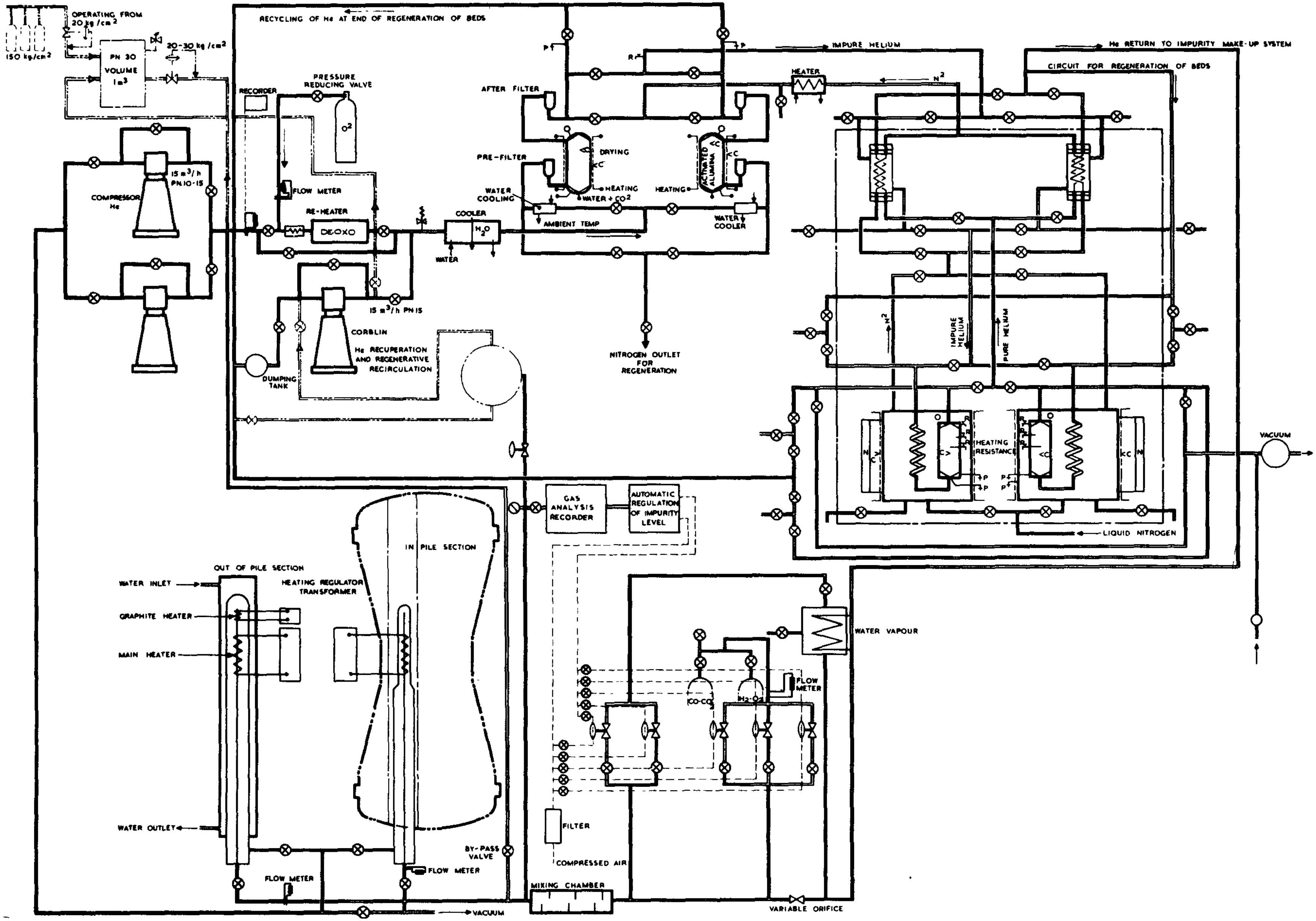

Figure 10. General flow diagram for BR2 loops

(*b*) Condensation of entrained fission product metals in a pre-cooler;

(*c*) Trapping of residual halogens and delay of noble gases in large charcoal delay beds operating at ambient temperatures;

(*d*) The oxidation of hydrogen and carbon monoxide with copper oxide;

(*e*) The freezing out of water and carbon dioxide at sub-zero temperatures;

(*f*) The trapping of long-lived xenon and krypton together with any nitrogen, methane or argon impurities by adsorption on charcoal at liquid nitrogen temperatures.

Each stage of the purification process has been the subject of investigations, both in small laboratory equipment and in a large scale pilot plant. Laboratory scale experiments related to stage (*a*) have shown that even at temperatures up to 450 °C active charcoal was quite adequate for delaying halogens released from the fuel. The delay beds operating at ambient temperature have been found to tolerate a water content of the charcoal up to 0.5% without appreciable effect on their function.

In the pilot plant, stages (*d*), (*e*) and (*f*) have been investigated with particular attention to the freezing out of water and carbon dioxide and to the delay and trapping of xenon and krypton. Two different freezer designs have been examined, a "tube in tube" type of freezer and a "tube in shell" type of freezer with extended surface. The latter has been found to give the better performance.

The delay and trapping of fission product noble gases in the presence of other gases has been examined, not only in the pilot plant, but also with dynamic adsorption measurements on a laboratory scale, with the collaboration of Battelle Memorial Institute, Geneva, and by basic studies on the relevant adsorption equilibria and adsorption rates.

It has been found that the single gas adsorption equilibrium data obtained for xenon and krypton could be fitted into an equation related to Dubinin's extension of Polanyi's theory (Fig. 11). This makes it possible to extrapolate adsorption data over a wide range of temperatures. It was also observed that a characteristic curve for the charcoal used, which represents its properties as an adsorbent for single gases regardless of the adsorbates used, could be obtained following Dubinin's procedure.

In all the investigations in which it has been necessary to specify or control helium purity, a considerable amount of gas analysis has been involved. Since the permissible concentrations of oxidising impurities in helium are extremely low, existing methods including infra-red absorption, gas chromatography, mass spectrometry, ionisation gauges, etc., have had to be extended to the limit of their capabilities. In order to extend further the sensitivity of detection of impurities pre-concentration of these before analysis by conventional equipment has been investigated. One of the methods which has been successfully developed for the Project by the FOM Laboratory, Amsterdam, involves pre-concentration by thermal diffusion.

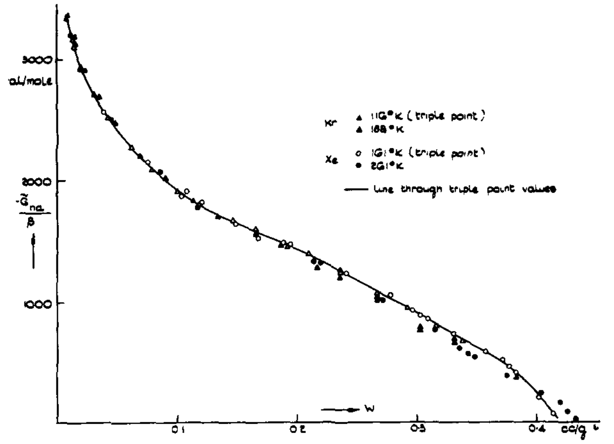

Figure 11. Triple point and 0.9 critical temperature xenon and krypton isotherms (BMI) extrapolated with the entropy method and plotted according to Dubinin

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ABSTRACT - RÉSUMÉ - АННОТАЦИЯ - RESUMEN

A/122 Royaume-Uni

Revue des travaux de recherche et de mise au point dans le projet DRAGON

par L. R. Shepherd *et al.*

Le cycle uranium-thorium dans les grands réacteurs de puissance modérés au carbone est décrit brièvement.

Dans le réacteur expérimental DRAGON, le cœur est petit et il est apparu judicieux d'employer deux types de combustible disposés en deux zones: l'un est un mélange d'uranium-235, de thorium-232 et de carbone dans des proportions qui peuvent être considérées comme valables pour le combustible d'un grand réacteur de puissance; l'autre contient de l'uranium-235 et du zirconium sous forme de monocarbures, et constitue environ les trois quarts du cœur. On décrit les principales caractéristiques de ce cœur du point de vue physique des réacteurs.

L'adoption pour le réacteur expérimental DRAGON d'éléments combustibles drainés a nécessité la mise au point de graphites spéciaux. Les problèmes que pose l'obtention des caractéristiques physiques voulues pour ces graphites et les difficultés de production sont exposés brièvement. Bien que le gaz de refroidissement soit l'hélium, la présence d'impuretés oxydantes entraîne une corrosion et un phénomène de transfert de masse à la surface du graphite. Ce phénomène a été étudié expérimentalement à l'échelle du laboratoire et aussi avec des boucles hors pile et en pile.

Un programme complémentaire de travaux sur la purification de l'hélium pour éliminer les impuretés chimiques et les produits de fission entraînés a aussi été entrepris à l'échelle du laboratoire et dans une installation pilote.

La diffusion des produits de fission et leur comportement à haute température dans les combustibles à base de graphite et de carbures est un des principaux problèmes dans des réacteurs de ce type. Une solution à ce problème consiste à utiliser des particules enrobées de carbone pyrolytique et de carbure de silicium. Les résultats d'expériences d'irradiation d'échantillons divers de combustibles constitués de particules de monocarbures d'uranium et de zirconium et de bicarbures d'uranium et de thorium enrobées sont exposés.

La fabrication des combustibles formés de particules enrobées et l'assemblage des éléments combustibles pour le réacteur expérimental DRAGON se fait sur le lieu d'implantation du réacteur. Une description sommaire du procédé de fabrication est donnée.

A/122 Соединенное Королевство

Обзор научно-исследовательских и опытно-конструкторских работ, связанных с проектом создания реактора DRAGON

Л. Р. Шеперд *et al.*

Дается краткое описание уран-ториевого цикла для крупного энергетического реактора с графитовым замедлителем. В экспериментальном реакторе DRAGON активная зона небольшая, и оказалось желательным использовать два вида ядерного топлива, расположенного в двух зонах. Один вид топлива состоит из U^{235}, Th^{232} и графита в пропорциях, которые могли бы стать типичными для крупных энергетических реакторов. Другой вид топлива включает U^{235} и цирконий в форме монокарбидов; причем этот вид топлива занимает около трех четвертей активной зоны реактора. В докладе рассматриваются основные особенности физики данной активной зоны реактора.

Использование в экспериментальном реакторе DRAGON тепловыделяющих элементов, охлаждаемых потоком газа, потребовало разработки специальных сортов графита. В докладе кратко описываются проблемы достижения требуемых физических характеристик графита и трудности его производства. Хотя в качестве теплоносителя в реакторе используется гелий, однако присутствие окисляющих примесей вызывает коррозию и перенос массы с поверхности облучаемого графита. Это явление изучалось в лабораторных экспериментах, а также в испытательных петлях вне и внутри реактора. В лабораториях и на опытной установке была проведена дополнительная программа работ по очистке гелия от химических примесей и увлекаемых продуктов деления.

Одной из главных проблем, касающихся реактора даного типа, является проблема диффузии продуктов деления и их выделения из графит-карбидного топлива при высоких температурах. Решение этой проблемы нашли в использовании топливных гранул, покрытых пирографитом и карбидом кремния. Рассматриваются результаты экспериментов по облучению различных образцов топлива из гранул, покрытых уран-циркониевым монокарбидом и уран-ториевым дикарбидом.

Производство топлива из таких гранул и изготовление из него тепловыделяющих элементов для экспериментального реактора DRAGON осуществляется на месте сооружения реактора; дается описание производственного процесса.

A/122 Reino Unido

Resumen del trabajo de investigación y desarrollo para el proyecto DRAGON

por L. R. Shepherd *et al.*

Se describe brevemente el ciclo del uranio-torio en un reactor de gran potencia con moderador de carbono. En el experimento del reactor DRAGON, el núcleo es pequeño, y se ha considerado conveniente emplear dos tipos de combustible, dispuestos en dos zonas. Un tipo consiste en uranio-235, torio-232 y carbono, en proporciones que pueden ser típicas de la composición en un reactor de gran potencia. El otro tipo de combustible contiene uranio-235 y circonio en forma de monocarburos, y constituye aproximadamente las tres cuartas partes del núcleo. Se describen las principales características físicas de esta disposición del núcleo.

La adopción del elemento combustible purgado en el experimento del reactor DRAGON ha exigido la producción de grafitos especiales. Se repasan brevemente los problemas que presenta el logro de las características físicas apropiadas en estos grafitos, y las dificultades de producción. Aunque se usa helio como refrigerante, la presencia de impurezas oxidantes produce corrosión y transporte de masa en las superficies de grafito descubiertas. La investigación de este fenómeno se ha llevado a cabo en experimentos a escala de laboratorio, y también en circuitos exteriores e interiores a la pila. Se ha realizado igualmente, a escala de laboratorio y en una planta piloto, un programa de trabajo complementario sobre la purificación del helio para eliminar las impurezas químicas y los productos de fisión arrastrados en la purga.

La difusión de los productos de fisión y su extracción de los elementos de grafito/carburo a altas temperaturas, es uno de los mayores problemas en reactores de este tipo. Se ha buscado una solución al problema en la utilización de partículas revestidas de pirocarbono y carburo de silicio. Se repasan los resultados de las experiencias de irradiación sobre distintas muestras de combustibles de monocarburo de uranio/circonio y bicarburo de uranio/torio, hechos de partículas revestidas.

El proyecto lleva a cabo, en la sede del reactor, la producción de combustibles de partículas revestidas y su adaptación al elemento combustible del experimento del reactor DRAGON. Se da un bosquejo del proceso de producción.

L'essai en puissance d'un noyau VULCAIN

par J. Storrer* et S. Rigg**

Le Programme anglo-belge de recherche et de développement du réacteur VULCAIN comprend notamment l'essai en puissance d'un cœur de ce type. Cette expérience aura lieu de 1965 à 1968 à Mol (Belgique) dans la centrale atomique BR3 du Centre d'étude de l'énergie nucléaire (CEN) et constitue une des étapes importantes en vue de la construction d'un prototype de réacteur VULCAIN compact [1].

Le fonctionnement du réacteur VULCAIN est fondé sur le principe de la modération variable: le refroidissement et la modération du cœur sont notamment assurés par un mélange d'eaux lourde et légère dont on réduit périodiquement la teneur en eau lourde pour compenser les pertes de réactivité résultant de l'épuisement du combustible. Ce procédé permet de fonctionner en puissance sans barres absorbantes dans le cœur et conduit par conséquent à une meilleure économie neutronique et à une durée de vie accrue.

Les buts principaux de l'essai BR3/VN peuvent se résumer comme suit: i) observer le comportement du combustible à des taux d'épuisement élevés, ii) relever les caractéristiques opératoires d'un cœur VULCAIN tout au long de sa vie, iii) essayer des circuits d'eau lourde à haute pression, iv) éprouver divers équipements particuliers tels que les mécanismes hydrauliques de barres d'arrêt.

Le présent mémoire décrit brièvement le cœur BR3/VN et son instrumentation. Il souligne de plus les principaux problèmes rencontrés lors de l'adaptation des circuits primaires du BR3 à l'emploi de mélanges D_2O/H_2O; ces circuits avaient en effet été construits à l'origine pour de l'eau sous pression, et c'est la première fois non seulement que l'on réalise pareille conversion, mais également qu'un réacteur utilise de l'eau lourde à des pression et température aussi élevées que 140 kg/cm^2 et 262 °C respectivement. On trouvera pour terminer quelques remarques sur le programme d'exploitation envisagé.

La centrale BR3 fonctionne en puissance depuis octobre 1962 avec son premier cœur qui sera épuisé en août 1964. Les modifications VULCAIN prendront alors cinq mois qui seront suivis de la période d'essai des circuits avec de l'eau légère et au cours de laquelle on chargera le combustible. Après d'autres essais avec le mélange initial de D_2O/H_2O, la centrale BR3/VN doit être mise en service au cours de l'été 1965 et fonctionnera pendant environ trois ans.

PROBLÈMES DE CONCEPTION ET DE MISE AU POINT DES INSTALLATIONS BR3/VULCAIN

La puissance électrique nette de la centrale BR3 est égale à 10,5 MW et correspond à une puissance thermique de 40,9 MW au réacteur. L'eau pressurisée à 140 kg/cm^2 alimente le générateur de vapeur à une température de 269 °C et retourne ensuite au réacteur par deux tuyauteries comportant chacune sa pompe de circulation et son clapet antiretour. Le débit primaire atteint 2 800 m^3/h dont 90% traversent le cœur. Les circuits auxiliaires, à l'exception évidemment du circuit de mise sous pression, sont à basse pression (10 kg/cm^2 maximum) et se trouvent dans une cave adjacente au bâtiment du réacteur.

Les modifications aux installations existantes, et les problèmes de conception et de mise au point qui en découlent, proviennent de l'emploi d'un cœur complètement différent et utilisant un mélange à base d'eau lourde pour son refroidissement et sa modération. La cuve du réacteur, notamment, doit être munie de nombreuses traversées supplémentaires et ses parties internes doivent être remplacées. On a dû mettre au point non seulement des assemblages de combustible, des tubes « modérateurs » en zircaloy, des barres absorbantes et leurs mécanismes, mais également une instrumentation très complexe du cœur. Un système original d'aspersion a été conçu et éprouvé pour assurer le refroidissement du combustible pendant la purge du mélange D_2O/H_2O et l'introduction de l'eau légère qui doit permettre l'emploi du système actuel de remplacement du combustible sous eau. Enfin, les circuits d'eau primaire ont été modifiés pour recueillir les fuites, réduire les pertes vers l'atmosphère et vers les circuits d'eau légère et éviter tout risque d'accident de réactivité par injection intempestive d'eau légère.

Ces questions ont été étudiées en détail et les solutions retenues ont fait l'objet d'analyses et d'essais permettant de vérifier leurs possibilités de réalisation et de réduire leur coût.

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CUVE ET PARTIES INTERNES DU RÉACTEUR (fig. 1)

Les nouveaux équipements ne peuvent être introduits dans le bâtiment du réacteur que par le sas d'entrée de 1,04 m sur 1,97 m. Le couvercle du réacteur ne pouvait dès lors être remplacé et on a dû insérer un collier de 305 mm de hauteur (diamètre extérieur 1 715 mm) entre les brides de la cuve pour permettre les nombreuses traversées nécessaires à l'instrumentation, au circuit d'aspersion et aux mécanismes de barres hydrauliques. Soixante-seize traversées sont prévues et leurs diamètres sont compris entre 17 et 54 mm. Cette dernière dimension est limitée par l'intervalle entre les goujons assurant la fermeture de la cuve; les 32 goujons existants doivent par ailleurs être remplacés par des pièces plus longues. Le collier est en acier au carbone, plaqué, sauf sur sa partie extérieure, de 7 mm d'acier inoxydable auquel les tuyauteries de traversée de même métal sont soudées.

Le couvercle du réacteur possède douze traversées pour mécanismes de barres à vérins magnétiques. Dix de ces mécanismes seulement seront utilisés, de manière à libérer deux traversées pour le raccordement d'appareils de mesure du flux neutronique comme indiqué plus loin.

Toutes les parties internes, à l'exception de l'écran thermique, seront donc remplacées. Ces nouvelles pièces sont en acier inoxydable 18/8 et comprennent: i) un panier de support du cœur prenant appui à hauteur de la bride de la cuve, ii) une plaque de maintien du cœur avec caisson d'arrosage, iii) les plaques attachées au collier et portant les gaines des mécanismes de barres magnétiques ainsi que le « panier » qui contient les tubes guides pour l'instrumentation du cœur. Une enveloppe en acier inoxydable entoure le cœur et le sépare du réflecteur. Elle est nervurée horizontalement et verticalement de manière à réduire la quantité de matière neutrophage, l'épaisseur de sa paroi ne dépassant pas 1,6 mm.

DESCRIPTION GÉNÉRALE DU CŒUR

Le cœur (fig. 2) comprend des assemblages de combustible et des tubes « modérateurs », ces derniers permettant l'introduction de barres neutrophages. On a choisi un réseau de cellules hexagonales toutes identiques. Cette solution permet de ne décider de l'emplacement respectif du combustible et des barres qu'à un stade avancé de l'étude, et se prête facilement à l'obtention de cœurs plus grands par ajout de cellules périphériques. Bien que le réacteur VULCAIN ne doive comprendre que des barres d'arrêt [1], le cœur BR3/VN sera muni de barres qui pourront être utilisées aussi bien pour le réglage que pour l'arrêt, de manière à assurer un maximum de souplesse de fonctionnement. Deux cellules ont été situées à l'aplomb de mécanismes existants de barres BR3 et leurs positions ont fixé le pas du réseau des 91 cellules. Les huit autres mécanismes BR3 utilisés seront légèrement décentrés par rapport aux barres qu'ils actionnent. Il y a, de plus, huit tubes modérateurs dont quatre contiennent des barres hydrauliques.

L'eau traverse le cœur de bas en haut. Son débit est de 2 500 m^3/h, dont 2,5% seulement parcourent les tubes modérateurs. Le réfrigérant et le modérateur ne sont d'ailleurs séparés que dans le cœur et leur vitesse y atteint 2 m/s et 0,2 m/s respectivement.

On sait que les barres absorbantes seront normalement hors du cœur lors du fonctionnement en puissance; afin de maintenir le réacteur critique tout au long de sa vie, la teneur du mélange D_2O/H_2O sera graduellement réduite de 85 à quelques pour cent. L'enrichissement initial de 7% en ^{235}U doit permettre d'atteindre environ 25 000 MWj/t U, soit quelque 15 000 heures à pleine puissance, malgré les pertes de réactivité dues à l'instrumentation du cœur et aux nombreux échantillons à irradier. On pourra augmenter en fin de vie la réactivité disponible en modifiant la disposition des assemblages combustibles ou en remplaçant certains de ceux-ci par du combustible neuf. Ceci doit permettre d'irradier certains barreaux combustibles jusqu'à rupture de gaine.

Les calculs et expériences de physique font l'objet d'une communication séparée [2]. Les études de flux de claquage (*burn-out*) ont été basées sur les formules courantes et sur les résultats expérimentaux obtenus lors d'essais spéciaux.

ASSEMBLAGES DE COMBUSTIBLE

Le barreau de combustible est constitué essentiellement d'un empilement de pastilles d'UO_2, d'un diamètre de 7,5 mm, dans des tubes à soudure longitudinale en acier inoxydable 18/8 écroui de 0,5 mm d'épaisseur. Il doit permettre d'atteindre un minimum de 40 000 MWj/t U dans les pastilles les plus sollicitées. Cependant les marges de sécurité sont telles que des taux de combustion nettement plus élevés devraient pouvoir être atteints par endroits, ce qui en fait constitue un des principaux sujets d'intérêt de l'expérience BR3/VN.

Le barreau est obturé aux deux bouts par des bouchons soudés et sa longueur totale atteint 1 235 mm, dont 1 000 mm de combustible. La densité des pastilles a été limitée pour tenir compte du gonflement et chaque pastille possède en outre une cuvette à chaque extrémité pour assurer un espace libre supplémentaire, dont une partie est d'ailleurs comblée par la dilatation thermique de l'UO_2. De cette manière, la gaine ne sera pas mise sous tension pour un taux de combustion atteignant 40 000 MWj/t U. Ceci suppose que l'UO_2 remplira les cuvettes, ce que l'expérience déjà accumulée tend à démontrer. On a prévu également un espace libre au sommet du tube pour éviter que la pression des gaz de fission ne dépasse la pression de l'eau primaire même en fin de vie. Un ressort en alliage réfractaire comprime la colonne de combustible par

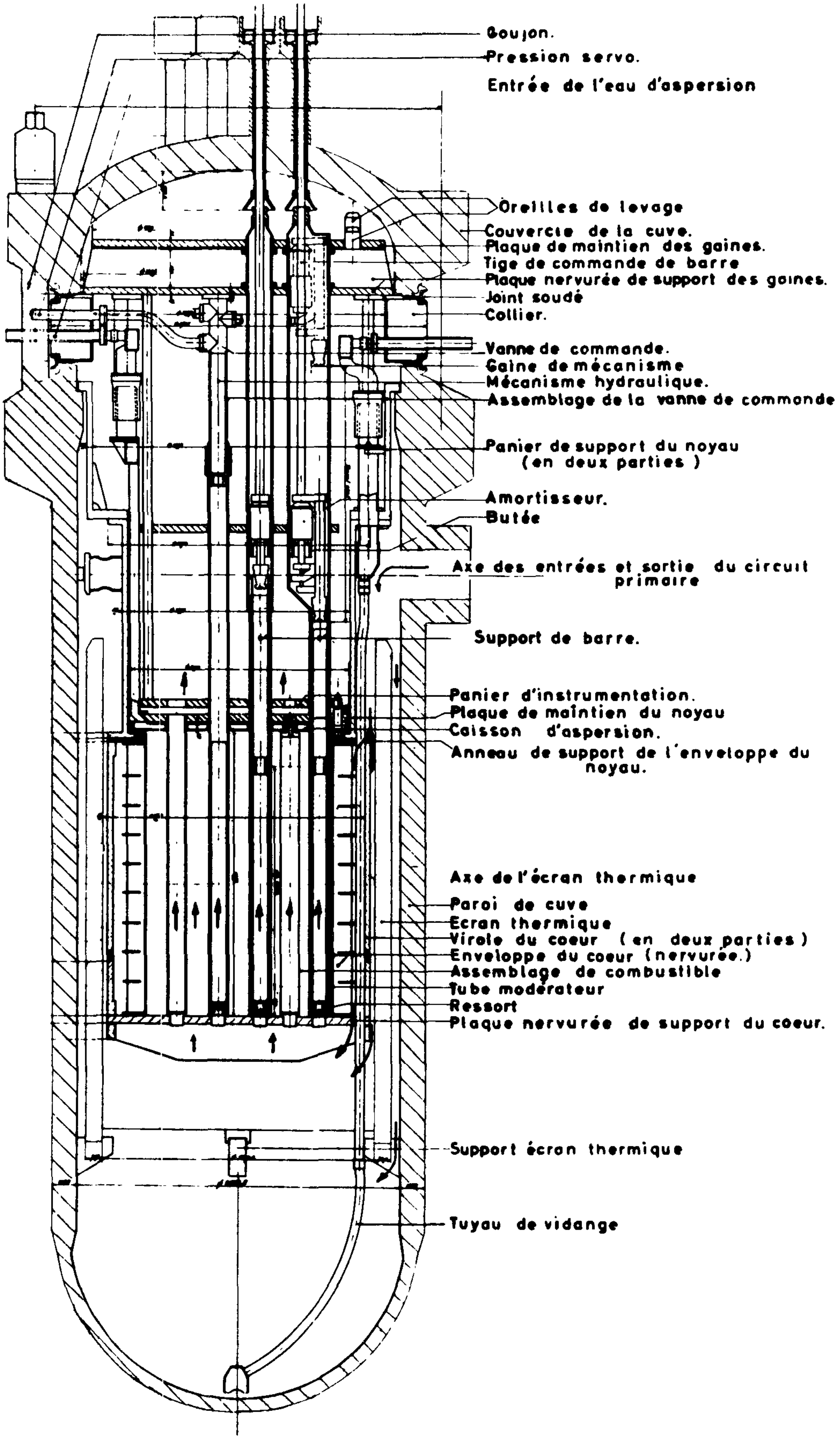

Figure 1. Cuve du réacteur (sans instrumentation en pile)

l'intermédiaire d'une pastille d'Al_2O_3. Une pastille de même matériau et longue de 100 mm se trouve sous la colonne et réduit la quantité de matériaux structuraux dans le réflecteur inférieur.

La densité de puissance et flux thermique moyens du barreau atteindront respectivement 15,2 kW par mètre de longueur active et 57 watts par cm^2 de gainage. On a calculé qu'avec le remplissage à l'hélium la température centrale de la pastille la plus chaude ne dépassera pas 1 750 °C.

Six des 73 assemblages combustibles sont constitués de barreaux de même diamètre extérieur que les autres mais de paroi réduite à 0,38 mm. Ceci permettra d'observer la tenue de gaines ayant une plus faible marge de sécurité à l'écrasement.

La disposition générale d'un assemblage combustible est représentée aux figures 3 et 4. Il comprend une botte hexagonale de 37 barreaux au pas de 13,7 mm. Ces barreaux sont retenus à leur base par une plaque perforée permettant le passage de l'eau et soudée à l'intérieur d'une enveloppe en acier inoxydable écroui. Cette enveloppe est percée de trous triangulaires qui ont été choisis après des essais de résistance et d'écoulement.

Cinq grilles et deux pièces d'extrémités sont soudées dans l'enveloppe. Les grilles permettent la dilatation axiale des barreaux tout en empêchant leur déplacement radial et leur flexion due aux gradients thermiques. La tête de l'assemblage est conçue de manière à permettre le passage des barreaux. Ceux-ci peuvent ainsi être chargés en tout dernier lieu. Cette opération se fera d'ailleurs sur le site pour éviter toute déformation des grilles lors du transport.

Le volume total de matériaux structuraux dans le cœur ne dépasse pas 20% du volume des gaines de barreaux.

Des études et des essais poussés ont permis la mise au point des différentes pièces constituant l'assemblage combustible. Parmi ces essais, mentionnons le cyclage thermique de barreaux, la vérification de la tenue des grilles et la sollicitation de l'enveloppe en compression, torsion et flexion. Un assemblage prototype a finalement été soumis dans une boucle d'essai aux conditions de température, pression et débit régnant dans le BR3.

La moitié des assemblages combustibles est fournie par le « Production Group » de la UKAEA, tandis que l'autre moitié est fabriquée par la société belge MMN à partir de poudre d'UO_2 fournie par « Métallurgie Hoboken ». Cette dernière a été approvisionnée en UF_6 par la UKAEA.

TUBES MODÉRATEURS, BARRES DE CONTRÔLE ET D'ARRÊT ET LEURS MÉCANISMES

Sur un total de 18 tubes modérateurs, il y aura 14 tubes courts (1,4 m) et 4 tubes longs (2,5 m), ces derniers guidant les barres neutrophages commandées hydrauliquement. Ils sont fabriqués en zircaloy 4 qui absorbe moins l'hydrogène que le zircaloy 2. Les tubes ont un diamètre intérieur de 80 mm et un contour hexagonal de 85,4 mm sur pans. Ils sont obtenus par filage et étirage et sont recuits sous vide. Seuls les longs tubes sont ensuite usinés intérieurement. Tous les tubes sont finalement décapés et recouverts en autoclave d'une couche protectrice d'oxyde noir. La partie supérieure des tubes longs aurait pu être constituée d'acier inoxydable puisqu'elle ne se trouve pas dans le cœur mais le temps disponible n'a pas permis de mettre au point un joint satisfaisant entre ce matériau et le zircaloy.

Chaque tube est centré à la base par un trou circulaire dans la plaque de support du cœur et le débit d'eau y est réglé par un orifice approprié. Les tubes sont par contre ouverts au sommet: les tubes courts y sont maintenus en place par la plaque de maintien du cœur tandis que les tubes longs sont centrés par les assemblages des vannes de commande des mécanismes hydrauliques, comme décrit plus loin.

Quatre tubes courts ne contiendront pas de barres mais seront munis d'instrumentation, d'échantillons à irradier et d'une source primaire et d'une source secondaire de neutrons.

Un des désavantages de matériaux tels que l'acier au bore pour les barres neutrophages de réacteurs de puissance provient de leur consommation sous irradiation, avec comme conséquence une perte d'efficacité et un certain gonflement. Ceci est évité dans le cas d'un réacteur VULCAIN puisque ses barres sont hors du cœur lors du fonctionnement en puissance et retirées à une distance suffisante pour que même leur base ne soit exposée qu'à des flux de neutrons thermiques acceptables.

Les barres tubulaires BR3/VN de 68/78 mm de diamètres et 1 035 mm de longueur sont du type trappe à neutrons. Elles sont coulées par centrifugation en acier inoxydable 18/16 non gainé, contenant 2% en poids de bore, et l'épaisseur brute de 15 mm est réduite à 5 mm par usinage. La résistance de ces barres a été éprouvée par de nombreux essais. C'est ainsi par exemple qu'une pièce tubulaire d'une longueur de 40 mm a résisté à une force de compression radiale de 1 200 kg avant l'apparition de fissures. Une autre pièce d'essai, longue de 220 mm et reposant sur des arêtes vives distantes de 160 mm, a été soumise en son milieu à l'impact d'un mouton de 18 kg tombant de 1 mètre de hauteur; des amorces de fissures ne sont apparues qu'après une douzaine de chocs et uniquement aux appuis et au point d'impact.

L'excentricité de huit des dix mécanismes est comprise entre 35 et 80 mm (fig. 5). La base de la barre coulisse dans un tube modérateur court en zircaloy tandis que son support en acier inoxydable est guidé dans une gaine de même matériau. La gaine des mécanismes excentrés a une section horizontale en forme de 8 tout au long de la course de la tige de commande. Le grappin peut être ouvert à distance lors du déchargement du combustible, la

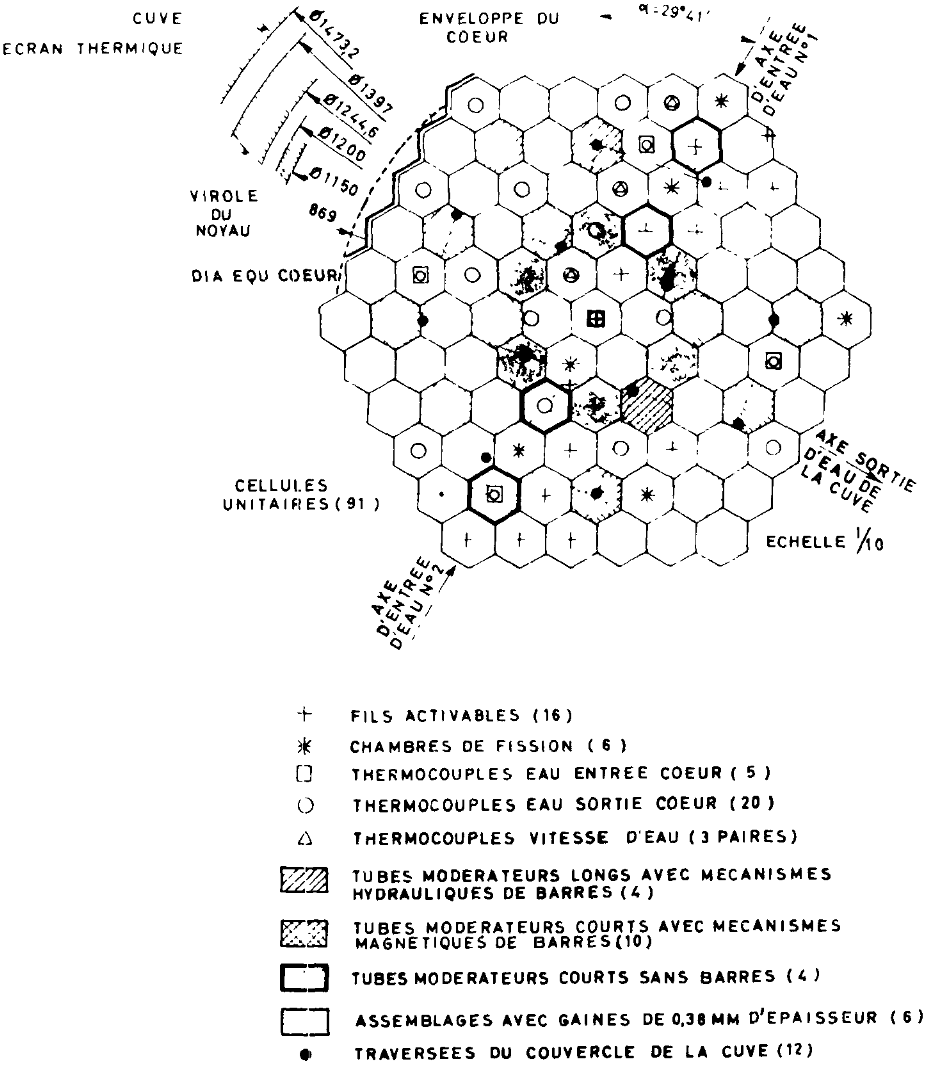

Figure 2. Coupe du cœur BR3/VN avec instrumentation

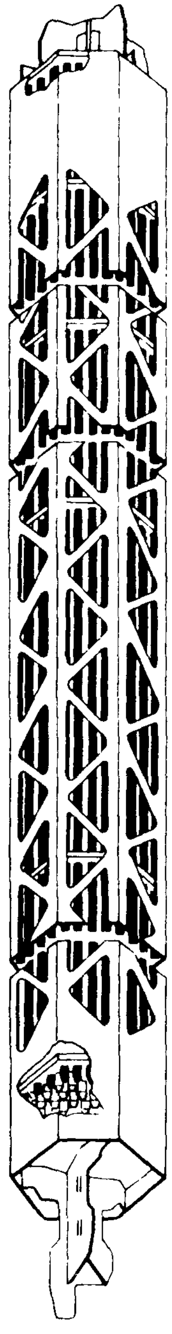

Figure 4. Assemblage de combustible

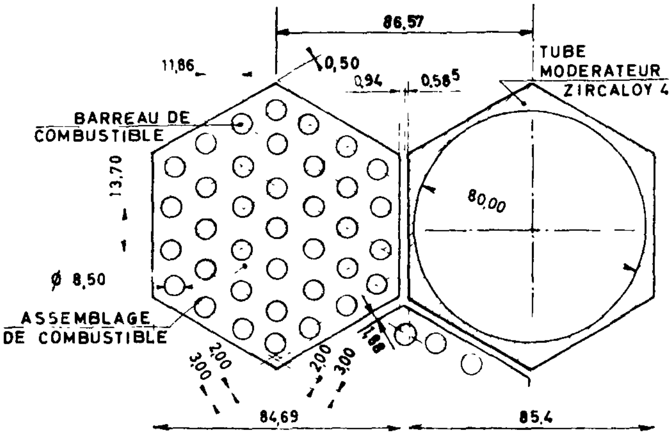

Figure 3. Assemblage de combustible et tube modérateur

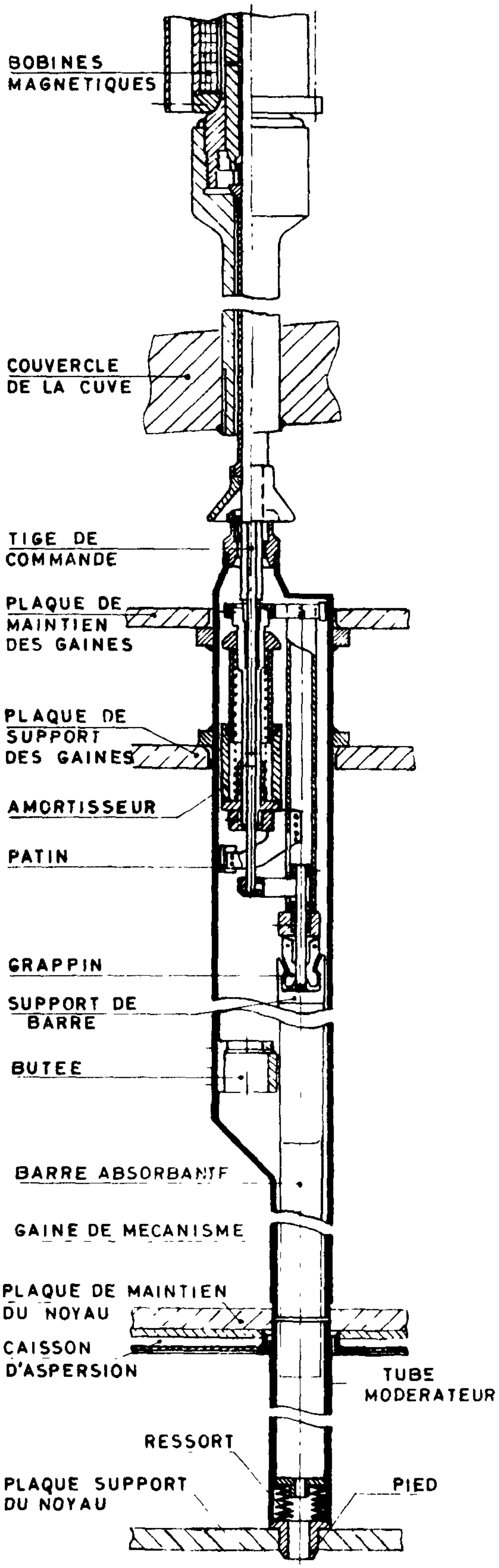

Figure 5. Mécanisme magnétique de barre

barre prenant alors appui à sa base sur un ressort prévu au pied du tube modérateur. Les gaines sont centrées à leur partie inférieure par la plaque de maintien du cœur et suspendues à la plaque de support attachée au collier. Elles reprennent le choc des parties mobiles des mécanismes de contrôle lors de la chute (*scram*) quand l'amortisseur solidaire de chaque tige de commande heurte la butée attachée à la gaine; la flexion de la tige de commande est empêchée par des patins situés de part et d'autre de l'amortisseur et coulissant dans la gaine. Des essais hors pile en eau froide ont permis de vérifier le bon fonctionnement de ces dispositifs peu courants.

Quatre barres sont mues hydrauliquement (fig. 6). Elles sont semblables aux autres barres mais sont pourvues d'un fond muni d'un petit trou et de deux colliers en zircaloy réduisant le jeu entre tube et barre.

Dans ce type de mécanisme hydraulique la barre monte ou reste en position haute par suite de la différence de pression entre l'entrée du tube et l'endroit où l'eau primaire quitte la cuve et auquel le sommet du tube est relié par l'intermédiaire d'une vanne de commande. Cette dernière permet également de relier le sommet du tube à l'entrée d'eau dans la cuve, où règne une pression plus élevée; le débit de modérateur est alors inversé et provoque la chute assistée de la barre de 10 kg, celle-ci étant ralentie en fin de course par un amortisseur approprié. Les tuyauteries de raccordement de la vanne de commande aux sources BP et HP sont donc entièrement situées à l'intérieur de la cuve, tandis que la servo-pression actionnant la vanne est amenée de l'extérieur par une conduite traversant le collier. Cette conduite est branchée par une soupape pilote, soit à une source de haute pression, soit à une source de basse pression, de manière à placer la vanne principale dans la position commandant respectivement la levée ou la chute de la barre. Le système est donc intrinsèquement sûr puisque toute chute de la servo-pression, due par exemple à la rupture de sa conduite, provoque l'insertion de la barre dans le cœur.

La servo-pression haute peut être réglée (fig. 6) par deux vannes manuelles 1 et 2 à toute valeur comprise entre les pressions amont et aval d'une pompe primaire. La vitesse de retrait de la barre dépend en effet non seulement, entre autres causes, de la densité de l'eau primaire, mais aussi de la position intermédiaire de la vanne de commande qui est déterminée par la valeur de la servo-pression agissant sur un ressort.

La servo-pression basse devant assurer l'arrêt d'urgence (*scram*) peut être réglée entre la pression amont de la pompe et la pression atmosphérique. Le temps de réponse de la vanne de commande, et partant le délai d'arrêt d'urgence, est en effet lié à la valeur de la servo-pression basse.

La position et la vitesse de chaque barre sont indiquées par un dispositif électromagnétique.

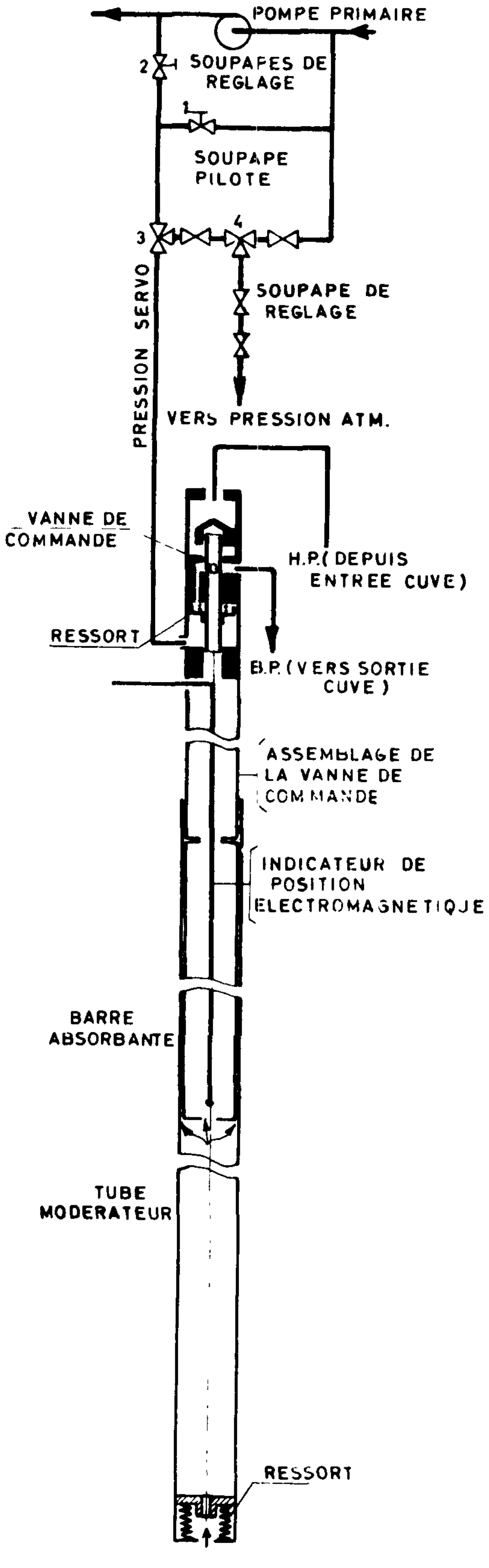

Figure 6. Schéma de mécanisme hydraulique de barre

Chaque barre est en outre munie de son propre système de vanne de commande et soupape pilote afin d'assurer un maximum de souplesse. Les vannes de commande et leurs tuyauteries de raccordement à l'intérieur du réacteur font partie de l'assemblage du collier; les jonctions avec les tuyauteries HP et BP et avec les tubes modérateurs longs munis de leurs barres sont assurées par des joints munis de segments d'étanchéité.

Un des quatre mécanismes hydrauliques est pourvu d'instruments de mesure pour l'enregistrement de ses principales caractéristiques d'opération.

Les mécanismes hydrauliques ne sont installés que près de la périphérie du cœur afin de réduire la réactivité reprise par les barres de ces systèmes expérimentaux, de raccourcir leurs tuyauteries et de faciliter le passage de l'instrumentation du cœur.

Un mécanisme hydraulique prototype a été essayé à température ambiante dans du kérosène, dont la densité est proche de celle de l'eau primaire à sa température de service. Il sera aussi essayé dans un banc d'essai à chaud, parallèlement à la mise en service des mécanismes dans le réacteur BR3 en l'absence de combustible, les pertes de charge dues au cœur étant simulées par des étranglements prévus dans la plaque de maintien du cœur.

Les dix barres à mécanismes magnétiques permettent l'arrêt à froid du réacteur sous D_2O/H_2O, à l'aide, si nécessaire, d'une petite quantité d'acide borique dissout dans l'eau qui peut être enlevée par un déminéraliseur lors du redémarrage. Ces barres peuvent donc assurer le contrôle complet du réacteur et sa sécurité, ce qui a été jugé indispensable du fait que les mécanismes hydrauliques doivent encore être éprouvés. Les barres de ces derniers contribueront cependant à augmenter la marge d'antiréactivité disponible à l'arrêt.

INSTRUMENTATION EN PILE [3]

On sait que le but essentiel de l'expérience BR3/VN est d'établir les caractéristiques d'un cœur VULCAIN jusqu'à des taux de combustion élevés. Un grand nombre d'instruments de mesure est donc nécessaire pour vérifier la validité du modèle théorique et garantir une marge de sécurité adéquate durant le fonctionnement du réacteur.

Les points de mesure (fig. 1) sont les suivants:

a) *Température de l'eau* (thermocouples en chromel-alumel): i) entrée et sortie du cœur (5 + 16 points); ii) réflecteur, fond et sommet de la cuve (3 points); iii) sortie du modérateur (2 points); iv) si possible, sortie des chenaux chauds (2 points).

b) *Flux neutronique*: i) distribution axiale du flux thermique ($1/v$) en 16 points dont 2 dans le modérateur et 14 dans des tubes remplaçant des barreaux combustibles (dysprosium et manganèse); ii) mesures locales du spectre neutronique par matériau fissile en 6 quelconques des 16 points ci-dessus; iii) mesure locale du flux neutronique par six chambres de fission.

c) *Vitesse de l'eau*: débit à la sortie de 3 assemblages combustibles, par mesure du temps de transport de l'eau entre 2 thermocouples espacés de quelque 23 cm.

d) *Température de gaine*: par thermocouples enrobés dans les gaines de quelques barreaux combustibles; ce type de mesure est à l'étude.

Le raccordement de chaque détecteur à l'intérieur de la cuve (fig. 7) est guidé par un tube. Les entrées se font par le collier de la cuve, sauf pour les mesures de flux qui utilisent deux traversées existant dans le couvercle. L'étanchéité de chaque traversée est assurée par deux joints comprimés munis d'un collecteur de fuite intermédiaire. Après dépressurisation on peut remplacer n'importe quel détecteur sans ouverture de la cuve.

Les thermocouples d'eau et les chambres de fission sont immergés tandis que les détecteurs de flux coulissent à l'intérieur de doigts de gant à double paroi (épaisseurs 1,75 et 1,25 mm) avec manomètre intermédiaire signalant tout percement du doigt de gant extérieur. Les doigts de gant plongent jusque dans le cœur et les détecteurs qu'ils abritent sont manœuvrés, individuellement ou en groupe, par une machine située sur les dalles de blindage surplombant le réacteur et munie de 16 moteurs commandés à distance. Après irradiation dans le cœur et refroidissement en dessous des dalles de blindage, les fils activables sont retirés par la machine, individuellement ou par paire, à travers 16 tubes disposés sur un cercle de 112 mm de diamètre. Les activités peuvent alors être mesurées sur place en une vingtaine de points par fil au moyen d'un ou deux compteurs à scintillation montés sur une plaque tournante. Les mesures sont transmises à la salle de comptage et permettent d'établir les cartes de flux. Les échantillons fissiles par contre doivent être retirés manuellement de la machine sous la protection d'écrans appropriés et portés à la salle de comptage. La périodicité des mesures sera de l'ordre de 10 et 40 semaines respectivement pour les fils activables et les échantillons fissiles.

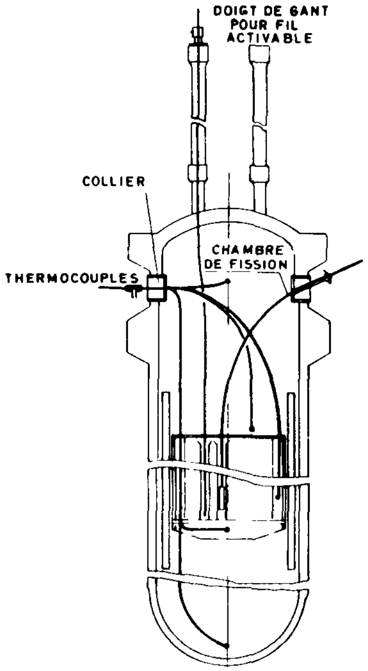

Figure 7. Trajets d'instrumentation

Un processeur à 50 entrées, à 20 scrutations par seconde au maximum, recueillera les données des thermocouples, des chambres de fission et des appareils de mesure les plus importants montés sur les circuits extérieurs à la cuve.

On étudie également la possibilité d'installer un oscillateur de réactivité dans un double doigt de gant spécial descendant jusque dans un tube modérateur et prenant la place d'une des dix barres de contrôle. Cet oscillateur serait basé sur le principe du mouvement alternatif d'un tube à l'intérieur d'un autre, chacun de ces tubes comprenant des bandes successives d'acier inoxydable avec et sans bore. Cet oscillateur doit pouvoir provoquer des perturbations totales de $10^{-3}\delta k/k$ avec des fréquences comprises entre 0,005 et 1 Hz.

DÉCHARGEMENT ET RECHARGEMENT DU COMBUSTIBLE

Le réacteur BR3 actuel se décharge sous eau. Cette méthode pourrait être utilisée en fin de vie du cœur BR3/VN puisque l'eau primaire ne contiendra pratiquement plus d'eau lourde à ce moment. Elle n'est évidemment pas directement applicable lors de déchargements intermédiaires dont l'éventualité ne peut être écartée à priori.

Diverses méthodes ont été examinées. L'une de celles-ci consiste dans l'emploi d'une machine blindée de déchargement, le mélange D_2O/H_2O demeurant dans le réacteur. Le dispositif actuel peut également être utilisé à condition de remplacer préalablement le mélange primaire par de l'eau légère sans interrompre pour autant le refroidissement du cœur. Trois méthodes de substitution ont été étudiées: i) dilution progressive du mélange D_2O/H_2O par de l'H_2O; ii) purge du mélange D_2O/H_2O par un liquide intermédiaire que l'on sépare ensuite par centrifugation ou évaporation, et purge de ce liquide par de l'H_2O; iii) purge sous pression de gaz, suivie de l'introduction d'H_2O, avec refroidissement intermédiaire par le gaz ou une recirculation du mélange D_2O/H_2O aspergeant le combustible.

Cette dernière méthode, dite « d'aspersion », a été choisie dans le cas qui nous occupe. L'efficacité de l'aspersion a été démontrée dans un banc d'essai (fig. 8) utilisant un assemblage de combustible postiche. Chacun des 17 tubes contenait une chaufferette électrique pouvant fournir une puissance maximale de 300 watts, équivalente à six fois la puissance moyenne dégagée par un barreau une semaine après l'arrêt du réacteur. Dix de ces tubes étaient munis chacun de cinq thermocouples enrobés

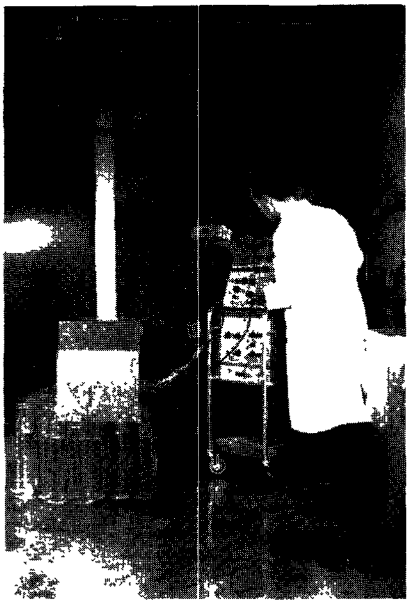

Figure 8. Banc d'essai d'aspersion de combustible

dans la gaine et raccordés par l'intérieur des tubes afin d'éviter toute perturbation de l'écoulement.

De l'eau à 15 °C et à 95 °C a été pulvérisée à l'aide de divers pommeaux sur des tubes chauffés ou non, et collectée séparément à la base de chaque tube. Les tensions aux bornes des 50 thermocouples étaient relevées en 2 secondes, amplifiées et envoyées à un oscilloscope dont on pouvait photographier l'écran.

La solution retenue consiste dans l'emploi d'eau à température ambiante pulvérisée à travers des trous de 1,5 et 1,7 mm de diamètre prévus dans un caisson solidaire de la partie inférieure de la plaque de maintien du cœur. On a constaté qu'avec ce dispositif la température moyenne des thermocouples s'établissait aux environs de 55 °C (la température maximale atteignant 108 °C) pour une puissance unitaire de 300 watts par barreau et un débit par assemblage aussi faible que 5 l/min. Ce procédé de refroidissement offre donc toute garantie d'efficacité.

Des plaquettes de diverses épaisseurs et pourvues de trous de 0,7 à 3 mm de diamètre ont été installées dans le BR3 pour mettre en évidence un colmatage éventuel.

Notons que durant la purge de l'eau du réacteur le niveau d'eau est indiqué par une sonde introduite après retrait d'un doigt de gant d'instrumentation. Le système d'aspersion comprend deux circuits à l'extérieur du réacteur, l'un pour le mélange D_2O/H_2O et l'autre pour de l'eau légère boriquée. Chacun de ces circuits est muni d'un réservoir de stockage, de deux réfrigérants et de deux pompes et n'est raccordé à la cuve que lors des purges d'eau. Le caisson d'aspersion est cependant relié en permanence au système d'injection de sécurité qui doit submerger le cœur dans le cas de la rupture d'une tuyauterie primaire.

Après rechargement du combustible l'eau boriquée est remplacée de la même manière par le mélange D_2O/H_2O.

CIRCUITS D'EAU PRIMAIRE

L'adaptation des circuits primaires a constitué un des problèmes majeurs lors de la conversion du BR3 en raison du coût élevé de l'eau lourde. On a dû en effet vérifier soigneusement l'étanchéité des circuits existants et étudier les possibilités de réduire, non seulement les pertes d'eau, mais également les *fuites récupérables* qui augmentent la charge des circuits de recueil et de réinjection.

Les pertes d'eau primaire ont été mesurées en opération par différence entre les quantités d'eau d'appoint et de récupération et par détection d'eau tritiée dans l'air de ventilation. D'après les premiers résultats obtenus ces pertes seraient inférieures à 1 ou 2 kg/h. On s'efforcera d'en repérer les sources lors des travaux d'adaptation et de les supprimer dans toute la mesure possible. Aux raccordements entre circuits de D_2O et de H_2O, des systèmes à trois vannes avec tuyaux de collecte intermédiaires assureront l'isolement nécessaire.

Les tiges de vannes étaient munies de doubles garnitures avec collecteurs de fuites maintenus sous une légère dépression. Ces fuites ont été mesurées à l'aide d'appareils conçus spécialement et se sont révélées négligeables; celles qui atteignaient quelques cm^3/h ont été supprimées après remplacement des garnitures.

En plus de l'installation du nouveau système d'aspersion déjà cité, les modifications aux circuits existants ont porté en ordre principal sur: i) le circuit de purge et d'évents, avec récupération de l'eau en circuit fermé et décharge à la cheminée à travers une trappe froide réduisant à 0,2% l'humidité des gaz rejetés; ii) le circuit d'appoint, où l'on doit empêcher toute introduction intempestive d'eau légère pouvant conduire à un accident de réactivité; iii) le circuit d'injection de sécurité, où l'eau utilisée doit être boriquée dès les premiers instants.

EXPLOITATION

La centrale BR3 est exploitée par le « Groupe industriel pour l'exploitation du BR3 » sous le contrôle du CEN. Le programme d'exploitation BR3/VN devra simuler dans la mesure du possible les conditions de fonctionnement d'un réacteur VULCAIN et comprend notamment: i) l'exploitation du réacteur toutes barres dehors, avec addition périodique d'eau légère. Les variations de réactivité à court terme seront compensées par les barres de contrôle bien que le système VULCAIN sera essayé régulièrement: il s'agit d'un réglage par variation de la température moyenne de l'eau et par poison soluble pour compenser respectivement l'effet Doppler et l'empoisonnement Xénon. Son emploi permanent n'est pas possible au BR3 par suite de limitations propres à l'installation; ii) le fonctionnement périodique à pression réduite jusqu'au niveau (90 kg/cm^2) proche de l'ébullition à la sortie du chenal le plus chaud; iii) le cyclage thermique du combustible pour simuler le fonctionnement d'un réacteur marin qui est une des applications les plus prometteuses du réacteur VULCAIN.

L'étude de ces essais sera grandement facilitée par l'instrumentation du cœur.

REMERCIEMENTS

Cette communication résume les travaux d'étude et de mise au point de nombreuses personnes appartenant aux organismes suivants: Marine Reactor Design Office et Reactor Engineering Laboratory, Risley; Reactor Fuel Laboratory, Springfields; Reactor Materials Laboratory, Culcheth; Fairey Engineering, Stockport; BelgoNucléaire, Etude et Construction Evence Coppée-Rust (ECEC), SERAI, Bruxelles; Métallurgie et Mécanique Nucléaires (MMN), Dessel; Fabrique Nationale d'Armes de Guerre (FN), Herstal; Cockerill-Ougrée, Seraing et Hoboken; Mercantile Marine Engineering & Graving Docks C^o, Anvers; Métallurgie Hoboken, Hoboken; Electro-Navale & Industrielle (ENI), Aartselaar; Henricot, Court-St-Etienne; etc. avec la coopération du CEN et du Groupe d'exploitation du BR3.

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ABSTRACT - RÉSUMÉ - АННОТАЦИЯ - RESUMEN

A/515 Belgium

The VULCAIN core power experiment

By J. Storrer and S. Rigg

The Joint Anglo-Belgian programme of research and development on the VULCAIN reactor calls for the power operation of a VULCAIN core. This experiment will take place from 1965 to 1968 in the BR3 nuclear power plant at Mol, Belgium, on the site of the Centre d'étude de l'énergie nucléaire (CEN).

The VULCAIN reactor type is based on the variable moderation principle, using varying proportions of light and heavy water to compensate for the decreases in reactivity due to fuel depletion. It permits power operation with all absorber rods out of the core, leading to improved neutron economy and longer core life.

The main objectives of the experiment can be summarized as follows: (i) to determine the fuel behaviour at high burn-ups, (ii) to verify the design parameters of a VULCAIN core and its behaviour during the whole core life, (iii) to gain experience in high pressure D_2O systems and (iv) to test various pieces of equipment.

The modifications to the BR3 plant will take place during the latter part of 1964, after the first pressurized water core has been used up. They consist mainly in the adaptation of (i) the BR3 reactor vessel to the use of a VULCAIN core and (ii) the primary plant to the use of a H_2O-D_2O mixture.

The internal equipment of the reactor vessel is to be completely replaced. Ten absorbing rods will be operated by the existing magnetic jack mechanisms located on the vessel lid, special eccentric holding devices being required to connect eight of the rods which are offset. Four prototype hydraulic mechanisms will also be used. Extensive in-pile instrumentation is provided: (i) the flux wires slide inside thimbles attached to two vacated rod mechanism penetrations in the vessel lid and (ii) the thermocouples and fission chambers are immersed and connected through a "collar" which is added between the vessel flanges.

The main problem concerning the primary systems is due to the use of a D_2O-H_2O mixture. It is intended to operate BR3, which was originally designed as a H_2O plant, up to 2 000 psia (140 kg/cm^2) and 500 °F (260 °C) which is higher than any existing D_2O reactor. Extensive tests have therefore been performed on the BR3 plant to trace the leaks and determine their size, in order to determine the necessary improvements.

The VULCAIN core consists of 91 theoretical cells of the same hexagonal cross section. Seventy-three cells each contain one fuel assembly, while the remaining cells each accommodate one Zircaloy tube which may guide a circular flux-trap type absorber rod. The initial D_2O-H_2O mixture rises through the core almost entirely in the fuel zone with only a small part entering the Zircaloy "moderator" tubes. The fuel assemblies have been developed and supplied, half by the UK and half by Belgium, each manufacturer starting from UF_6 gas supplied by the UKAEA.

The operating programme will comprise many cycling and perturbation tests to subject the fuel to conditions similar to those encountered in a land-based or ship propulsion unit and obtain sufficient experimental data to arrive at a satisfactory mathematical model of the core behaviour. Various reactor control and water treatment methods will also be experimented, and the core will be operated at various pressures, down to the lowest pressure compatible with safe operation.

A/515 Бельгия

Испытания на мощности активной зоны реактора VULCAIN

Ж. Сторер, С. Ригг

Совместная англо-бельгийская программа по реактору VULCAIN предусматривает испытания на мощности активной зоны такого типа. Эти испытания намечено провести в 1965—1968 годах на атомной электростанции BR-3 в Научно-исследовательском центре по атомной энергии (CEN.) в Моле, Бельгия.

Для компенсации уменьшения реактивности, вызываемой потреблением топлива, в реакторе такого типа используется замедлитель из смеси тяжелой и обычной воды, соотношение которых изменяется в процессе работы реактора. Применение смешанного замедлителя позволяет увеличить срок службы активной зоны и дает возможность эксплуатировать реактор на мощности без поглощающих стержней в активной зоне, что значительно улучшает экономию нейтронов.

Основные задачи, поставленные перед этим экспериментом, сводятся к следующему:

1) определение поведения топлива при высоких степенях выгорания; 2) проверка параметров активной зоны реактора VULCAIN и ее поведения в течение всего срока службы; 3) приобретение опыта работы с тяжеловодными системами высокого давления; 4) испытание различных частей оборудования.

Изменения на атомной электростанции BR-3 будут произведены в последние месяцы 1964 года, после того как будет израсходована первая активная зона реактора с избыточным давлением. В основном изменения будут заключаться в приспособлении корпуса реактора к установке активной зоны реактора VULCAIN, с одной стороны, и в приспособлении первичных контуров к использованию смеси D_2O/H_2O, с другой стороны.

Внутреннее оборудование корпуса будет заменено полностью. Десять поглощающих стержней будут приводиться в действие существующими механизмами (с магнитным приводом), расположенными на крышке корпуса, что требует специальных соединений для восьми стержней, центры которых смещены по отношению к их механизмам. Будут также использованы четыре опытных гидравлических привода. В реакторе предусмотрена сложная аппаратура: проволоки для измерения потока перемещаются в пальцах манипулятора, соединенных с двумя крестовинами крышки, которые раньше использовались для приводов стержней, термопары и камеры деления погружены в воду, и их соединения проходят через «хомуток», установленный между бортами корпуса.

Использование смеси тяжелой и обычной воды создает сложную проблему. Действительно, первичные контуры реактора BR-3 были сконструированы только для использования обычной воды. Кроме того, реактор будет эксплуатироваться при температуре 260° C и давлении 140 *кг/см²*, т. е. при значительно более высоких параметрах, чем какой-либо из существующих реакторов, использующих тяжелую воду. Поэтому были проведены тщательные испытания контуров реактора BR-3 с целью отыскания течей и определения их размера, с тем чтобы определить необходимые усовершенствования.

Активная зона состоит из 91 идентичной теоретической ячейки шестиугольного сечения. 73 ячейки заполняются топливными сборками, а остальные — трубками из циркалоя, которые могут служить направляющей круглого поглощающего стержня типа нейтронной ловушки. Первоначальная смесь D_2O/H_2O поступает в активную зону снизу, почти полностью проходит через зону топлива и только небольшая часть через трубки для замедлителя из циркалоя. Половина сборок была разработана и поставлена Англией и половина Бельгией, причем каждый изготовитель осуществлял полный цикл производства, исходя из UF_6, который был поставлен Управлением по атомной энергии Англии.

Программа эксплуатации будет включать большое количество испытаний по циклическим изменениям и возмущениям. Это необходимо для того, чтобы подвергнуть топливо воздействию условий, аналогичных условиям, характерным для наземной силовой установки, и получить достаточное количество экспериментальных данных, чтобы найти удовлетворительную математическую модель поведения активной зоны. Будут также проведены эксперименты по различным методам управления реактором и методам водоподготовки; активная зона будет работать при различных давлениях вплоть до наименьшего, при котором все еще возможна безопасная работа реактора.

A/515 Bélgica

Ensayo en régimen de potencia de un núcleo tipo VULCAIN

por J. Storrer y S. Rigg

En el programa común anglo-belga de estudio y perfeccionamiento del reactor VULCAIN figura el ensayo en régimen de potencia de un núcleo de este tipo, que se desarrollará desde 1965 hasta

1968 en la central nucleoeléctrica BR3 de Mol, Bélgica, donde se encuentra el Centre d'étude de l'énergie nucléaire (CEN).

En el reactor de tipo VULCAIN se utiliza la moderación variable, realizada especialmente mediante mezclas de agua pesada y agua ligera, a fin de compensar las disminuciones de reactividad debidas al agotamiento del combustible. Gracias a esto es posible su funcionamiento sin necesidad de barras absorbentes, lo cual mejora apreciablemente la economía neutrónica y prolonga la vida del núcleo.

Los principales objetivos del ensayo pueden resumirse de la siguiente manera: i) comprobar el comportamiento del combustible para grados de quemado elevados; ii) verificación de los parámetros de un núcleo VULCAIN y de su manera de conducirse en todo el curso de su vida; iii) adquirir experiencia en sistemas de D_2O bajo presión, y iv) ensayos de diversas partes del equipo.

Las modificaciones de la central BR3 se efectuarán en los últimos meses de 1964, una vez que se haya agotado el combustible del primer núcleo de agua bajo presión. Dichas modificaciones consisten esencialmente, por una parte, en adaptar el recipiente del reactor BR3 de modo que pueda utilizarse un núcleo VULCAIN, y, por otra, en reajustar los circuitos primarios para que pueda emplearse una mezcla D_2O/H_2O.

Se ha de reemplazar completamente el equipo interno del recipiente del reactor. El accionamiento de diez barras absorbentes se hará por medio de los mecanismos ya existentes (gatos magnéticos) situados sobre la tapa del recipiente, pero que exigen el empleo de piezas de conexión especiales para las ocho barras situadas excéntricamente con respecto a su mecanismo. Por otra parte, se usarán cuatro prototipos de mecanismos hidráulicos. Se ha preparado para el interior del reactor un equipo de instrumentos muy completo; los cables para la medición del flujo se deslizan por el interior de canaladuras unidas a dos traviesas de la tapa que se utilizaban anteriormente para los mecanismos de las barras, mientras que las cámaras de fisión y los termopares están sumergidos, atravesando sus conexiones un "collar" montado entre las bridas del recipiente.

El empleo de una mezcla de agua pesada y agua ligera origina un serio problema. En efecto, los circuitos primarios del reactor BR3 habían sido construidos para utilizar agua ligera únicamente; además, en el nuevo reactor se alcanzarán presiones de 140 kg/cm^2 y temperaturas de 260 °C, es decir, que las condiciones serán más severas que las de cualquier otro reactor existente de agua pesada. Por tal motivo, se han ensayado escrupulosamente los circuitos de la instalación a fin de localizar las fugas y determinar su importancia para, en consecuencia, aportar las mejoras pertinentes.

El núcleo VULCAIN consta de 91 celdas teóricas de la misma sección hexagonal; 73 de estas celdas contienen un conjunto combustible cada una y las restantes alojan cada una un tubo de Zircaloy que puede servir de guía a otra barra absorbente de sección circular. La mezcla primaria de D_2O/H_2O penetra en el núcleo por su parte inferior y casi todo el caudal atraviesa la región del combustible, mientras que sólo un poco pasa por los tubos « moderadores » de Zircaloy. Los conjuntos combustibles se han desarrollado y construido por partes iguales en el Reino Unido y en Bélgica, y cada fabricante realiza el ciclo completo a partir del UF_6 gaseoso suministrado por la UKAEA.

El programa de operación comprenderá diversos ensayos de ciclado y perturbación para someter al combustible a condiciones parecidas a las que se encuentran en una unidad con base terrestre o de propulsión naval, con lo que se obtendrán datos experimentales suficientes para conseguir un modelo matemático satisfactorio del comportamiento del núcleo. También se ensayarán varios métodos de control del reactor y de tratamiento del agua. Además, se hará funcionar el núcleo a presiones distintas, hasta la presión más baja que sea compatible con su operación sin riesgo.

The SEFOR reactor — aspects of international cooperation

By W. Schnurr* and J. R. Welsh**

The implementation of the SEFOR project has added a new variation to international cooperation in the field of the peaceful use of nuclear energy. For the first time, a non-US group is participating in the construction of a reactor and in the execution of a research and development program financed by the United States Atomic Energy Commission (USAEC). On the American side, the project is carried through by Southwest Atomic Energy Associates (SAEA) and General Electric Company (GE), in addition to the USAEC, and the European side by Gesellschaft für Kernforschung mbH (Federal Republic of Germany) and the European Atomic Energy Community (EURATOM). The main reason for instituting this international cooperation is the scientific and technical significance of the development of fast breeder reactors. The project constitutes an important part of the fast breeder programs of USAEC, EURATOM, and Gesellschaft für Kernforschung. SAEA is the first group of electric companies in the United States to participate in a plutonium-fueled fast reactor experiment.

This paper aims firstly to describe the SEFOR reactor, then gives a historical survey of the project up to the formulation of the contracts, and finally gives an account of its implementation. It illustrates the obstacles along the way, starting from an existing common volition and winding up in a series of contracts acceptable to partners pertaining to different nations and different legal systems and pursuing different interests. It was considered advisable, therefore, to devote special attention to the design of the contracts and the explanation of their most important features. The paper is concluded by a survey of the intended execution of the project.

DESCRIPTION OF SEFOR

The Southwest Experimental Fast Oxide Reactor (SEFOR) is a sodium-cooled fast experimental reactor which will serve the following main purposes:

(*a*) Gathering experience for the operation of large PuO_2-UO_2 reactors;

(*b*) Investigating and measuring the Doppler effect in steady state operation;

(*c*) Investigating and measuring the Doppler effect by power excursions;

(*d*) Determining safety criteria for large plutonium-fuelled power reactors.

The reactor will have a thermal power of 20 MW but is not intended to generate electricity. The core is housed in a double-walled vessel and will comprise some 660 fuel rods in stainless-steel cans, the rods being grouped in clusters within the core. The fuel consists of a mixture of PuO_2-UO_2, with a plutonium content of approximately 15 per cent, some 2 200 kg of fuel being needed. The rods have an outside diameter of 2.54 cm; 84 cm (roughly corresponding to the core height) are filled with pellets of the PuO_2-UO_2 fuel. The rod ends are made of steel and act as axial reflectors. The radial reflectors are made of Inconel and contain eighteen movable cylinders for controlling the reactor. The cooling system has two inner sodium cycles, a third cycle transmitting the heat to the air. The valves of the cooling system have been designed in such a way as to enable the sodium level to be lowered during refuelling operations. The steel reactor containment building is cylindrical in shape with a spherical top and will withstand an internal pressure of 3 atm. Core and cooling system are housed in this building. The ventilating plant is over the fuel testing rooms in the operations building. The ventilators are connected to an exhaust stack 53 m high standing by itself. On top of the core, a shielded cell has been installed for checking fuel rods, handling is by means of manipulators and operations may be viewed through lead glass windows.

Neutron lifetime is about 5×10^{-7}s. The neutron spectrum is a relatively soft one, having 20 per cent fission below the limit of 10 kV. The Doppler coefficient ($T\ dk/dT$) is approximately -0.008. These characteristics definitely point to a future oxide-fuelled power-reactor.

The reactor installation will be built on a site of 250 ha (620 acres) in Arkansas, USA, some 20 miles southwest of Fayetteville, a small university town of 20 000 inhabitants. The site location is poorly cultivated and only sparsely populated. The plant consists of a one-story operations building, partly topped by the ventilation room. The operations building contains the necessary offices, conference rooms, storage facilities, workshops and, in the part facing the reactor building, the control

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** Southwest Atomic Energy Associates, Little Rock, Arkansas.

room. A fuel storage area has also been provided.

For operating and servicing the reactor there is a staff of thirty persons and in addition there is a technical and scientific staff for taking care of the research and development program.

HISTORY OF THE PROJECT

The concept of SEFOR was developed by GE in a contract with the Atomic Energy Commission. This contract, which is still in effect, covers work on the fast ceramic reactor, and the major activity includes a broad investigation of ceramic fuels and the physics of fast reactors. The contract was awarded to General Electric as a result of competitive bidding in 1959. The SEFOR concept was first proposed to the USAEC in April 1961 and disclosed to the scientific public for the first time at the Conference on Power Reactors in October 1961 in Vienna, when GE presented a paper on the topic. Design and purpose of the reactor project aroused the special interest of members of Gesellschaft für Kernforschung m.b.H. (Karlsruhe Nuclear Research Center)* attending the conference. They had been conducting studies on a fast breeder project since 1960. The research work done so far in Karlsruhe had shown the necessity of building an experimental facility for testing specifically the dynamic behavior of fast reactors, and reactor POWDER GODIVA was to be built on the premises of the Karlsruhe Nuclear Research Center for that purpose. However, as the GE project not only extended beyond the aims of the Karlsruhe facility, but, in addition, was to pursue scientific aims interesting the Karlsruhe group, the possibility of participating in the GE project was ventilated.

The enterprise was heavily supported by SAEA, a group of seventeen utility companies in the southwest of the United States, which had given financial support to research programs aimed at the development of breeder reactors since 1957. After negotiations with GE, SAEA agreed to assume part of the cost of reactor construction.

At General Electric's suggestion, Karlsruhe visited the USAEC in company with General Electric in February 1962. The German offer of participation to the amount of $2 million in financing the research and development program met with a favorable reception.

By the fall of 1962, the SEFOR project had been expanded in the scientific realm. In a seminar on fast dynamic test reactors in Washington from October 31st to November 2nd 1962, it was expressly stated that the FARET and SEFOR projects would be excellent supplements to each other and might thus well be parts of one program. On the basis of the Report to the President of November 1962 it was possible to expand the USAEC program. This report contained some ideas on the development of fast reactors with oxide fuel containing plutonium which were considered important, and it contained some far-reaching deliberations on tapping new sources of energy.

The expansion of the USAEC fast breeder program produced a positive solution to the SEFOR financing problem: USAEC bore the cost of carrying out the research and development program, whereas the other partners financed the cost of constructing the plant. However, this required a considerable increase in the contribution of Gesellschaft für Kernforschung.

In the course of the negotiations, the cooperation between Gesellschaft für Kernforschung and EURATOM in the field of fast reactor development, laid down in an agreement of association, became important. Within the framework of that agreement, EURATOM participates in financing the research work done at Karlsruhe. It was possible to include the SEFOR plant in the association between EURATOM and Gesellschaft für Kernforschung thereby supplementing the series of experimental facilities provided for this program. The result of the negotiations between SAEA, Gesellschaft, EURATOM, and GE was a Memorandum of Understanding signed by SAEA and Gesellschaft on March 18th 1963, which may be regarded as the nucleus of all following negotiations. In this Memorandum, Gesellschaft für Kernforschung and EURATOM agreed to pay the sum of $5 million. The preliminary negotiations could be regarded as finished when, in December 1963, the USAEC agreed in a Memorandum of Understanding with SAEA to finance the research and development program.

Before the final contracts were elaborated by the partners working on the project, various kinds of contracts were discussed and checked. From the point of view of implementation of the project, the actual relationship between the partners would have been reflected best by founding a new company, with an independent legal status, out of the companies financing the project, especially SAEA and Gesellschaft. This new company then could have entrusted GE with planning and constructing the SEFOR installation and carrying out the research and development program.

This solution would have been a clear one and a very desirable one, also from the legal point of view, but it could not be realized because of the Atomic Energy Act of 1954. This law prohibits the USAEC from licensing construction and operation of a reactor project which is "controlled" by a non-national enterprise. The term "control" in the meaning of this provision has a very wide significance in the US, even today. It means any type of co-ownership, or something even like ownership, in a reactor installation in the USA, and the pos-

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* Gesellschaft für Kernforschung mit beschränkter Haftung is a non-profit corporation supported 75 per cent by the Federal Republic of Germany and 25 per cent by the state of Baden-Wurttemberg.

sibility of influencing construction or operation of such a reactor by direct orders to the manufacturer or operator. As one of the participants in the new company, Gesellschaft für Kernforschung certainly would have had a right in the reactor similar to ownership.

Thus, a way had to be found which would be within the limits set by American legislation, but also guarantee the interests of the European partners in relation to their financial and scientific contributions.

LEGAL ASPECTS

Contracts

Four contracts have been worked out and have now become effective; these are:

(*a*) Contract between SAEA and USAEC (subsequently called *AEC Agreement*;

(*b*) Contract between SAEA and GE on planning and constructing the SEFOR plant (subsequently called *SEFOR Contract*);

(*c*) Another contract between SAEA and GE on the execution of the research and development program (subsequently called *Program Contract*);

(*d*) Contract between SAEA and Gesellschaft für Kernforschung m.b.H. (subsequently called *SAEA-Gesellschaft Agreement*).

Figure 1 illustrates the system of contractual relations. As can be seen, SAEA is the central figure in the combination of these contracts. All legal relationships of the four parties are joined in SAEA. USAEC, Gesellschaft für Kernforschung and GE have no direct contractual relations with each other and are only related via SAEA.

The contents of the four contracts can be briefly summarised as follows. The *AEC Agreement* is the fundamental contract. In this contract, USAEC agrees to finance the research and development program as well as make fissile material and certain reactors of national research laboratories available for fuel element tests. SAEA in this contract have agreed to build the SEFOR plant; in discharging this obligation, SAEA will make use of GE. The conditions of carrying out this work are laid down in detail, and the agreement also contains an express provision on the right of Gesellschaft für Kernforschung to have active scientific and technical cooperation in the project. Moreover, it is said that, in signing and executing this contract, SAEA also acts for the benefit of Gesellschaft für Kernforschung. A corresponding provision is contained in the contract between SAEA and GE.

In the *SEFOR Contract*, SAEA have charged GE as the main contractor with planning and constructing SEFOR and, in the *Program Contract*, with carrying out the research and development program.

In the *SAEA-Gesellschaft Agreement*, the basis for cooperation between SAEA and Gesellschaft für Kernforschung has been laid down. SAEA and Gesellschaft für Kernforschung must consult and agree on all matters of policy and on all questions affecting costs which are to be decided or determined by SAEA. In the event of disagreement, such questions will be decided by arbitration.

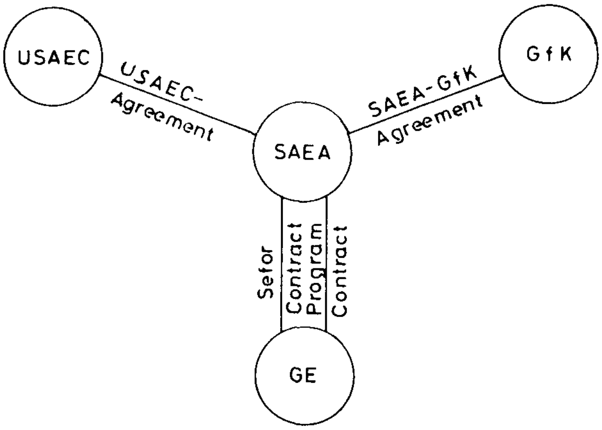

Figure 1. The system of contractual relations for the SEFOR reactor

The whole project is financed in the following manner. The cost of planning and constructing SEFOR, including the cost of purchasing the site, is borne by SAEA to a total of $5.9 million and by Gesellschaft für Kernforschung to a total of $5.0 million. All costs exceeding $10.9 million will be borne in full by GE. The cost estimate for the construction of the reactor (without development of fuel elements, which is part of the research and development program) provides for a sum of $12.35 million.

As has been mentioned earlier, USAEC finances the whole research and development program upon indication up to a total of some $12.7 million. In case reaching the objectives of the program will require higher expenditures, these will be borne by GE.

Title, warranty, and liability

The site for erecting the reactor installation is owned by SAEA. The installation proper is owned by GE during the construction phase. With the first fueling procedure, title in the reactor installation also passes to SAEA.

The warranties assumed by GE for construction of the reactor and execution of the research and development program are far-reaching ones. GE warrants to build the reactor in such a way as to enable the research and development program, especially the tasks described in close detail in the *AEC Agreement* and the *Program Contract*, to be carried out and the intended objectives to be reached.

The nuclear and non-nuclear liability risk of the parties to the project, apart from AEC, is covered by insurance as far as possible. The cost of insurance is borne by GE; part of it will be refunded to GE by the AEC within the framework of the financing of the research and development program after the passing of title in the SEFOR installation to SAEA. Moreover, GE will be held blameless by the US Government, in accordance with Section 170 of the Atomic Energy Act of 1954. GE has agreed to indemnify SAEA and Gesellschaft against liability to the extent not covered by insurance and to the extent not caused by acts or omissions by SAEA or its members or acts or omissions of Gesellschaft.

COMMITTEES

SAEA and Gesellschaft für Kernforschung will be in close contact, through the Project Review Committee and the Technical Policy Committee, with the construction of SEFOR and the research and development program at all times.

The Project Review Committee is composed of representatives of the managements of SAEA and Gesellschaft für Kernforschung. It will meet at least twice a year. The function of this Committee will be to review performance under the SEFOR Contract and under the Program Contract and to review generally information supplied by GE.

The Technical Policy Committee has been created especially to view the execution of the research and development program. Its members are one leading scientific representative from each of Gesellschaft für Kernforschung and GE. It will also meet semiannually. Members of SAEA and USAEC may attend its meetings.

GE is obliged to make detailed reports before both committees, showing the work performed since the last meeting and the work planned for the following six months.

EVALUATION OF KNOWLEDGE

As it is not the aim of the SEFOR project to erect the prototype of a power reactor, but, essentially, to carry out an experimental program with a reactor specially built for the purpose, the results to be expected will consist, in the first instance, of new knowledge and technical knowhow. Thus, it was necessary to find ways enabling each of the parties to the contract to obtain this information to the extent desired. It was also necessary to determine arrangements for the treatment of patentable inventions and the consequent utilization of industrial rights. Due to the material cooperation of USAEC, it followed most automatically that the treatment developed by the Commission in the US for fixing rights to the knowledge obtained became the basis of the contractual provisions. Soon it became apparent that the existing regulations were flexible enough to leave space for the wishes of the non-US partners. Now, the contract provides that practically all partners have free access to the knowledge, including all patentable inventions. This knowledge may be disseminated to the partners by the contractor erecting the plant in the form of reports or notes as well as drawings or similar data. They may be liberally used in the proper fields of interest, save for the restriction that this utilization has to be in accordance with the provisions of the Atomic Energy Act of 1954.

In view of the special interests of the European partners for their own economic area, it was provided that information can be freely communicated and used industrially in the countries of the European Community without additional provisions in the contracts.

Moreover, the European partners have the possibility of delegating trained experts for participation in the designing, constructing, and testing stages of the work so that they may become fully conversant with the details of all problems. In order to make this cooperation effective, the groups cooperating in the United States are supposed to have so-called “correspondence groups” in Karlsruhe. By using this structure, the European partners are in a position to evaluate the communicated results and, if they choose to do so, make suggestions.

With respect to any invention or discovery not made or conceived in the course of or under the AEC Contract or the SEFOR Contract and covered by a patent or patent application owned or controlled by GE and which invention or discovery is actually incorporated or embodied in SEFOR or its fuel by GE, GE has agreed to grant non-exclusive licenses under non-discriminatory, customary commercial terms and conditions to the other partners and other responsible parties for the use of such invention in fast nuclear reactor power plants.

The provisions for issuing publications correspond to the usual regulations.

EXECUTION OF THE PROJECT

In the contract it has been foreseen that building the SEFOR reactor will take three years. Concurrent with the construction work, the first phase of the research and development program, which is going to supply important data for the design of the reactor and the core, will be carried out.

After insertion of the first core, the second phase of the research and development program will start; its completion will take a period of three to five years. In that time, experiments with the reactor and theoretical investigations should have been carried out up to the point where the objectives of the program have been reached. The second phase ends in decommissioning the reactor. However, the contracts provide for the possibility of continuing cooperation between SAEA, Gesellschaft, and GE within the framework of another research program. Each of the partners may carry out such a program by himself, or together with other partners, under complete assumption of the responsibility for the reactor. The partners not joining this new program are entitled to make full use of the results derived from this research program free of charge.

CONCLUSIONS

This paper shows that a relatively complicated network of contracts had to be established in order to safeguard the highly diverse interests of the industrial and non-profit making organizations, cooperating here as partners, in relation to their contributions, and in order to stay within the legal provisions of national and supranational authorities on both sides of the Atlantic. In formulating the contracts the partners have taken pains to make them simple and clear. The future will show whether the type of cooperation that was chosen here will prove to be satisfactory.

ABSTRACT - RÉSUMÉ - АННОТАЦИЯ - RESUMEN

A/533 République fédérale d'Allemagne

Le réacteur SEFOR: les aspects d'une collaboration internationale

par W. Schnurr et J. R. Welsh

Le réacteur SEFOR (Southwest Experimental Fast Oxide Reactor), d'une puissance thermique de 20 MW, est en construction à Fayetteville (Arkansas), aux Etats-Unis. Il est refroidi au sodium et utilise des combustibles à PuO_2-UO_2. Il est construit par l'Atomic Power Equipment Department de la General Electric pour le compte de Southwest Atomic Energy Associates avec une importante contribution financière de la Gesellschaft für Kernforschung m.b.H., de Karlsruhe.

Le but de ce réacteur est de démontrer la sûreté des caractéristiques d'exploitation et la sécurité inhérente d'un grand réacteur de ce type. L'installation servira à réaliser un vaste programme de recherche et de développement. Sous l'égide de l'Atomic Energy Commission, il sera exécuté par la General Electric en tant que sous-traitant de Southwest Atomic Energy Associates.

Les principaux motifs de cet ample effort de coopération ont été les suivants: Le Centre de Karlsruhe avait déjà un programme actif dans le domaine des surrégénérateurs à neutrons rapides, et avait envisagé dès 1960 la construction d'un réacteur expérimental du même genre.

La Southwest Atomic Energy Associates (groupe de 17 fournisseurs d'électricité du sud des Etats-Unis) patronnait depuis longtemps le développement dans le domaine nucléaire. Vu l'intérêt croissant que suscitent les surrégénérateurs rapides, elle a décidé d'appuyer la mise au point de ce type de réacteur.

L'Atomic Power Equipment Department de la General Electric, comme le Centre de Karlsruhe, avait saisi la grande importance d'un tel programme expérimental et avait étudié un projet de construction qui fut présenté tout d'abord à la Conférence de l'AIEA à Vienne en 1961.

De 1961 à 1963, une série de négociations entre ces partenaires, l'USAEC et l'EURATOM aboutissaient à un accord sur la construction du réacteur et l'exécution du programme de recherche et de développement.

Etant donné les intérêts différents des groupes participants et le fait que SEFOR est le premier réacteur à être construit aux Etats-Unis avec une aide substantielle de groupes non américains, les négociateurs ont eu à faire face à de nombreux problèmes difficiles et durent chercher des solutions nouvelles.

Après une discussion détaillée des motifs techniques et scientifiques mentionnés ci-dessus et un historique du projet, le mémoire décrit les relations juridiques entre les divers partenaires. En plus, il traite des problèmes financiers et de l'organisation créée pour garantir à tous les partenaires l'influence et le droit de contrôle voulus. Enfin, la question de l'utilisation des renseignements et des brevets obtenus ainsi que l'échange de personnel et des connaissances sont discutés, eu égard en particulier aux accords internationaux existants.

A/533 ФРГ

Реактор SEFOR — аспекты международного сотрудничества

В. Шнурр, И. Р. Вэлш

В Фэйет-Вилле, шт. Арканзас, США, строится юго-западный экспериментальный реактор на быстрых нейтронах с топливом в виде системы PuO_2 — UO_2 и натриевым охлаждением. Тепловая мощность этого реактора составляет 20 *Мвт*. Реактор строится отделом атомно-энергетического оборудования фирмы «Дженерал электрик» для Юго-Западной энергетической ассоциации. Значительную долю финансирования осуществляет Акционерное общество ядерных исследований, Карлсруэ. Задачей создания этого реактора является демонстрация надежных эксплуатационных характеристик и прису-

щей этой системе безопасности на большом реакторе на быстрых нейтронах с плутоний-урановым топливом. На этой установке будет проводиться большая программа научно-исследовательских и опытно-конструкторских работ. Эта программа будет осуществляться под руководством Комиссии по атомной энергии фирмой «Дженерал электрик» по субконтракту фирмы «Саутвест атомик энерджи ассошиитс».

Основными побудительными мотивами для такого широкого сотрудничества были следующие.

Центр в Карлсруэ имеет активную программу в области разработки энергетических реакторов-размножителей на быстрых нейтронах и уже в 1960 году рассматривал вопрос о строительстве динамического опытного реактора на быстрых нейтронах.

Фирма «Саутвест атомик энерджи ассошиитс» — группа из 17 коммунальных предприятий, обслуживающих Юг Соединенных Штатов, руководит перспективной разработкой проблем ядерной энергии. Учитывая растущий интерес к энергетическим реакторам-размножителям на быстрых нейтронах, фирма решила поддержать разработку реактора этого типа.

Отдел атомно-энергетического оборудования фирмы «Дженерал электрик», подобно атомному центру в Карлсруэ, сознавая жизненную важность программы, провел проектное изучение, которое впервые рассматривалось на конференции МАГАТЭ в Вене в 1961 году.

В период с 1961 по 1963 год были проведены переговоры между названными партнерами — Комиссией по атомной энергии США и Комиссией Евратома. Эти переговоры привели к соглашению, предусматривающему строительство реактора и определяющему характеристики программы научно-исследовательских и опытно-конструкторских работ.

Имея в виду различную заинтересованность участвующих групп и то обстоятельство, что реактор SEFOR является первым реактором, который должен быть построен в США с существенной поддержкой со стороны не американских групп, договаривающиеся стороны оказались перед затруднительными проблемами и должны были найти многие новые решения.

После детального обсуждения названных технических и научных проблем и обзора исторического развития этого проекта в докладе описаны юридические взаимоотношения между различными партнерами. Далее в докладе будут изложены проблемы финансирования и организации, возникшие в связи с необходимостью гарантировать всем партнерам соответствующее влияние и контроль. Наконец, обсуждаются вопросы использования получаемой информации и патентов, а также обмена персоналом, обмена знаниями, причем особое внимание будет уделено существующим международным соглашениям.

A/533 República Federal de Alemania

El reactor SEFOR:
Aspectos de la cooperación internacional

por W. Schnurr y J. R. Welsh

En Fayetteville, Arkansas, Estados Unidos, se está construyendo el « Southwest Experimental Fast Oxide Reactor », que es un reactor rápido experimental de óxido con combustible de plutonio, refrigerado por sodio, con una potencia térmica de 20 MW. Lo construye el General Electric Atomic Power Equipment Department para la Southwest Atomic Energy Associates, contribuyendo considerablemente a su financiación la Gesellschaft für Kernforschung m.b.H. de Karlsruhe. El objeto de este reactor es demostrar las características de operación confiable y aspectos inherentes de seguridad de un reactor de potencia, cargado con combustible de uranio-plutonio. En esta instalación se realizará un amplio programa de investigación y desarrollo. Será realizado por la General Electric, patrocinado por la Atomic Energy Commission, bajo subcontrato para la Southwest Atomic Energy Associates.

Los principales alicientes para este amplio esfuerzo de cooperación fueron los siguientes:

El Centro de Karlsruhe tenía un activo programa en el campo del desarrollo de reproductores rápidos de potencia y ya en 1960 concibió la construcción de un reactor rápido de pruebas dinámicas.

La Southwest Atomic Energy Associates, un grupo de 17 empresas que sirven al Sur de los Estados Unidos, había financiado durante mucho tiempo el desarrollo de la energía nuclear. En vista del creciente interés por los reactores rápidos reproductores de potencia, decidieron apoyar el desarrollo de este tipo de reactores.

El General Electric Atomic Power Equipment Department — lo mismo que el Centro de Karlsruhe — comprendió la importancia vital de un programa y realizó un estudio de proyecto que fue presentado por primera vez en la Conferencia de 1961 del Organismo Internacional de Energía Atómica en Viena.

Durante los años de 1961 a 1963 se realizaron una serie de negociaciones entre los grupos interesados arriba citados, la USAEC y la Comisión de Euratom, que condujeron finalmente a un acuerdo que comprendía la construcción del reactor y la realización del programa de investigación y desarrollo.

En vista de los intereses diversos de los grupos participantes y del hecho de que el SEFOR es el primer reactor a construir en los Estados Unidos con aportaciones importantes de grupos no estadounidenses, las partes negociadoras se enfrentaron con problemas difíciles y han tenido que buscarse muchas soluciones nuevas.

Después de una discusión detallada de los alicientes técnicos y científicos antes mencionados y

de un análisis del desarrollo histórico del proyecto, el artículo describe las relaciones legales entre los distintos interesados. Abarca además los problemas de financiación y describe la organización que fue creada para garantizar a todas las partes la influencia y control necesarios. Finalmente, se discute la cuestión del empleo de las patentes e informaciones obtenidas y el intercambio de personal y conocimientos, considerando especialmente los convenios internacionales existentes.

Review of engineering work for the DRAGON Project*

By G. Franco,** H. W. Müller,*** S. B. Hosegood**** and L. H. Prytz*****

This paper reviews the main aspects of the engineering work for the DRAGON Reactor Experiment and discusses the design, manufacture, site construction and testing of the 20 MW(th) graphite-moderated, helium-cooled, high temperature reactor located at Winfrith, Dorset, England. In most of the reactor components, the work has been affected to different extents by the novel features peculiar to this type of reactor, such as the use of very pure helium as a coolant, the use of an uncanned ceramic fuel, the high coolant temperatures and the extreme compactness of the plant. Because of space limitations, attention is concentrated here on those features which are the most significant in a high temperature reactor such as DRAGON. Features such as the instrumentation, control rod mechanisms and other important components of the reactor are not discussed but a considerable amount of information has already been published on these particular topics and on the reactor facility in general in the Annual Reports of the DRAGON Project [1-4].

Construction work, carried out with the help of a large number of contractors and organizations in the different signatory countries, started in April 1960, criticality occurred in the late summer of 1964 and full power operation is expected early in 1965. The execution of the engineering work at Winfrith involved the selection and the recruitment of a maximum of 140 staff, and these engineers, draughtsmen and ancillaries of different nationality and technical background had then to be organized into a working team. In addition, it was necessary to set up and implement the necessary co-ordination with the other Divisions of the Project, the Engineering Group of the United Kingdom Atomic Energy Authority, Lloyd's Register and the many contractors who contributed to the engineering work on the reactor.

Fig. 1 outlines the construction programme where the "Critical Path Method" has been adopted with satisfactory results since October 1963. Fig. 2 shows the over-all expenditure for the engineering work, with the exception of the expenditure for some of the rigs and prototypes required for the development programme carried out by the Research and Development Division of the project. Fig. 3 gives the over-all engineering staff effort, i.e., engineers, draughtsmen and ancillaries both of the project and of the UKAEA Engineering Group at Risley, which was asked to carry out the detailed design of the buildings and of some plant on the basis of the specifications laid down by the project. Fig. 4 shows the labour for site work carried out by contractors to the project's specifications and supervised by the Engineering Group.

PRIMARY CIRCUIT

The reactor is designed to contain within its primary pressure barrier not only core, reflector and heat exchangers, but also the charge machine, gas circulators, control mechanisms, neutron source drive and viewing systems, the idea being to avoid mechanical shaft seals and to have only electrical penetrations. The primary circuit thus comprises a long main vessel surrounded by a number of communicating branch vessels (Figs. 5a and 5b). The alignment of this complex structure was obtained by prescribing fairly tight tolerances, and using templates and jigs for the manufacture of the various components. In this way no serious difficulties were met during the site erection of the internal steelwork, core bed plate and main shield plug. Reflectors and dummy core also fitted in without trouble, having been carefully erected beforehand.

At the beginning of 1964, the complete circuit was successfully tested with helium under a pressure of 370 psig (27 atm absolute) and over-all leak tightness was within the specified high standard of 0.1% per day of the gas contained in the circuit. This success is the result of careful design of the vessels, valves, pipes and their joints, of extensive materials and welding techniques control, of conscientious supervision of manufacture and erection, of progressive testing and of substantial development work particularly on valves, joints and electrical penetrations. The components of the primary circuit are in accordance with Class I standard of BSS 1500, ASME Code of Practice for Unfired Pressure Vessels, and Lloyd's Requirements for Nuclear

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* OECD High Temperature Reactor Project, Winfrith, Dorset, England; this Project is one of the joint undertakings of the European Nuclear Energy Agency.

** Seconded by Comitato Nazionale per l'Energia Nucleare, Italy.

*** Seconded by the European Atomic Energy Community.

**** Seconded by the United Kingdom Atomic Energy Authority.

***** Seconded by the Institutt for Atomenergi, Norway.

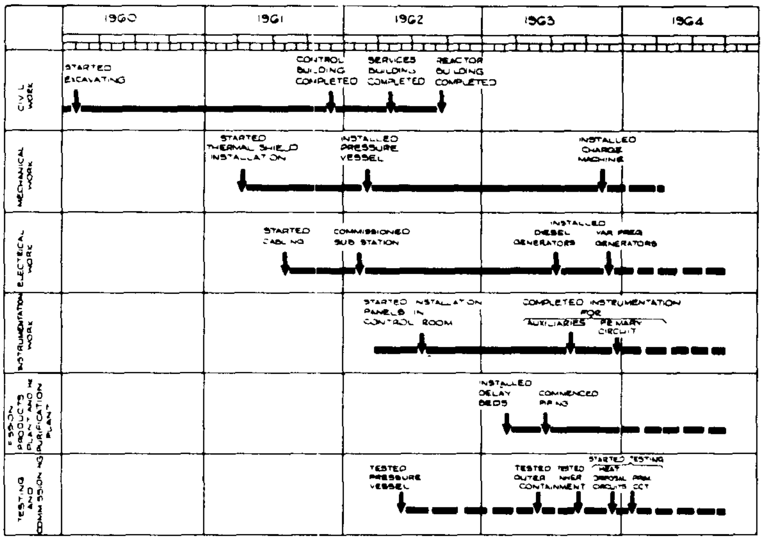


Figure 1. DRAGON construction programme

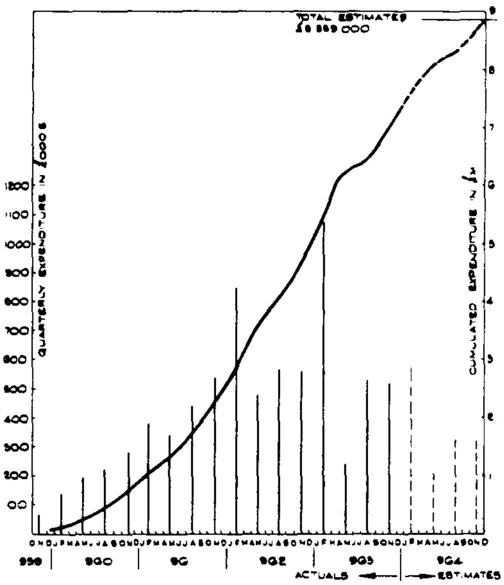


Figure 2. Over-all engineering expenditures

Category A Vessels. The material, an aluminium killed open hearth quality steel, underwent ultrasonic tests and Pellini and Robertson tests, as well as tests for creep and fatigue. In order to check on damage due to irradiation and graphitisation, steel specimens will be put in the reactor.

LEAK TIGHTNESS

A test vessel simulating the reactor vessel top dome and the 6 ft diameter flanged joint was built and successfully tested for stresses and leak tightness to helium. The conclusions were that:

(*a*) Welds of Lloyd's Category A Standard are reliably leak tight;

(*b*) A 6 ft diameter unloaded seal weld feature remains leak tight after 250 pressure cycles;

(*c*) A 6 ft diameter metal gasket maintains a leak tightness of about 10^{-8} atm cm^3/s, provided very stiff flanges and high seating pressures are being used, i.e., 17 tons/in^2 for silver and 12 tons/in^2 for aluminium gaskets (Fig. 6);

(*d*) Helium leak detection by mass spectrometer is a useful method even for large pressure components.

Other experiments on smaller joints confirmed these observations, and it was decided that, wherever demountable joints were required, flanges could give satisfactory results. Joints for constructional pur-

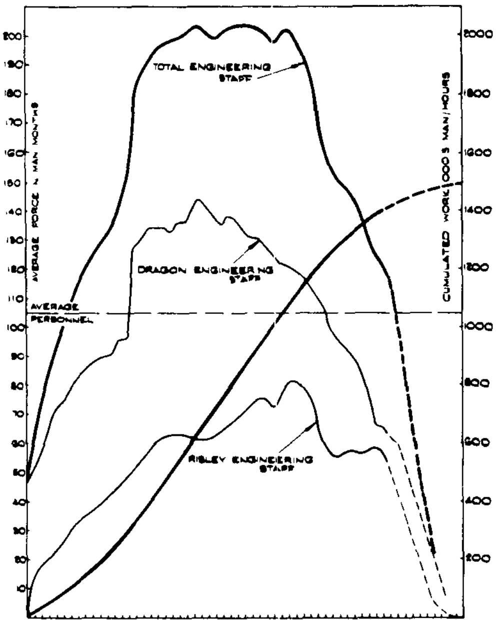


Figure 3. Engineering staff effort

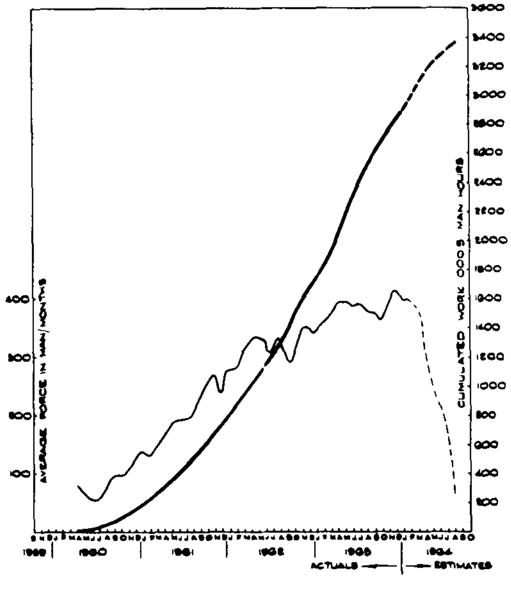
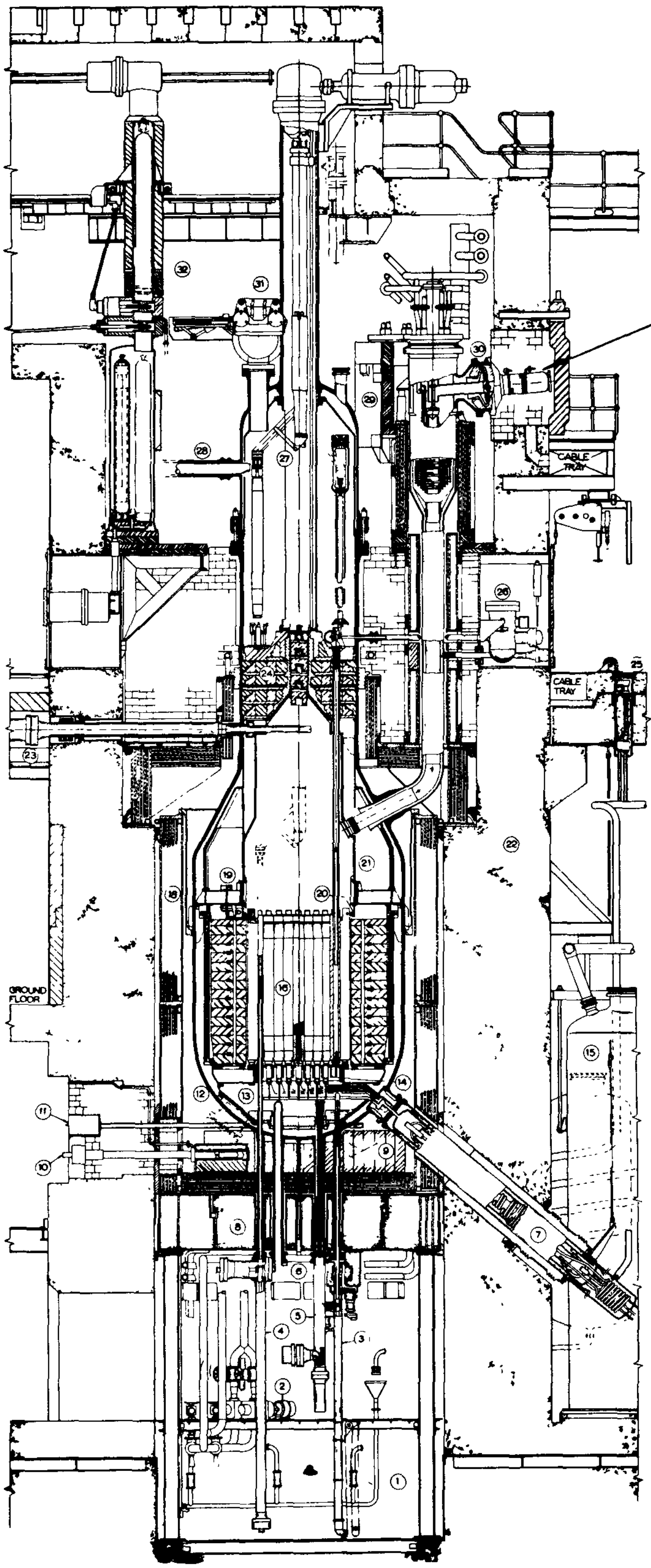


Figure 4. Site labour



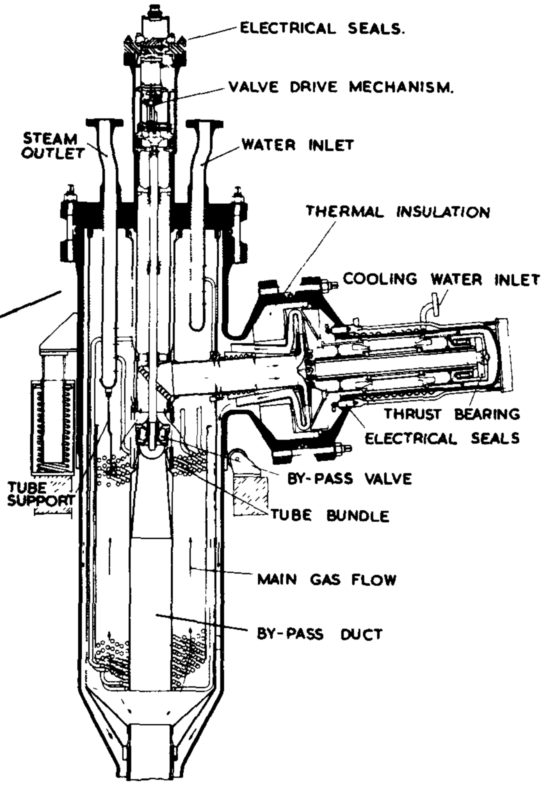


Fig. 5b.
Cross-section of heat exchanger/circulator unit

REF No	DESCRIPTION
1	ARRANGEMENT OF REACTOR PIT
2	SPECIMEN FACILITY COOLANT CIRCUIT
3	FISSION CHAMBER ASSEMBLY
4	NEUTRON SOURCE DRIVE
5	THERMOCOUPLE BRANCH
6	RE-ENTRANT TUBE
7.	PURGE GAS PRE-COOLER
8	BOTTOM BIOLOGICAL SHIELD
9	THERMAL COLUMN
10	ION CHAMBER
11	SPECIMEN FACILITY
12	REACTOR PRESSURE VESSEL
13	SUPPORT STRUCTURE INSIDE PRESSURE VESSEL
14	CORE & STATIC GRAPHITE BEDPLATE
15	HEAT SINK & DUMP TANK INSTALLATION.
16	FUEL ELEMENTS
17	REFLECTOR ASSEMBLIES
18	THERMAL SHIELD
19	CORE UNCLAMP MECHANISM
20	CORE SEAL
21	SUPPORT STRUCTURE INSIDE PRESSURE VESSEL
22	CONCRETE BIOLOGICAL SHIELD
23	RETRACTABLE TV VIEWING FACILITY
24	MAIN SHIELD PLUG
25	VALVE FLOOR.
26	CONTROL ROD MECHANISM.
27	CHARGE/DISCHARGE MACHINE INSTALLATION
28	NON-RETRACTING TV VIEWING FACILITY
29	HEAT EXCHANGER SHIELDING
30	PRIMARY HEAT EXCHANGER & CIRCULATOR
31.	MAIN ENTRY VALVE
32.	LOAD FACILITY

poses are seal welded with an aluminium gasket fitted for a local leak test (Fig. 7). At joints which may require maintenance, a silver gasket provides the barrier and is backed by seal welding in high activity areas, and by an elastomer O-ring in cool areas (Fig. 8). Metal gaskets are trapped by concentric grooves accurately machined in the flange surfaces. For the main vessel, machining was carried out during the quiet hours to avoid vibrations from working presses and other workshop machinery. The flange faces were protected by steel rings during handling and transit, and were thoroughly cleaned on site prior to assembly.

The method of double sealing proved very useful as it permitted local leak testing progressively during erection. It was also used for the numerous electrical penetrations (Fig. 9). The seal used is an alumina ceramic insulator brazed to a pressure plate with a silicon rubber backing seal. Some pressure plates carry 240 such seals, all of which had to be soundly brazed in one heating operation.

HEAT REMOVAL SYSTEM

The layout of the heat removal system in general, and the primary heat exchanger/circulator unit in particular, has been determined by the following requirements: [5]

(*a*) Minimum water volume in the secondary circuit in order to limit graphite-water reactions in the core as a possible consequence of tube failure. This was achieved by splitting the secondary system into six independent circuits. This also facilitated accessibility and maintenance and reduced the primary gas flow per unit so that gas bearing circulators became a feasible proposition;

(*b*) Removal of reactor decay heat by natural convection in case of power supply failure;

(*c*) The high standard of leak tightness of the primary circuit which led to a "canned" design for the unit with only two demountable flanges;

(*d*) Space limitations which made it necessary to aim for a very compact design of the heat transfer unit and in consequence a high heat flux.

Primary circuit heat exchangers

Table 1 summarises some of the important design data [1-5] and Fig. 5b shows one of the six heat exchanger/circulator units. The evaporator tube bundle consists of seven multistart helicoils fitting into each other concentrically. The tube's outer diameter is 18 mm, thickness 2 mm, and the material is carbon steel. By increasing the number of starts with helix diameter, the angles of inclination and the heated tube lengths are equal, despite the differences in diameter of the coils. The by-pass valve controls the gas flow through the tube bundle and hence the reactor inlet temperature. It also acts as an isolation valve for the associated circulator. Like all the other drives in the primary circuit the valve drive mechanism is totally enclosed in a pressure casing with only the electrical connections forming a seal towards the atmosphere. A bellows permits access to the mechanism even with the rest of the primary circuit pressurised.

Although the secondary circuit pressure is below the primary circuit pressure during reactor operation and hence the consequences of small leaks across the tube bundle are less severe than in high pressure steam generators, the number of welds per heat transfer unit has to be kept to a minimum. Manufacturing problems rendered this difficult and there are actually 373 welds per tube bundle. Each weld was leak tested individually during the fabrication sequence and finally the total leak rates of the complete tube bundle were determined. The results obtained under the stringent conditions of the design pressure outside and vacuum inside the bundle turned out to be near the sensitivity limit of the helium mass spectrometer used for this test (2×10^{-10} atm cm^3/s).

Circulators

To avoid leakage and oil contamination problems associated with high speed rotary shaft seals, gas bearing circulators with motors encapsulated in the primary pressure system were used. Although gas bearing units, running mainly with 2 inch diameter bearings, have been successfully operated before, it soon became evident during the progress of the DRAGON circulator design that an extensive development and testing programme was necessary to ensure reliable performance of these 4 inch diameter bearings. Due to the experimental nature of the Reactor Experiment a very extensive working range had to be specified for the circulators [6].

Fig. 5b shows all the major parts enclosed in the pressure casing which fits on a flange of the heat exchanger shell. A single-stage type of blower with overhung impeller was chosen, the diffuser being parallel and vaneless. The blower is driven by a squirrel-cage motor carried by the two radial journal gas lubricated bearings which are attached to flexible

Table 1. Design data of primary heat exchangers

Thermal duty, total	$6 \times 3.33 = 20$ MW(th)
Helium mass flow per unit	3.5 lb/s (1.6 kg/s)
Helium temperature, inlet heat exchangers	740 °C
Helium temperature, outlet to circulator (helium by-passed 8%)	335 °C
Working pressure, helium side, inlet	294 psia (20.6 kg/cm^2)
Working pressure, steam side, outlet	229 psia (16.1 kg/cm^2)
Saturation temperature at working pressure (outlet)	200.7 °C
Exit steam fraction	approx 17%
Gas side heat transfer coefficient	800 kcal/m^{2}h °C
Gas side heat flux, inlet	440 kW/m^2
Water side heat flux, inlet	566 kW/m^2
Gas side heat flux, outlet	81.4 kW/m^2
Water side heat flux, outlet	104.6 kW/m^2

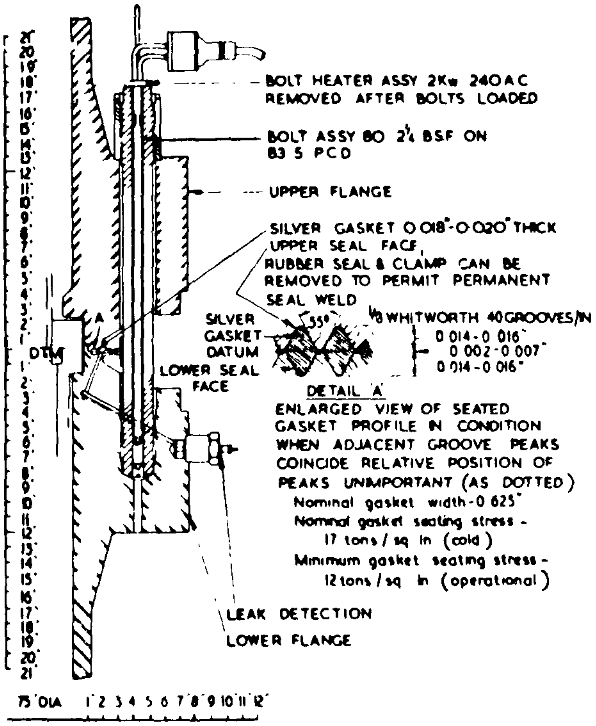


Figure 6. Section of reactor main flange

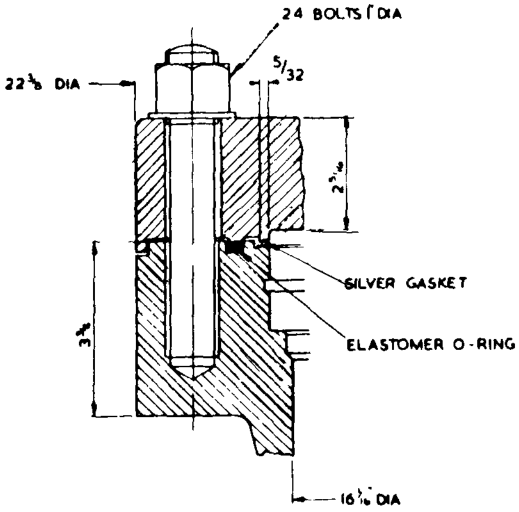


Figure 8. Typical demountable joint absorber rod drive vessel cover

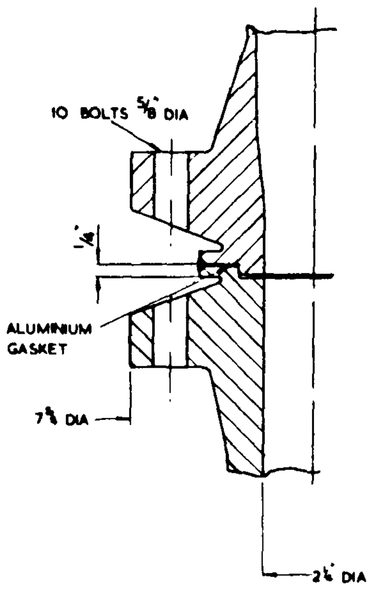


Figure 7. Typical seal welded joint as used on control rod branches

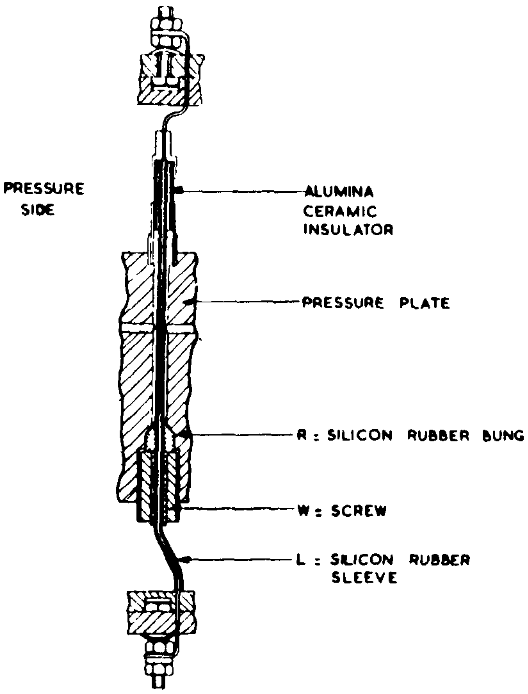


Figure 9. Typical electrical penetration assembly through pressure plate

diaphragms in the casing. At the other end of the shaft is the gas lubricated thrust bearing. A flexible suction pipe connects the heat exchanger outlet with the intake of the circulator preventing any thermal expansion or deformation of the heat exchanger being transferred to the blower.

The major problems in developing this type of bearing were related to the load carrying capacity and stability over the full running range, to the jacking gas system and to the compatibilities of bearing surfaces in clean inert gas when rubbing at start/stop conditions. After methods of suppressing gas film instability, such as small clearances, anti-whirl grooves and bearings with a slight ovality, had been tried the manufacturer verified that a scheme employing three shallow pockets at each end of the journal bearings with vented grooves at the leading edge of the pocket proved equally satisfactory. In order to minimise the problem arising from rubbing surfaces at low speed a molybdenum disulphide treatment on the shaft surface was applied after it had been roughened by vapour blasting [7]. Most of the failures which occurred during testing arose from thrust bearing instabilities caused by insufficient thrust. In addition to increasing the aerodynamic thrust on the impeller the manufacturer finally developed a counter thrust bearing which gave further thrust so that the specified running conditions could be met.

An additional set of circulators, which use pivoted pad type bearings, have been ordered for the Reactor Experiment. Experience has shown that pad bearings are inherently free of instability problems, though their load-carrying capacity is inferior to the cylindrical bearing. By using composite materials containing PTFE (Teflon) for the bearing surfaces excellent rubbing conditions were achieved eliminating the use of jacking gas but these bearing surfaces are more restricted in temperature and radiation than plain metallic surfaces. In addition to the manufacture of these blowers, an extensive research and development programme on pad type gas bearings has been initiated to explore their use for larger machines in power reactors. Results so far indicate that a load of about 1 kg/cm^2 of projected bearing area appears feasible. Various bearing materials are being tested including molybdenum disulphide impregnated graphite.

CHARGE/DISCHARGE MACHINE

To simplify the problems associated with the handling of fuel elements and other reactor components, which in the Reactor Experiment mean a large number of operations, the charge machine has been permanently installed within the reactor vessel (Fig. 5a). This solution also reduces the amount of heavy shielding that would be needed for a charge/discharge machine outside the inner biological shield. As any maintenance of the driven parts would necessitate the breaking of the primary circuit, the reliability of the machine was a very important factor.

As the choice of pure helium as primary coolant restricts the choice of materials for sliding parts, such as bearings or gears, and as this problem becomes more severe with rising temperature, the more complex mechanisms have been installed in extensions of the pressure vessel, following the same philosophy as that used for other parts of the reactor such as the control rod mechanisms. Temperature and radiation levels are then low enough to allow lubrication with low vapour pressure mineral oil and greases with inorganic gelling agents. Transmissions, for the radial arm and the grapple, operating in the hotter regions of the reactor use lightly loaded ball bearings, and ball screws and splines that are effectively running dry, but trace quantities of molybdenum disulphide improve considerably the frictional properties. Mechanical safety of built-in parts is guaranteed by torque limiting clutches.

During reactor operation the machine is at rest inside the transfer chamber and protected from radiation and high temperature by a graphite/steel shield plug. When the reactor is shut down, and after removal of the shields from the central penetration of the main plug, the grapple can operate in the core chamber and carry out any of the following duties, all with a precision of the grapple positioning of ± 0.1 in: replace used fuel elements by new ones in the core, remove the spike support of any fuel element and replace it using a "spike removal tool," replace any of the live reflector blocks, replace any of the twenty-four winding heads and related absorber rods, remove possible broken fuel elements with a special tool, handle neutron flux scanning devices which can be introduced into the coolant channels and manipulate a seal bung which increases leak tightness of the main entry valve.

In order to ensure reliable performance and the high precision required, careful control was exercised during manufacture and shop testing and the latter was carried out in clean conditions on a rig simulating the pressure vessel. After alignment and operational checks the machine was calibrated and a comprehensive functional test undertaken. These operations were repeated and extended on site after the machine had been erected on a rig in clean conditions, this time, however, using the "upper bell" of the pressure vessel to enclose the machine. It was only after these tests were satisfactorily completed that the entire machine was introduced into its final position inside the pressure vessel for the hot tests in helium, after having completed its commissioning test in air at ambient temperature.

LOAD/UNLOAD EQUIPMENT

The mechanical problems associated with this equipment, which transports the spent fuel elements from the reactor via a canning cell to storage facilities inside and outside the reactor containment and also introduces new elements, are less severe as these steps are usually undertaken in air or industrial nitrogen at ambient temperature. However, some special features are worth mentioning.

Main entry valve

This provides a gas lock between the transfer chamber of the pressure vessel and a movable flask. It is of the straight-through passage type. The gastight joint is made by a silver alloy faced plug acting on a stainless steel faced seat. These materials were chosen because the expected temperature and radiation level prohibited the use of elastomer gaskets. The leakage rate achieved was smaller than 7×10^{-4} atm cm^3/s per cm of seal at 20 atm absolute pressure differential [3].

Canning cell

The fuel elements will have to be canned immediately after leaving the reactor through the main entry valve. It was originally intended to seal the fuel element canisters by soldering, but a seal consisting of a ground metal lip inside a cone is now being used. The sealing forces are transmitted by a ball lock device. This closure mechanism, with its associated canning cell, which allows repeated opening and closing without detriment to the leak tightness, has been chosen because:

(*a*) The can is to serve for containing both new and used fuel elements and hence seals have to be made and broken more than once;

(*b*) Due to the small number of fuel elements, the canning facility costs should be kept low.

The leak rates achieved under both vacuum and pressure conditions are of the order of 10^{-6} atm cm^3/s.

PRIMARY COOLANT CONTROL

In any reactor a number of ancillary systems and components are necessary to control the quantity and quality of the primary coolant. In most cases fairly conventional components are involved, such as compressors, receivers and pressure controllers, or water treatment plants and catalytic recombiners. In a high temperature gas-cooled reactor, however, the chemical activity of the core materials at the very high temperatures reached, together with other characteristics, such as incomplete fission product retention by the fuel elements, necessitate the use of novel processes and equipment for coolant control.

The essential functions of coolant control in a high temperature reactor are:

(*a*) To maintain the inert coolant gas in a sufficiently pure state to avoid unacceptable rates of corrosion of the high temperature core materials;

(*b*) To trap out any fission products escaping from the fuel elements in such a way as to minimise the build-up of activity in the primary circuit of the reactor;

(*c*) To perform the conventional functions of controlling pressure levels in the primary circuit and of providing supplies of cool, clean, primary coolant gas to components requiring such supplies; these functions include control of admission and discharge of gas to and from the reactor system.

Additional functions are the detection and location of faulty fuel elements, the sampling and analysis of impurities in the coolant, and the detection and location of coolant leaks. For the DRAGON Reactor Experiment, equipment has been provided to perform all the functions listed above.

Purge system

In the light of the information available in 1959-60, it was apparent that, unless greatly improved fuel materials could be developed, activities in the primary coolant circuit would be embarrassingly high, if the fission products escaping from the fuel were allowed to pass freely into the main coolant stream. Accordingly a purged fuel element design was adopted, in which an attempt was made to sweep away the fission products in a comparatively small stream of helium passing through the fuel elements, before they could contaminate the main stream of primary coolant helium. The magnitude of the purge flow (approximately 8 g/s) was chosen so that it would not only be suitable for sweeping away the fission products, but would also provide a suitable rate of turnover of the primary circuit helium inventory (about three times every twenty-four hours) for continuous purification purposes.

The purge stream from each fuel element is first sampled to permit detection and location of faulty fuel elements, and to provide experimental information on fission product release characteristics of the fuel elements. The combined purge stream is then passed through a series of fission product traps, whose function is to eliminate the shorter-lived activities and to dispose of the resultant decay heat, before passing to a helium purification plant. The helium purification plant is designed to trap out substantially all the remaining (long-lived and stable) fission products, as well as to remove all potentially harmful chemical impurities, such as water vapour and carbon dioxide, thus providing a purified stream of clean, inactive helium, to be returned to the primary circuit, or supplied to other sub-systems and components as required [3].

In the absence of extensive experimental data, arbitrary assumptions had to be made and these led to a design decay heat load for the fission product traps in the region of 1% of the total thermal power of the reactor, with a total stored activity of about eight megacuries. These assumptions also brought problems in ensuring guaranteed cooling, adequate containment and in providing for remote maintenance of components such as valves, whose reliability could not be guaranteed for the life of the reactor. Although solutions were found to these problems for the DRAGON Reactor, it was clear that extrapolation of such a system to power outputs in the range above 1 000 MW(th) would involve appreciable expenditure.

Coolant purification plant

In the DRAGON purge circuit, coolant purification is achieved, once the most intense activities have been trapped out, by low temperature trapping. An oxidiser containing CuO and Cu in active form at about 350 °C is first used to convert CO and hydrogen to the more readily trapped CO_2 and water vapour. These are then removed by freezing out on a low temperature heat exchanger, and the remaining impurities and long-lived fission gases are adsorbed in activated charcoal traps, cooled by liquid nitrogen. Such a low temperature purification process has two major advantages:

(*a*) The traps can easily be regenerated when their capacity is exhausted;

(*b*) The purified helium is virtually free from radioactivity, and can therefore be pumped, stored and distributed without difficulty.

It would appear worthwhile to retain these advantages in any future large reactor, having large steam generators operating at a higher pressure than the primary coolant, where a fairly large clean-up flow may be necessary to keep down the water vapour concentration in the primary circuit. Thus such a reactor would probably have two different purification systems—one taking a large flow would consist of fairly simple large capacity driers, for removal of water vapour and perhaps carbon dioxide, while a smaller flow would be routed to a purification plant rather similar to that used in DRAGON for removal of the remaining impurities and provision of an inactive helium supply.

It can be seen that, while advances in fuel element technology have eliminated many of the coolant purification problems faced by DRAGON, much of the work done will be directly applicable to future high temperature gas-cooled reactors. Furthermore the coolant control facilities provided for DRAGON will enable the widest possible range of fuel elements to be studied, as fission product emitting, as well as fission product retaining, types can be accommodated.

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ABSTRACT - RÉSUMÉ - АННОТАЦИЯ - RESUMEN

A/549 Italie

Revue des travaux de génie industriel pour le projet DRAGON

par G. Franco *et al.*

Le réacteur expérimental à haute température DRAGON, de 20 MW(th), modéré au graphite et refroidi par l'hélium, est actuellement dans sa phase finale de construction à Winfrith (Dorset), en Angleterre.

Les travaux de construction, exécutés avec la participation d'un grand nombre d'entreprises et d'organismes des différents pays signataires, ont débuté en avril 1960 et la divergence du réacteur est prévue pour le deuxième trimestre de 1964.

Le mémoire passe en revue les principaux aspects des travaux de génie industriel aux différents stades du projet; études, fabrications et construction sur le site, essais; ces travaux ont tous été influencés de différentes manières par les caractéristiques nouvelles de ce type de réacteur, telles que l'utilisation de l'hélium comme gaz de refroidissement, l'emploi de combustibles céramiques non gainés, la haute température du gaz de refroidissement et le fait que l'installation est extrêmement compacte.

Une des caractéristiques communes à tous les éléments du circuit primaire est la nécessité d'obtenir un haut degré d'étanchéité, qui serait normal pour un laboratoire mais nouveau pour une grande installation. D'autres sujétions proviennent de la nécessité de purifier l'hélium de refroidissement de tous les produits de fission et impuretés chimiques, afin d'éviter toute réaction chimique avec le graphite chaud; cette purification impose, de plus, la mesure de concentration extrêmement faible des impuretés subsistant dans l'hélium et ceci durant la marche du réacteur.

L'utilisation d'hélium extrêmement pur a imposé des précautions toutes spéciales dans le choix des

matériaux pour les paliers et les engrenages, du fait qu'ils ne fonctionnent pas dans une atmosphère oxydante comme c'est généralement le cas.

D'une manière générale, on a veillé à ce que le personnel et le matériel soient de haute qualité afin de satisfaire les conditions de sécurité et d'exploitation et de faciliter les problèmes de construction sur le site du réacteur expérimental qui, par sa nature et ses objectifs, est plus complexe que ne le serait un réacteur de puissance.

A/549 Италия

Обзор инженерных работ по проекту строительства реактора DRAGON

Г. Франко *et al.*

Экспериментальный реактор DRAGON тепловой мощностью 20 *Мвт* относится к типу высокотемпературных реакторов с графитовым замедлителем и гелиевым теплоносителем, строительство которого в Уинфрите в графстве Дорсет находится в настоящее время на заключительном этапе.

Физический пуск реактора планируется на второй квартал 1964 года. Строительные работы, выполняемые при участии большого числа подрядчиков и организаций стран, подписавших соглашение по проекту DRAGON, начались в апреле 1960 года.

В докладе освещаются основные аспекты инженерных работ, осуществляемых на стадиях проектирования, изготовления узлов, строительства на месте и испытаний; на все эти работы в различной степени оказали влияние новейшие конструктивные особенности, связанные с реактором этого типа, такие как использование гелия в качестве теплоносителя, использование керамического топлива без оболочек, высокие рабочие температуры теплоносителя и исключительная компактность реакторной установки.

Одним из требований, влияющих на все компоненты первичного контура, является необходимость обеспечить очень высокую степень герметичности, которая была бы нормальной в лабораторных условиях, но является новой для крупной установки. К другим требованиям относятся необходимость очистки гелиевого теплоносителя как от продуктов деления, так и от химических примесей в целях избежания химических реакций с горячим графитом и необходимость измерения крайне незначительных уровней содержания примесей в ходе работы реактора.

Использование гелия высокой чистоты означает, что следует уделить особое внимание выбору материалов для подшипников и приводов, которые предназначены для работы не в окисляющей атмосфере, как это обычно имеет место.

В общем для удовлетворения требований безопасности и эксплуатации и для облегчения строительных проблем на месте, связанных с данным экспериментальным реактором, который по своему характеру и назначению является более сложным, чем мог бы быть энергетический реактор, потребовались высококачественные материалы и высококвалифицированная рабочая сила.

A/549 Italia

Obras de ingeniería del proyecto DRAGON

por G. Franco *et al.*

El reactor experimental DRAGON, de 20 MW(t), es un reactor de temperatura elevada moderado por grafito y refrigerado por helio, cuya construcción está terminándose en Winfrith, Dorset, Inglaterra.

Se calcula que alcanzará la criticidad durante el segundo trimestre de 1964, y su construcción, en la que participó un gran número de contratistas y organizaciones de los diferentes países signatarios, se inició en abril de 1960.

En la memoria se examinan los principales aspectos de las obras de ingeniería durante las sucesivas fases de proyecto, fabricación de materiales, obras de construcción y ensayos, en todos los cuales, si bien en diferente medida, hubo que tener en cuenta las nuevas características que distinguen a este tipo de reactor, tales como el uso del helio como refrigerante, el empleo de combustible cerámico sin revestimiento, las elevadas temperaturas del refrigerante y la extremada compacidad de la planta.

Uno de los requisitos que afectan a todos los componentes del circuito primario es la necesidad de satisfacer normas muy estrictas de hermeticidad, que serían normales para un laboratorio, pero constituyen algo nuevo para una instalación de estas dimensiones. Otros requisitos son la necesidad de purificar el helio, tanto en lo que se refiere a los productos de fisión como a las impurezas químicas (el helio debe ser muy puro para evitar que reaccione químicamente con el grafito caliente), y la necesidad de medir las pequeñísimas cantidades de impurezas que aparezcan durante el funcionamiento del reactor.

El empleo de helio muy puro ha obligado a prestar especial atención a la elección de materiales para cojinetes y engranajes, puesto que en este caso no trabajan, como habitualmente, en atmósfera oxidante.

En general, se han establecido especificaciones muy estrictas para los materiales y la mano de obra, a fin de satisfacer los requisitos de seguridad y las condiciones de funcionamiento y facilitar la solución de los problemas de construcción *in situ* de este reactor experimental que, por su propia naturaleza y finalidad, es más complicado que un reactor de potencia de tipo normal.

International collaboration in nuclear reactor projects, including developments of major co-operative installations

Chairman: F. Perrin (France)

Paper P/193
Paper P/295 (presented by Y. V. Arkhangelsky)
Papers P/121, P/122 (presented by C. A. Rennie)
Paper P/596 (presented by V. O. Eriksen)
Paper P/533 (presented by W. Schnurr)
Paper P/515 (presented by J. Storrer)
Paper P/840 (presented by M. A. El-Guebeily)
Paper P/549 (presented by G. Franco)

GENERAL DISCUSSION

B. Torki (Tunisia): Mr. Smyth and Mr. Arkhangelsky, what, in your opinion, are the areas in nuclear energy in which co-operation between different countries would be desirable in the future? For instance, in the construction of large power reactors?

Secondly, given that co-operation means collaboration among equals rather than assistance given by one country to another, are there any areas where co-operation of that kind is possible between technically advanced and developing countries? If so, please specify them.

H. D. Smyth (USA): I am not sure I would like to try and name offhand any particular fields for co-operation so I will limit myself, if I may, to Mr. Torki's second question. As I understand the question, it is whether there is any way in which a developing country can co-operate in scientific or technical fields with a developed country on a basis of equal partnership.

There are, in my view, three ways in which such co-operation can occur, namely, on the financial plane, between individual scientists and between groups.

On the financial plane, the proportion of funds contributed to a joint project by either partner can be determined entirely by their relative interest in the project.

In terms of individual co-operation, there is no reason why scientists from a developing country cannot meet those from a developed country on an equal basis. The big countries have no monopoly on brains. Young men from a developing country can compete on an equal basis as students in centres of learning anywhere. There may also be senior people in a developing country just as competent in a particular field as their colleagues elsewhere, though there will probably not be as many of them.

In terms of group co-operation on a project, it would seem likely that, in particular fields, such as agriculture or medical investigations of specific diseases which may be better known in a less developed country, a combined group might have members from the developing country at least as competent as those from the developed country. In such joint projects, it would be difficult to say which group made the greater contribution scientifically and technically, but the members of the group would be expected to contribute in terms of their individual experience and background of knowledge.

Naturally as the pool of scientific and technical people in developing countries grows in strength, the chances for co-operation on an equal basis will increase.

Y. V. Arkhangelsky (USSR): There are, in principle, no difficulties about finding areas for co-operation with the developing countries. There is always scope for co-operation on a basis of equality in sectors of mutual interest to the countries concerned. As regards specific cases, these would have to be formulated clearly and discussed jointly.

W. B. Lewis (Canada): I would like to contribute on this point. Canada's atomic energy programme, although not one of the largest, may claim a relatively long experience. We have found means for collaboration with a number of developing countries. The extent of the collaboration on an equal basis depends on the size of the contribution from the minor partner. Our most extensive experience of such collaboration has been with India; first in the Canada-India Reactor project and now continuing with heavy-water power reactor technology and the construction of a 200 MW(e) nuclear power plant. On the other hand, sometimes the collaboration has amounted only to sending or receiving a scientist or engineer to work as a full member of a team. It seems that satisfactory collaboration is possible on any desired scale over a very wide range of projects, from studies of cosmic ray neutrons or nuclear power economics to power reactor construction.

F. Perrin (Chairman): I have a few remarks I should like to make in conclusion. During this meeting, we have been told of a number of outstanding examples of joint enterprise, such as the DRAGON reactor, or of co-operation going beyond technical assistance proper, such as the construction of a power reactor in Czechoslovakia, with Soviet collaboration, along with more general ideas. Now, however, I should like to say a few words from the standpoint of the spirit in which international collaboration should henceforward be developed.

As has been repeatedly stressed, this Conference marks the starting point for great industrial achievements throughout the world and in this connexion we have seen the emergence of a new form of secrecy, one that needs to be kept to a minimum. The sphere of peaceful applications of nuclear energy was almost wholly freed from military secrecy by the first two big Conferences of 1955 and 1958. But now that these forthcoming achievements, particularly in the production of electric power from nuclear energy, involve considerable commercial interests, we find that much highly important information from the standpoint of the development of such power stations and assessment of their economic value is being kept secret on grounds of industrial or commercial copyright. I would merely like to point out that, although less sensational than the military form, this form of secrecy can be highly prejudicial to international co-operation, and that we all must make an effort to preclude abusive resort to this pretext and to ensure that technical and economic data, to the maximum extent consistent with respect for the essential economic interests of all countries, are published or freely communicated within the framework of any collaborative endeavour.

Lastly, it would, I think, be appropriate to recall here that in the course of this Conference we have had presented to us, quite apart from the projects for collaboration, technical assistance or joint ventures in regard to research and power reactors, ambitious projects for international collaboration with a view to the utilization of nuclear energy for desalting sea or brackish water. It is highly significant that it is this possible use of nuclear energy that has stimulated thoughts of international collaboration, for although the matter in question is one of great importance for mankind, it is not strictly a nuclear one, since conventional sources of energy can be used more economically for the purpose, possibly even as a first stage.

This observation makes, I think, a fitting conclusion to these comments, by underlining the fact that international co-operation in the nuclear energy field, apart from the objectives and benefits proper to it, may have a good effect on the development of fruitful international collaboration in many other fields and would thus contribute, in an even more effective and far-reaching way than we could hope to do in the field of nuclear energy alone, to the progress and peace of mankind.

Compte rendu de la séance C

Collaboration internationale dans l'étude ou l'exploitation de réacteurs nucléaires, y compris la création de grandes installations coopératives

Président: F. Perrin (France)

Mémoire P/193
Mémoire P/295 (présenté par Y. V. Arkhangelsky)
Mémoires P/121, P/122 (présentés par C. A. Rennie)
Mémoire P/596 (présenté par V. O. Erikson)
Mémoire P/533 (présenté par W. Schnurr)
Mémoire P/515 (présenté par J. Storrer)
Mémoire P/840 (présenté par M. A. El-Guebeily)
Mémoire P/549 (présenté par G. Franco)

DISCUSSION

B. TORKI (Tunisie): Je voudrais demander à M. Smyth et à M. Arkhangelsky quels sont, à leur avis, les domaines de l'énergie atomique dans lesquels la coopération entre différents pays serait souhaitable à l'avenir? Que pensent-ils, par exemple, d'un domaine tel que la construction de réacteurs de grande puissance?

Deuxièmement, la coopération étant entendue non comme une assistance d'un pays à un autre, mais comme une collaboration entre égaux, existe-t-il des domaines de l'énergie atomique où une telle collaboration soit possible entre pays techniquement avancés et pays en voie de développement? Si oui, quels sont-ils?

H. D. SMYTH (Etats-Unis d'Amérique): Comme je ne suis pas sûr de pouvoir désigner immédiatement les domaines possibles de coopération, je me bornerai, si on me le permet, à répondre à la deuxième question de M. Torki.

Si j'ai bien compris, il s'agit de savoir quelles possibilités existent pour un pays en voie de développement de coopérer sur un pied d'égalité avec un pays développé dans les domaines scientifique ou technique. A mon sens, il y a trois sortes de coopération possible: sur le plan financier, entre savants à titre individuel et entre groupes de savants.

Sur le plan financier, la part de chacun des partenaires dans le financement d'un projet commun dépend entièrement de l'intérêt qu'il attache à ce projet.

En ce qui concerne la coopération sur le plan individuel, il n'y a pas de raison pour que des savants d'un pays en voie de développement ne rencontrent pas sur un pied d'égalité leurs collègues d'un pays développé. Les grands pays n'ont pas le monopole de la matière grise. Les jeunes d'un pays en voie de développement peuvent rivaliser sur un pied d'égalité avec les autres étudiants dans des centres d'enseignement, où que ce soit. Il peut même y avoir dans les pays en voie de développement des personnes déjà expérimentées et aussi compétentes dans leur branche que leurs collègues d'autres pays, mais elles seront probablement moins nombreuses.

Quant à la coopération collective en vue de l'exécution d'un projet, il est à mon avis probable que dans des domaines précis, tels que l'agriculture ou la recherche concernant des maladies peut-être mieux connues dans un pays en voie de développement, les membres d'un groupe mixte qui sont originaires du pays en question seront au moins aussi compétents que les membres venant du pays développé. Il est peut-être difficile de dire lesquels contribuent le plus à la réalisation d'un projet commun, sur les plans scientifique et technique; normalement, la contribution de chaque membre du groupe dépend de son expérience et de ses connaissances.

Il est évident que plus les savants et les techniciens seront nombreux dans les pays en voie de développement, plus les possibilités de coopération sur un pied d'égalité seront grandes.

Y. V. Arkhangelsky (URSS): En principe, il n'est pas difficile de trouver des domaines de coopération avec les pays en voie de développement; la coopération sur un pied d'égalité est toujours possible dans des secteurs d'intérêt mutuel pour les pays intéressés. Quant aux cas précis, ils doivent être définis clairement et examinés en commun.

W. B. Lewis (Canada): Je voudrais dire quelques mots à ce sujet. Le programme canadien en matière d'énergie atomique, s'il n'est pas un des plus importants, se fonde néanmoins sur une assez longue expérience. Nous avons pu collaborer avec certains pays en voie de développement. L'importance de la collaboration sur un pied d'égalité avec un partenaire moins avancé dépend de l'ampleur de sa contribution. C'est avec l'Inde que nous avons été le plus loin dans ce sens, tout d'abord avec le projet de réacteur canado-indien, qui est maintenant suivi par des recherches sur la technologie des réacteurs de puissance à l'eau lourde, et par la construction d'une centrale électrique nucléaire de 200 MW(e). Dans d'autres cas, nous nous sommes bornés à envoyer ou à accueillir un savant ou un ingénieur qui a participé directement à des travaux d'équipe. Il existe, semble-t-il, une vaste gamme de projets pour lesquels une collaboration est possible au niveau souhaité, qu'il s'agisse de l'étude des neutrons des rayons cosmiques ou des avantages économiques de l'énergie d'origine nucléaire, voire de la construction d'un réacteur de puissance.

F. Perrin (Président): Je voudrais conclure par quelques remarques. Au cours de cette séance, on nous a présenté, à côté de considérations plus générales, quelques exemples marquants d'entreprises communes telles que le réacteur DRAGON, ou de coopération allant au-delà de la simple assistance technique, comme la construction en Tchécoslovaquie d'un réacteur de puissance avec la collaboration de l'Union soviétique. Mais je voudrais maintenant dire quelques mots au sujet de l'esprit dans lequel la collaboration internationale peut dès à présent se développer.

Comme on l'a souvent souligné, la présente Conférence marque le début de grandes réalisations industrielles dans le monde entier, et nous avons vu apparaître à ce propos une nouvelle forme de secret qu'il importe de limiter au maximum. Les deux premières grandes conférences, celle de 1955 et celle de 1958, avaient presque totalement libéré du secret militaire le domaine des applications pacifiques de l'énergie atomique. Mais, maintenant que les grandes réalisations prochaines, concernant notamment la production d'énergie électrique à partir de l'énergie atomique, mettent en jeu des intérêts commerciaux considérables, nous voyons que beaucoup d'informations de grande importance du point de vue du développement et de la valeur économique des centrales nucléaires sont gardées secrètes pour des raisons de propriété industrielle ou commerciale. Je voudrais simplement remarquer que cette forme de secret, quoique moins dramatique que le secret militaire, peut nuire gravement à la coopération internationale et que nous devons tous faire un effort pour éviter que ce prétexte ne soit invoqué abusivement et pour que, tout en respectant les intérêts économiques essentiels de tous les pays, le maximum d'informations techniques et économiques soient rendues publiques ou soient libéralement communiquées dans le cadre de toute entreprise de collaboration.

Enfin, je crois qu'il serait judicieux de rappeler maintenant qu'en dehors de projets de collaboration et d'assistance technique, ou des entreprises communes concernant les réacteurs d'étude ou les réacteurs de puissance, on nous a présenté, au cours de cette troisième Conférence, de grands projets de collaboration industrielle en vue de l'utilisation de l'énergie atomique pour le dessalement des eaux de mer ou des eaux saumâtres. Il est très significatif que ce soit cette possibilité d'utilisation de l'énergie atomique qui ait conduit à envisager une collaboration internationale, car, bien que ce domaine soit d'une grande importance pour l'humanité, il n'intéresse pas spécifiquement la science atomique puisque les sources classiques d'énergie peuvent être utilisées à cette fin, peut-être même, dans une première étape, plus avantageusement que l'énergie atomique.

Il me semble bon de terminer ces quelques remarques sur cette observation, car elle souligne que la coopération internationale dans le domaine de l'énergie atomique peut avoir, en dehors des objectifs et des bienfaits qui lui sont propres, une influence heureuse sur le développement d'une collaboration internationale féconde dans bien d'autres domaines, et contribuera ainsi, plus efficacement et plus profondément encore que nous ne pourrions le faire dans le seul domaine de l'énergie atomique, au progrès de l'humanité et à la paix.

Протокол заседания C

Международное сотрудничество в области проектирования ядерных реакторов, включая совместные разработки по основным установкам

Председатель: Ф. Перрен (Франция)

Доклады Р/193 (представил Г. Д. Смит)
Р/295 (представил Ю. В. Архангельский)
Р/121 (представил С. А. Ренни)
Р/596 (представил В. О. Эриксен)
Р/533 (представил В. Шнурр)
Р/515 (представил Дж. Сторрер)
Р/840 (представил М. А. Эль Гебейли)
Р/549 (представил С. Франко)

ОБЩАЯ ДИСКУССИЯ

Б. ТОРКИ (Тунис): Г-н Смит и г-н Архангельский, в каких областях использования атомной энергии, по Вашему мнению, желательно в будущем сотрудничество между различными странами? Например, в области строительства крупных энергетических реакторов?

Во-вторых, если сотрудничество означает совместную работу среди равных, а не помощь одной страны другой, то существуют ли области, где возможно сотрудничество такого рода между технически развитыми и развивающимися странами? Если это так, то определите их.

Г. Д. СМИТ (США): Я не уверен, что смогу назвать экспромтом какие-то особые области сотрудничества, поэтому ограничусь, если позволите, ответом на второй вопрос г-на Торки. Как я понимаю вопрос, он сводится к следующему: есть ли пути, по которым развивающаяся страна может сотрудничать с развитой страной в научной и технической областях на равных началах?

На мой взгляд, существуют три возможных пути развития такого сотрудничества: сотрудничество по линии финансов, сотрудничество между отдельными учеными и сотрудничество между группами ученых.

Что касается финансового сотрудничества, то суммы, вкладываемые каждым партнером в объединенный проект, могут полностью определяться относительной заинтересованностью в данном проекте.

Что касается персонального сотрудничества, то здесь нет причин, исключающих сотрудничество ученых развивающихся стран с учеными развитых стран на равных началах. Крупные страны не владеют монополией на умы. Молодежь развивающейся страны может заниматься на равных началах в качестве студентов учебных центров. В развивающейся стране могут быть также ученые старшего поколения, выступающие как полноправные участники в отдельно взятой области подобно их коллегам в других странах, но, вероятно, таких ученых немного.

Теперь относительно группового сотрудничества в осуществлении проекта; представляется вероятным, что в отдельных областях, таких как сельское хозяйство и медицинские исследования специфических заболеваний, которые могут быть лучше известны в менее развитой стране, объединенная группа может включать членов из развивающейся страны, по крайней мере столь же компетентных, как и члены группы из развитой страны. При осуществлении таких объединенных проектов трудно сказать, какая из групп сделает более ценный вклад в научном и техническом отношениях, но надо полагать, что члены такой группы примут участие соответственно с их индивидуальным опытом и знаниями.

Естественно, что по мере увеличения числа научных и технических кадров в развивающихся странах их шансы на сотрудничество на равных началах будут увеличиваться.

Ю. В. АРХАНГЕЛЬСКИЙ (СССР): В принципе нет трудностей в отыскании областей для сотрудничества с развивающимися странами. Всегда имеется возможность сотрудничества на равной основе в областях, представляющих взаимный интерес для стран-участниц. Что касается нетипичных случаев, то здесь они должны быть четко определены и совместно обсуждены.

У. Б. ЛЬЮИС (Канада): Я бы хотел высказаться по этому вопросу. Хотя канадская программа по использованию атомной энергии и не является самой обширной, но у нас имеется довольно большой опыт. Нами найдены пути сотрудничества с рядом развивающихся стран. Что касается сотрудничества на равных началах, то это зависит от степени участия младшего партнера. Наш наиболее обширный опыт такого сотрудничества касается Индии: вначале в области разработки канадско-индийского проекта реактора, а теперь в области разработки технологии тяжеловодного энергетического реактора и строительства атомной электростанции мощностью 200 *Мвт*. С другой стороны, иногда сотрудничество заключалось только в посылке или приеме ученого или инженера как полноправного члена группы. Удовлетворительное сотрудничество возможно, по-видимому, в любом желаемом масштабе в очень широком диапазоне осуществления проектов — начиная от изучения нейтронов космического излучения или экономики ядерных реакторов и кончая строительством реакторов.

Ф. ПЕРРЕН (председатель): В заключение я хотел бы сделать несколько замечаний. Во время этого заседания нам рассказали о нескольких ярких примерах проведения совместных мероприятий, например строительство реактора DRAGON, или о сотрудничестве вне рамок именно технической помощи, например строительство энергетического реактора в Чехословакии в содружестве с СССР наряду с наличием более общих идей. Но сейчас я хотел сказать несколько слов относительно атмосферы, в какой должно развиваться международное сотрудничество.

Как неоднократно подчеркивалось, данная конференция знаменует начало больших достижений в области промышленности во всем мире; в этой связи мы увидели, что возникла новая форма секретности, которую необходимо свести к минимуму. Область мирного применения ядерной энергии почти полностью свободна от секретности, присущей военному применению, о чем свидетельствуют две большие конференции 1955 и 1958 годов. Но теперь, когда эти будущие достижения, особенно в области получения атомной электроэнергии, представляют большой промышленный интерес, нами обнаружено, что большое количество информации, очень важной с точки зрения разработки таких атомных станций и оценки их экономических показателей, держится в секрете под предлогом охраны авторских прав в промышленном или торговом отношении. Мне бы только хотелось указать, что эта форма секретности, хотя и менее впечатляющая, чем военная секретность, может сильно повредить международному сотрудничеству и мы должны направить свои усилия на предотвращение злоупотреблений этими предлогами и добиться, чтобы технические и экономические данные, в максимальной степени совпадающие с основными экономическими интересами всех стран, публиковались бы или были бы доступны для свободного обмена в рамках сотрудничества.

Наконец, я думаю, здесь уместно напомнить, что в ходе данной конференции кроме проектов развития сотрудничества, оказания технической помощи или проведения объединенных мероприятий в отношении исследовательских и энергетических реакторов нам представили претенциозные проекты для международного сотрудничества по использованию ядерной энергии для опреснения морской или солончаковой воды. Крайне важно, что существует область использования ядерной энергии, которая стимулирует международное сотрудничество; этот вопрос имеет огромное значение для всего человечества, хотя здесь речь идет не только строго о ядерной энергии, так как для этой цели экономически более выгодно могут применяться обычные источники энергии, особенно, вероятно, на первой стадии.

Я полагаю, что на основании этих комментариев можно сделать соответствующий вывод, особенно подчеркнув тот факт, что международное сотрудничество в области ядерной энергии кроме его основных целей и выгод может оказать благоприятное влияние на развитие плодотворного международного сотрудничества во многих других областях и таким образом будет способствовать прогрессу и делу мира в интересах всего человечества даже более эффективно и перспективно, чем мы могли бы надеяться, если бы речь шла только об области использования ядерной энергии.

Acta de la sesión C

Colaboración internacional en el estudio y explotación de reactores y en la creación de grandes instalaciones cooperativas

Presidente: F. Perrin (Francia).

Documento P/193
Documento P/295 (presentado por Y. V. Arkhangelsky)
Documentos P/121, P/122 (presentados por C. A. Rennie)
Documento P/596 (presentado por V. O. Eriksen)
Documento P/533 (presentado por W. Schnurr)
Documento P/515 (presentado por J. Storrer)
Documento P/840 (presentado por M. A. El-Guebeily)
Documento P/549 (presentado por G. Franco)

DISCUSIÓN GENERAL

B. TORKI (Túnez): Quisiera preguntar a los señores Smyth y Arkhangelsky cuáles son, a su juicio, los sectores de la energía nuclear en que convendría establecer en el futuro una cooperación entre los distintos países y si entre esos sectores figura, por ejemplo, la construcción de grandes generadores nucleares.

Por otra parte, dado que la cooperación significa la colaboración entre iguales más bien que la ayuda de un país a otro, conviene saber si hay sectores en los que una cooperación de esta índole sea posible entre países técnicamente adelantados y países en desarrollo. En caso afirmativo quisiera que me dijeran cuáles son esos sectores.

H. D. SMYTH (Estados Unidos de América): No querría mencionar a la ligera ningún sector especial para la cooperación, y, por tanto, me limitaré a contestar a la segunda pregunta del Sr. Torki. Si no me equivoco, lo que desea saber es de qué manera un país en desarrollo puede cooperar en campos científicos o técnicos con un país desarrollado en condiciones de igualdad.

A mi juicio, esa cooperación puede efectuarse de tres maneras distintas, a saber: en el plano financiero, entre hombres de ciencia y entre grupos.

En el plano financiero, la proporción de los fondos con que cada parte habrá de contribuir a un proyecto mixto puede determinarse sin más que considerar su interés relativo en el proyecto.

Desde el punto de vista de la cooperación individual, nada impide que los hombres de ciencia de un país en desarrollo colaboren con los de un país desarrollado en condiciones de igualdad. Los grandes países no tienen el monopolio de la inteligencia. Los jóvenes de un país en desarrollo pueden competir en condiciones de igualdad como estudiantes en los centros de enseñanza de cualquier parte del mundo. Pueden ser también el elemento directivo de un país en desarrollo, siendo tan competentes en un campo determinado como sus colegas de otro país cualquiera, aunque probablemente su número sea menor.

En cuanto a la cooperación de grupo en un proyecto, parece probable que en esferas determinadas, tales como la agricultura o las investigaciones médicas de enfermedades concretas, que pueden conocerse mejor en un país menos desarrollado, un grupo mixto tal vez esté integrado por miembros del país en desarrollo que sean, cuando menos, tan competentes como los miembros del país desarrollado. En tales proyectos comunes sería difícil decir qué grupo contribuiría más desde el punto de vista científico y técnico, pero cabría esperar que los miembros del grupo contribuyeran conforme a su experiencia individual y a sus conocimientos.

Por supuesto, a medida que aumente la cantidad de personal científico y técnico en los países en desarrollo, las posibilidades de establecer una cooperación en condiciones de igualdad aumentarán también.

Y. V. ARKHANGELSKY (Unión de Repúblicas Socialistas Soviéticas): En principio no es difícil encontrar sectores de cooperación con los países en desarrollo. La cooperación en condiciones de igualdad siempre es posible en sectores de interés mutuo para los países interesados. Por lo que respecta a los casos concretos, habría que formularlos claramente y examinarlos en común.

W. B. LEWIS (Canadá): Deseo contribuir al examen de esta cuestión. El programa de energía atómica del Canadá, sin ser de los más importantes, puede reivindicar una experiencia relativamente larga. Hemos hallado medios de colaborar con varios países en desarrollo. La amplitud de la colaboración en condiciones de igualdad depende de la cuantía de la contribución del país menos importante. La India es el país con el que hemos adquirido una experiencia más amplia sobre dicha colaboración. Primero en el proyecto de reactor Canadá-India, y ahora con la tecnología de reactores de agua pesada y la construcción de una central nucleoeléctrica de 200 MW(e). Ahora bien, la colaboración se ha limitado en ocasiones a enviar o recibir un hombre de ciencia o un ingeniero para que trabaje como miembro de un equipo sin restricción en sus funciones. Al parecer, se puede establecer una colaboración satisfactoria en cualquier escala que se desee respecto de una gama muy variada de proyectos, que va de los estudios de los neutrones en los rayos cósmicos o de los factores económicos de la energía nuclear hasta la construcción de generadores nucleares.

F. PERRIN (Presidente): Deseo formular algunas observaciones a guisa de conclusión. En esta sesión, se nos ha hablado de varios ejemplos destacados de proyectos mixtos, tales como el reactor DRAGON, o de la cooperación que traspasa los límites de la asistencia técnica propiamente dicha, como la construcción de un generador nuclear en Checoslovaquia, con la colaboración soviética, así como de ideas más generales. Desearía ahora decir algunas palabras sobre el espíritu que debe inspirar en lo sucesivo la colaboración internacional.

Como reiteradamente se ha destacado, esta Conferencia marca el punto inicial de grandes realizaciones industriales en todo el mundo, y en este orden de ideas hemos visto surgir una nueva forma de secreto, que hay que reducir a un mínimo. Las aplicaciones pacíficas de la energía nuclear estaban casi en absoluto libres del secreto militar cuando se celebraron las dos primeras grandes Conferencias de 1955 y de 1958. Pero ahora que estas inminentes realizaciones, en particular en la producción de energía eléctrica de origen nuclear, entrañan un interés comercial considerable, observamos que se mantiene secreta una información mucho más importante desde el punto de vista de la creación de esas centrales nucleoeléctricas y de la evaluación de su valor económico, fundándose en los derechos de patente industrial o comercial. Deseo limitarme a indicar que, aunque esta forma de secreto es menos sensacional que la de tipo militar, puede perjudicar mucho a la cooperación internacional, y que todos nosotros debemos esforzarnos por impedir que se recurra de un modo abusivo a este pretexto y por garantizar que, en toda la medida compatible con el respeto a los intereses económicos esenciales de todos los países, los datos de orden técnico y económico se publiquen o se comuniquen libremente en todos los proyectos de colaboración.

Por último, estimo que convendría recordar aquí que en el curso de esta Conferencia, además de los proyectos de colaboración, de asistencia técnica o de proyectos mixtos respecto de la investigación y los generadores nucleares, se nos han presentado proyectos ambiciosos de colaboración internacional a fin de utilizar la energía nuclear para la desalinización de agua de mar o salobre. Es muy importante que esta posibilidad de utilizar la energía nuclear sea lo que haya estimulado la idea de la colaboración internacional porque, aun cuando se trata de una cuestión muy importante para el género humano, no es de índole estrictamente nuclear, ya que las fuentes corrientes de energía pueden utilizarse a dicho efecto de un modo más económico, según parece incluso como primera etapa.

A mi juicio, estas palabras constituyen una conclusión adecuada a las observaciones que he formulado porque destacan que la cooperación internacional en el campo de la energía nuclear, aparte de los objetivos y beneficios que le son inherentes, puede influir favorablemente en el establecimiento de una colaboración internacional fecunda en otros muchos campos y contribuir así, de manera mucho más eficaz y trascendente de lo que cabe esperar en la esfera de la energía nuclear, al progreso y la paz del género humano.

Session H

CLOSING OF THE CONFERENCE

Record of Session H

Closing of the Conference

President: **V. S. Emelyanov**

ЗАКЛЮЧИТЕЛЬНАЯ РЕЧЬ ПРЕДСЕДАТЕЛЯ КОНФЕРЕНЦИИ, ПРОФЕССОРА В. С. ЕМЕЛЬЯНОВА
Closing address by Mr. V. S. Emelyanov, President of the Conference

Closing address by Mr. Sigvard Eklund, Director General of the International Atomic Energy Agency

Déclaration de clôture de M. P. P. Spinelli, directeur de l'Office européen des Nations Unies, représentant du Secrétaire général de l'Organisation des Nations Unies
Closing statement by Mr. P. P. Spinelli, Director of the European Office of the United Nations, representative of the Secretary-General of the United Nations

ЗАКЛЮЧИТЕЛЬНАЯ РЕЧЬ ПРЕДСЕДАТЕЛЯ КОНФЕРЕНЦИИ, ПРОФЕССОРА В. С. ЕМЕЛЬЯНОВА

Дамы и господа!

Третья международная конференция Организации Объединенных Наций по применению атомной энергии в мирных целях завершила свою работу.

По количеству представленных докладов, а также длительности ее работы Третья конференция — меньше двух предыдущих, но значение ее тем не менее велико. Большой интерес к докладам, серьезность и глубина их обсуждения превзошли то, что ожидалось.

Дружественная атмосфера, царившая во всех залах, где происходили доклады, и дискуссии между участниками Конференции свидетельствуют о благоприятной атмосфере, сложившейся в последнее время, об условиях, создающих предпосылки для успешного научно-технического сотрудничества, а хорошая теплая погода, установившаяся в эти дни в Женеве, корреспондировала теплоте людских отношений.

Работой Конференции интересовались не только ученые, но также государственные и общественные деятели, и значительное внимание ей уделили представители прессы. Это можно видеть из полученных в адрес конференции приветствий, телеграмм, писем и многочисленных корреспонденций, опубликованных в мировой печати, с изложением многих докладов и описанием экспонатов, размещенных на стендах выставки. В докладах и реакции на них отражены надежды на то, что атомная энергия будет приносить людям большую пользу, что эта могучая сила будет служить делу мира, приведет к тому, что исчезнет страх и рассеется подозрительность.

На Конференции присутствовало много представителей промышленности. Это очень хорошо. Если представители промышленности проявляют интерес к научным исследованиям, это значит, что промышленность чувствует аромат готовой пищи. Это — одно из безошибочных свидетельств практической ценности тех вопросов, которые обсуждались на Конференции.

На Конференции представлены результаты интересных и важных исследований о том, как будут в ближайшие десятилетия покрываться потребности в энергии в отдельных районах мира.

Во многих докладах звучала уверенность в том, что атомные электростанции во многих странах и районах могут уже в настоящее время производить электроэнергию по ценам или сравнимым с энергией, получаемой от электростанций, работающих на угле, или даже дешевле. За шестилетний период времени между второй и третьей Конференцией было построено значительное количество атомных реакторов. В настоящее время во всем мире действует свыше пятисот реакторов различного типа и мощности, учитывая реакторы, предназначенные для проведения исследовательских работ, испытания материалов, а также разрабатываемых конструкций тепловыделяющих элементов, ядерного топлива и для целей обучения.

За последние годы разработан и опробован не один тип атомного реактора, который может быть принят для промышленного использования уже в настоящее время.

Оценивая будущее атомной энергетики, можно отметить, что, в отличие от второй, на третьей конференции была выражена большая уверенность в том, что этот источник энергии в ближайшие 10—15 лет будет наиболее дешевым источником энергии и получит значительное развитие.

В докладах на Конференции приведены интересные сведения о том, какими энергетическими ресурсами располагают многие страны мира, в том числе развивающиеся страны Азии, Африки и Латинской Америки.

Как это можно видеть из докладов, рассмотренных на Конференции, многие страны обращают свои взоры к могучему источнику новой энергии — энергии ядерных процессов как к единственному источнику, способному обеспечить потребности в энергии этих стран.

На пленарных заседаниях и технических сессиях Конференции рассмотрены важные вопросы о формах и видах ядерного топлива, о конструкционных материалах, средствах защиты, влиянии радиоактивного облучения на материалы, процессы коррозии и много других важных вопросов, стоящих в повестке дня мировой науки и техники, всех тех организаций, кои занимаются атомной энергией.

На Конференции было представлено много докладов, имеющих большое практическое значение, а экспонаты выставки подчеркивали реальность и осуществимость того, о чем рассказывали специалисты с трибун Конференции.

На выставке приведены не только макеты, но наиболее важные элементы работающих электростанций, действующие установки по преобразованию тепловой энергии ядерных процессов в электрическую, многочисленные приборы, основанные на использовании радиоактивных изотопов и излучений.

На выставке были показаны разнообразные устройства по термоядерному синтезу, в том числе действующие установки, доставленные прямо из лабораторий.

На Конференции имело место обсуждение таких проблем, как проблема опреснения соленых вод.

Эта проблема является одной из важнейших для многих стран мира. Она многогранна. Решение проблемы опреснения соленых вод, и прежде всего морских вод, не только имеет большое экономическое и научно-техническое значение — решение этой проблемы открывает новые возможности для мирного использования атомной энергии.

Это — путь наиболее разумного, наиболее плодотворного применения достижений атомной науки и техники.

Для Третьей конференции характерно то, что на ней совершенно не было скованности, которая проявлялась на Первой конференции и имела место также и на Второй.

Дискуссии носили свободный характер и касались не только законченных исследований, но также и ведущихся, таких, по которым еще нет окончательных результатов.

Чрезвычайно отрадно было слышать, как во время дискуссии по проблеме термоядерного синтеза были затронуты не только завершенные работы, но также те, что предстоит выполнить в ближайшем будущем.

В проблемах атомной энергетики, имеющих первостепенное значение для обеспечения человечества неисчерпаемыми ресурсами энергии, мы имеем благоприятные возможности для эффективного международного сотрудничества ученых всех стран мира.

Конференция свидетельствует о том, что научные связи расширяются и крепнут, а международная политика, исходящая из положения о возможности мирного сосуществования государств с различным социальным строем, является единственно разумной политикой.

В 1958 году на Второй конференции высказывались опасения, что количество участников и докладов на Третьей конференции будет так велико, что ее практически нельзя будет созвать, нехватит ни места для всех желающих на ней присутствовать, ни времени для заслушивания докладов. Такая опасность действительно существовала, но ее удалось устранить.

Возможности для организации конференции были найдены, а интенсивная работа ее участников, наполненная глубоким содержанием, свидетельствует о большой предварительной работе, проведенной до созыва Конференции. Созвать конференцию и обеспечить ее успех было бы невозможно, если бы к ней не проявлялся глубокий интерес со стороны Генерального Секретаря Организации Объединенных Наций г-на У Тана. Его международный авторитет, внимание и оказанная помощь значительно содействовали успеху.

Большой вклад в организацию Конференции своим непосредственным участием в ее подготовке и разумными советами внес также Заместитель и представитель Генерального Секретаря ООН г-н Филипп де Сейн, которому оказывали помощь Заместитель директора Европейского отделения ООН и его сотрудники.

Подготовка программы Конференции и всего механизма ее работы является результатом больших усилий, приложенных Генеральным директором Международного агентства по атомной энергии доктором Зигвардом Эклундом, который, выполняя одновременно обязанности Генерального директора Международного атомного агентства, взял на себя дополнительную ответственность за подготовку программы Конференции и ее проведение.

Значительное содействие и помощь в организации работы Конференции были оказаны также его Специальным помощником. Тяжелое бремя принял на свои плечи Научный секретариат Конференции, возглавляемый профессором Ягодиным.

Им пришлось решать трудные задачи о том, каким путем наиболее разумно наполнить докладами пленарные и технические сессии с тем, чтобы показать наиболее ярко и объективно результаты мировой науки и техники в области мирного атома.

Большая работа проведена теми учеными, на долю которых легла ответственность за руководство работой как пленарных, так и технических секций.

Им было необходимо быстро и точно делать выводы из дискуссий и подводить итоги.

Директор Европейского отделения ООН г-н Спинелли как до начала Конференции, так и во время ее работы проявлял заботу и оказывал большую помощь, содействуя успеху Конференции.

Задолго до открытия Конференции Начальник административных служб приступил к принятию всех необходимых мер с тем, чтобы привести в действие весь сложный механизм ее обслуживания; с помощью всех своих сотрудников — устных и письменных переводчиков, сотрудников службы документации, дежурных в залах заседаний, секретарей и машинисток, предоставленных Европейским отделением ООН, Международным агентством по атомной энергии и другими организациями, — он много потрудился с тем, чтобы обеспечить повседневную работу Конференции.

Представители прессы оказывали содействие Конференции, широко освещая ее работу. На их долю выпала сложная миссия переводить трудные понятия современной науки на доступный для всех язык.

От имени всех участников Конференции я хотел бы выразить всем содействовавшим успеху Конференции благодарность.

Я хотел бы поблагодарить правительство Швейцарии и власти города Женевы за оказанное гостеприимство и внимание.

Дамы и господа!

Конференция закончила свою работу, и мы можем сказать, что она уже принесла большую пользу, которую трудно в нескольких словах охарактеризовать, но еще бо́льшую пользу она принесет в дальнейшем.

Конференция, подобно аккумуляторной станции, зарядила нас новой энергией и вдохновила на новые научные и инженерные исследования. Она связала нас невидимыми нитями взаимной дружбы и симпатий. Она убедила нас в том, что мы многое можем сделать, если умножим наши усилия с тем, чтобы атомная энергия служила только делу мира и прогресса.

Конференция показала, какие огромные возможности таят в себе атомные ядра. Ученые, прибывшие в Женеву из многих стран мира, показали нам пути к революционным преобразованиям во многих областях науки, техники, в экономике, здравоохранении, культуре. Но мы не можем забывать, что атом в наше время носит две формы — гражданскую и военную. И, как образно сказал в своем приветствии участникам нашей Конференции Председатель Совета Министров Советского Союза Никита Сергеевич Хрущев, «военный атом препятствует полнокровному развитию атома мирного. Вот почему важно решение проблемы всеобщего и полного разоружения и отказ от любых шагов, которые вели бы к расползанию ядерного оружия на нашей планете». Необходимо снять с атома военную форму, демобилизовать его.

Каждый расщепленный и каждый синтезированный атом должны служить только делу мира — это должно стать нашим девизом.

Translation

Closing address by Mr. V. S. Emelyanov, President of the Conference

Ladies and Gentlemen,

The Third United Nations International Conference on the Peaceful Uses of Atomic Energy has finished its work.

Judged by the number of papers submitted and by its length, the Third Conference has been smaller than its two predecessors; but this in no way diminishes its importance. The great interest shown in the papers, and the seriousness and depth of the discussions, have exceeded expectations.

The friendly atmosphere which has reigned in all the meeting rooms in which the papers were presented, and the discussions between the participants in the Conference, bear witness to the agreeable atmosphere which has grown up in recent years and to conditions creating the *sine qua non* for successful scientific and technological co-operation, while the fine warm weather which has blessed Geneva for the past few days has matched the warmth of the human relations at the Conference.

The work of the Conference has been of interest not only to scientists, but also to government and social workers; and the representatives of the Press have given much attention to it. This can be seen from the messages, telegrams and letters addressed to the Conference, and from the numerous articles published in the world press expounding many of the papers and describing the exhibits displayed on the stands at the Exhibition. Both in the papers themselves and in the discussions to which they have given rise, the hope has been expressed that atomic energy will bring mankind great blessings, that this mighty force will serve the cause of peace, abolish fear and dispel suspicion.

The Conference has been attended by many representatives of industry. This is a very good thing. If the representatives of industry show interest in scientific research, that means that industry scents the savour of a hot meal. This is an unerring testimony to the practical value of the questions that have been discussed at the Conference.

The results of interesting and important research into the problem of how the energy requirements of various regions of the world will be met in the coming decade have also been presented to the Conference.

Many papers rang with the conviction that in many countries and regions of the world atomic power stations are already able to produce electricity at prices either equal to or lower than those of energy produced in coal-burning plants. A considerable number of atomic reactors have been built during the six years that have elapsed between the Second and Third Conferences. At the present time, there are already in operation in all parts of the world more than 500 reactors of various types and capacities, including those designed for carrying out research and for testing materials, as well as for the design and construction of fuel elements, the development of nuclear fuels, and, lastly, training purposes.

In recent years, more than one type of atomic reactor that can already be used for industrial purposes has been designed and tried out.

As to the future of atomic energy, it may be observed that, in contrast to the Second Conference, great confidence was expressed at the Third that within the next 10 to 15 years this will become the cheapest source of energy, and will be very considerably developed.

Papers presented at the Conference gave interesting information about the energy resources of many countries of the world, including the developing countries of Asia, Africa and Latin America.

As can be seen from the papers considered at the Conference, many countries are fixing their sights on this powerful new source of energy — that released by nuclear processes — as the sole source capable of meeting their energy requirements.

At the general and technical sessions of the Conference important questions have been discussed relating to the forms and types of nuclear fuel, to constructional materials, to protective media, to the effects of irradiating materials and to corrosion, as well as many other important problems on the agenda of peaceful science and technology of all the organizations that are concerned with atomic energy.

Many papers of great practical significance were presented at the Conference, while the displays on the stands at the Exhibition emphasized the reality and realisability of what the experts said on the podium.

At the Exhibition, not only models, but also the most important parts of actual electric power stations, working apparatus for the conversion of the thermal energy of nuclear processes into electricity, and many types of apparatus and instruments based on the use of radioactive isotopes and irradiation, were on display.

Various types of installation for thermonuclear fusion, including working apparatus brought straight from the laboratory, were also to be seen at the Exhibition.

Such problems as that of the desalination of salt water were discussed at the Conference.

This is a most vital problem for many countries. It has many aspects. The solution of the problem of producing fresh water from salt water, and in particular from sea water, is not only of great economic, scientific and technological importance, it also opens up new possibilities for the peaceful use of atomic energy.

This is the path of the most intelligent and most fruitful application of the achievements of atomic science and technology. It is typical of the Third Conference that there has been absolutely none of the restraint that marked the First Conference and persisted into the Second.

The discussions have been entirely free and have referred not only to completed research, but also to that still in course where no definite results have yet been achieved.

It was particularly pleasant during the discussion of the problem of thermonuclear fusion to hear not only finished research described but also studies that are on the verge of completion.

In the problems of the place of atomic energy in general energy policy, which are of vital importance for guaranteeing to mankind inexhaustible resources of power, we have propitious opportunities for effective international collaboration among scientists of all countries.

The Conference has borne witness to the fact that scientific links are being extended and strengthened, while an international policy based on the possibility of peaceful coexistence of States with different social systems is the only intelligent policy.

In 1958, at the Second Conference, fears were expressed that there would be so many participants and papers at the Third Conference that it would be a practical impossibility to convene it, since there would be neither room for all those who would wish to attend, nor time to listen to all the papers. Such a danger certainly existed, but it has been successfully averted.

Possibilities of organizing the Conference were devised, and the intense activity of all those taking part in it, full of vital matter, bears witness to the thorough preparations made before the Conference assembled.

It would have been impossible to convene the Conference and ensure its success but for the deep interest shown in it by the Secretary-General of the United Nations, U Thant. His international authority, and the attention and assistance he has given to the project, have contributed substantially to the Conference's success.

The Under-Secretary and representative of the Secretary-General, Mr. Philippe de Seynes, supported by the Deputy Director of the European Office and by his own staff, also made a great contribution to the organization of the Conference, both by the direct part he played in the preparations and by his wise counsels.

The preparation of the Conference programme and of the whole machinery of its deliberations is the outcome of great efforts put forth by the Director General of the International Atomic Energy Agency, Mr. Sigvard Eklund, who, while still discharging his functions as Director General, assumed the additional responsibility for preparing the Conference programme and seeing it through. Substantial assistance and co-operation in the organizational work of the Conference were also given by his Special Assistant. Another Scientific Secretariat of the Conference, with Professor Yagodin at its head, assumed the heavy burden of the scientific preparation of the Conference.

They succeeded in solving the difficult problem of the best and most intelligent way of allocating papers to the general and technical sessions in order to bring out in the sharpest and most objective focus the achievements of world science and technology in the field of the peaceful atom.

The Scientific Secretaries, on whom fell responsibility for the conduct of the general and technical sessions, have also done great work. They were faced with the difficult task of making a rapid yet accurate summary of the discussions and of evaluating the outcome of each session.

Both before the Conference and during it, the Director of the European Office of the United Nations, Mr. Spinelli, has devoted much care to its preparation and has lent great assistance which has greatly contributed to its success.

Long before the Conference opened, the Chief Conference Officer was busy taking all the necessary steps to set the complex servicing machinery into motion; and, with the devoted support of all his staff — the interpreters, translators, document and conference room officers, and secretarial staff, drawn both from the European Office and the International Atomic Energy Agency themselves and from outside — he has worked hard to maintain the daily functioning of the Conference.

The representatives of information media have also made a substantial contribution to the Conference by shedding a generous light on its work. They had the difficult job of translating the esoteric concepts of modern science into a language that can be understood by all. In the name of all participants in the Conference, I would like to express our gratitude to all of those who have contributed to its success.

I would also like to thank the Swiss Government and the authorities of the City of Geneva for the hospitality they have extended to us.

Ladies and gentlemen,

The Conference has finished its work, and we can affirm that it has already brought great benefits, which it is difficult to describe in a few words; but it will bring even greater benefits in the future.

The Conference, like a giant accumulator station, has charged us with new energy and inspired us to undertake new scientific and engineering research. It has bound us together with the invisible threads of mutual friendship and understanding. It has convinced us that we can do much, if only we renew and intensify our efforts to ensure that atomic energy serves only the cause of peace and progress.

The Conference has revealed the enormous possibilities locked up in the atomic nucleus. The scientists who have come to Geneva from many parts of the world have shown us the way to revolutionary progress in many branches of science, technology, economics, public health and culture. But we cannot forget that in our time and day the atom has two aspects — the civil and the military. And, as the Chairman of the Council of Ministers of the USSR, Nikita Sergeevich Khrushchev, said so graphically in the message which he addressed to the Conference: "The military uses of the atom represent an obstacle to the full development of its peaceful uses. Hence the importance of solving the problem of general and complete disarmament and refraining from any measures which might lead to the dissemination of nuclear weapons on our planet." We must divest the atom of its military form, we must demobilize it.

Our slogan must be "Every atom split and every atom fused shall serve the cause of peace alone."

CLOSING ADDRESS BY MR. SIGVARD EKLUND, DIRECTOR GENERAL OF THE INTERNATIONAL ATOMIC ENERGY AGENCY

Mr. President, Ladies and Gentlemen,

It is appropriate that this Closing Session should have been preceded by one devoted to international collaboration in atomic energy projects. It has very fittingly sounded the "last post" of the Third Geneva Conference, since the Conference itself has been a further example of international collaboration by men of good will, having common interests and similar objectives.

It might be said that the Conference now closing has been unspectacular when compared with the 1955 and 1958 ones. But what has impressed me is the fact that there is so much less of speculation now, so much more of information based upon experience. It can be said that we have reached the stage in atomic energy where we are consolidating our gains, and we are approaching the point at which we shall be chasing the last few per cent, which will yield the most valuable returns the achievement of which in any technology requires the greatest effort.

In bidding you farewell I would not want this opportunity to pass without expressing to the host organization, the United Nations, and especially to the European Office, my sincere thanks for their unfailing effort in providing all of us with the best possible service. The smooth way in which the Chief Conference Officer has conducted the complicated conference machinery cannot but create admiration.

Allow me also to express on behalf of the organization I am serving my sincere thanks to you, Mr. President, for the magnificent example you have given us all through your sustained interest in all facets of the operations of the Conference.

I will conclude by wishing you, both delegations and observers, a safe return to your countries, with the hope that you have found your visit to Geneva to be well worth-while.

Déclaration de clôture de M. P. P. Spinelli, Représentant du Secrétaire général de l'Organisation des Nations Unies

Monsieur le Président, Mesdames, Messieurs,

Au nom du Secrétaire général, qui ne peut malheureusement être présent parmi nous aujourd'hui, je tiens à dire combien nous sommes heureux d'avoir été les hôtes, pendant ces dix derniers jours, de la troisième Conférence internationale sur l'utilisation de l'énergie atomique à des fins pacifiques.

Nous estimons, et nous espérons que vous partagez ce sentiment, que la troisième Conférence a été, comme les deux précédentes, couronnée de succès, et qu'elle a contribué à l'échange de connaissances scientifiques dans un domaine qui est manifestement d'une importance capitale. Comme vous le savez, l'Organisation des Nations Unies et les institutions qui lui sont reliées consacrent une grande partie de leurs efforts et de leurs ressources à encourager la diffusion des connaissances scientifiques et techniques par-delà les frontières nationales. La présente Conférence marque une étape importante dans la poursuite de ces efforts, dont l'objectif final est d'élever les niveaux de vie dans le monde entier et de contribuer de la sorte à atténuer les tensions et à assurer une paix durable.

Avant de terminer, je ne veux pas manquer de féliciter, au nom du Secrétaire général et en mon nom personnel, le professeur Emelyanov de la manière dont il a présidé cette importante Conférence, et d'exprimer une fois de plus notre sincère gratitude à l'Agence internationale de l'énergie atomique, et en particulier à M. Eklund, pour la collaboration étroite et harmonieuse qu'ils ont apportée à l'Organisation des Nations Unies dans la préparation et l'organisation de la Conférence.

En exprimant l'espoir que vous rentrerez dans vos foyers enrichis par votre participation à la présente Conférence, je vous souhaite bon voyage.

Translation

Closing statement by Mr. P. P. Spinelli, Representative of the Secretary-General of the United Nations

Mr. President, Ladies and Gentlemen, on behalf of the Secretary-General, who unfortunately cannot be with us today, I wish to say how happy we are to have been the hosts of the Third International Conference on the Peaceful Uses of Atomic Energy during the last ten days.

We consider, and we trust you agree, that the Third Conference, like its two predecessors, has been a success, and has contributed towards the exchange of scientific knowledge in a field which is clearly of vital importance. As you know, the United Nations and its associated organizations devote much of their effort and resources to promoting the diffusion of scientific and technical knowledge beyond national frontiers. The present Conference constitutes an important stage in the pursuit of these efforts, the ultimate objective of which is to raise standards of living throughout the world, thereby contributing towards reducing tension and ensuring lasting peace.

Before concluding, I should like to congratulate Professor Emelyanov, on behalf of the Secretary-General and on my own behalf, on the manner in which he has presided over this important Conference, and to express once more our sincere gratitude to the International Atomic Energy Agency, and especially to Mr. Eklund, for their close and harmonious co-operation with the United Nations in the preparation and organization of the Conference.

I hope that you will return home the richer for having attended this Conference and I wish you all a pleasant journey.

Evening Lecture

Summary of the Conference

By Glenn T. Seaborg *

It is a great honor to be assigned the task of summing up this memorable Conference. After attempting to digest the enormous and diversified content of the sessions, I assure you that the challenge is equal to the honor. I therefore approach the task with humility. I ask the indulgence of the distinguished scientists and engineers assembled here; for in attempting to distill the essence from this notable meeting, I am painfully conscious that I shall be forced to leave out reference to work and points of view that are highly significant for world nuclear science and development. Fortunately, the deficiencies of this summary will be repaired by the publication of the full proceedings. Actually, I believe we shall all be affected by the Conference for a long time to come, and that we shall be able to assimilate the profusion of technical material presented here only after reflection in the weeks and months ahead.

Before I begin my discussion of the Conference itself, I should like to remark briefly upon a matter of historical significance which has been noted by other speakers. We have met in approximately the twenty-fifth anniversary year of the great discoveries which are responsible for our being here today.

Fittingly, we have seen during this anniversary year the first ripening of our labors. We have achieved economic nuclear power in limited but important geographical areas. I believe this Conference marks the beginning of the age of nuclear power. We can now foresee the end of the spectre of an energy shortage which has haunted the world since the beginning of the Industrial Revolution. As nuclear power technology progresses, I believe we can provide in the future enough energy for all of the peoples of the world — the energy that is central to the banishment of hunger, poverty and fear of the future.

The magnitude of the accomplishment in this quarter of a century can be appreciated by retrospection. Some of you will recall, as I do, the impact on nuclear science laboratories around the world of the startling reports in late 1938 and early 1939 of the discovery in Germany of nuclear fission by Otto Hahn and Fritz Strassman, with elucidations by Lise Meitner and Otto Frisch. Within only four years, the late Enrico Fermi and his colleagues operated a reactor. Even so, in this period many of us would have been content with the thought that nuclear power might be an economic reality by the turn of the century. I find it astonishing that so much has been accomplished in only twenty-five years.

The contribution of the three International Conferences to the progress which has been achieved has been substantial. The first conference, in 1955, dropped the shrouds of secrecy from many aspects of nuclear energy, and led to renewed communication among nuclear scientists and engineers of the world. In the second conference, communications and international cooperation were further expanded, and fusion research was removed from the pale of secrecy. This third Conference has made us all aware that we have reached the borders of the age of economic nuclear power, and it might well be called the Conference of Fulfilment.

And, now, let me turn to my attempt to distill the essence of this notable Conference.

GENERAL REMARKS

Let me begin with some general remarks, directed first to world power needs and the place of nuclear power in meeting those needs, and second to what some of us consider to be the three phases of nuclear power development.

The Conference has dramatized the fact that the world will require huge increases in available energy during the remainder of the century. The accelerating pace of the Scientific Revolution in the developed countries will require huge new increments of power. At the same time, we sorely need to bring the developing nations into the orbit of today's technologies. As Secretary-General U Thant reminded us in his opening remarks: "The main theme of the present Conference is nuclear power and this is a key issue for the long-term development of over half the world. If *per capita* consumption of electricity in the developing areas in our day is to compare with that now found in the major industrialized nations, the amount of additional power required will be so vast as to dwarf even the earth's immense reserves of fossil fuels and hydroelectric power."

Dr. Bhabha of India observed: "There is no power as expensive as no power."

What does the Conference seem to have concluded regarding the advantages of nuclear power

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* Chairman, United States Atomic Energy Commission.

in meeting these energy needs? The Conference has shown that economic nuclear power is coming of age, but its advantages go beyond economics alone. They permit nations to manage wisely their fossil fuel resources as irreplaceable raw materials rather than as sources of heat. As President Emelyanov observed in his opening remarks: "The raw materials for the chemical industry, for the manufacture of plastics, fabrics, artificial leather and similar products are natural gas, oil and coal. Organic fuels provide the chemical industry with its primary materials. If we go on using oil at the present rate, all our oil will soon be burnt up, and the chemical industry will be deprived of a most important source of raw material."

Let us see how the Conference gives us reason to believe in the future of nuclear power. Perhaps the most impressive indication of progress can be seen in Table 1. Here one can see how the installed nuclear capacity of the world has grown; from 1955 with only 5 megawatts, to 1958 with 185 megawatts, to 1964 with about 5 000 megawatts. The future prognosis is also excellent. One can see that by 1970 the total world nuclear power capacity will be about 25 000 megawatts and that by 1980 this will have increased to 150 000 to 250 000 megawatts.

As Commissioner Tape of the United States observed: "In the next century, nuclear power could well, as wood, coal and fluid hydrocarbons have all in their turn done, furnish over one-half of the nation's energy."

The testimony of the technical papers to the fact that nuclear power has come of age is supported by corridor discussions reflecting the entry of commercial competition. This in itself is a strong sign of economic arrival and I should like to think that it has not intruded too heavily on the Conference. However, competition—sometimes aggressive—inevitably accompanies economic development. It plays an important role in driving costs down. Perhaps it is pertinent to note the observation of one delegate which implied that aggressive techniques are sometimes needed to convince conservative financiers and utility engineers of the value of new developments.

Table 1. Nuclear power — past, present and future

(Electrical megawatts of installed capacity)

	1955	1958	1964	1970	1980
Belgium	—	—	12		
Canada	—	—	20		
France	—	—	150		
Germany	—	—	15		
Italy	—	—	525		
Japan	—	—	12		
Sweden	—	—	9		
UK	—	120	2 300		
USA	—	60	1 160		
USSR	5	5	900		
Other	—	—	—		
Total	5	185	5 103	25 000	150 000/ 250 000

It should be noted that our projections of nuclear power development do not assume a break-through in controlled thermo-nuclear fusion or in any now-unknown energy source. Such a development is not on the horizon, but could occur. If fusion does become practical and if it is economical, I am sure there will be time to modify our plans.

The subject of my second group of general remarks deals with reactors as we find them today and as we expect them to be in the future. Many of the delegates to this Conference view nuclear power in three phases, as shown in Fig. 1.

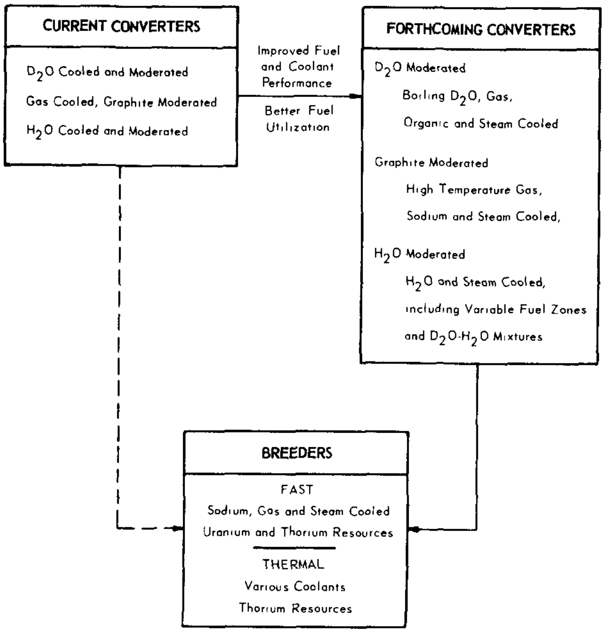


Figure 1. Evolution of nuclear power reactors

The first phase—reached in the past year or so—has been the development to economic competitiveness of three types of reactors: the graphite moderated, gas cooled reactor; the heavy water moderated, heavy water cooled reactor; and the light water moderated, light water cooled reactor.

The second phase will be the development of the improved or advanced converter reactors, including near breeders. These reactors, as indicated in Fig. 1, run a gamut of types—including heavy water moderated, graphite moderated, light water moderated, and even types using a variable moderation of heavy and light water. This phase of nuclear power development promises to bring greater fuel utilization, preparation of fuel for breeders at a faster rate and potentially even lower cost power than today's reactors. It must be recognized, however, that continued improvement of the presently economic reactor types will probably make them increasingly formidable competitors during most of the period when the advanced converters are being developed and used.

The third phase of nuclear progress, somewhat concurrent with the second phase, is the development of breeder reactors. This Conference has heard considerable discussion of fast breeder reactors using the plutonium and uranium-238 fuel cycle. Perhaps less discussion than they merit has been given to thermal breeders fueled on the thorium and uranium-233 fuel cycle. In either case, these breeder reactors promise to extend by an order of magnitude or more the fuel utilization of our uranium and thorium resources since they will produce more fissionable material than they consume. In essence, they are our key to unlocking the energy stores in the non-fissionable but extremely abundant isotopes uranium-238 and thorium-232.

It is important to note that not all delegates agree that these three phases can be arranged in a progression from the presently economic reactors to improved converters capable of even greater economies to a somewhat concurrent pursuit of a longer term program on breeder reactors. Some delegates feel there is no need for the intermediate converter phase and that nuclear power development programs of the respective countries should proceed directly to the breeder reactor phase as shown by the left-hand dashed line in Fig. 1. But the uncertainties still associated with the long-term economic outlook of breeder reactors would seem to provide a strong rationale for many countries to develop improved converters. Conversely there are some delegates who feel that no appreciable effort should be expended on breeders at this time since the present reactor types and improved converters could provide abundant power for many decades to come. If, as reported to the Conference by the United Kingdom, it will be possible to produce uranium from sea-water at prices not higher than \$20/lb of U_3O_8, this view may be considerably strengthened.

Clearly, the Conference shows that the aim of all of the nations is to achieve abundant economic nuclear power. We are approaching this goal in different ways, and it appears fortunate that alternative explorations are being made. It seems likely that the world's nuclear power base will for some time consist of a number of different systems. We are not likely to find a sharp cut-off point at which one type of reactor will cease to be useful. Moreover, it is unlikely that any advanced system—converter or breeder—will be widely adopted if it does not become economical. In my opinion, we will not see breeders in wide use, for example, if the technology is not advanced to the economically competitive stage. And, one can see circumstances in which breeders could only become economic if the price of nuclear fuel is driven up high enough.

The proceedings here show that the emphasis on nuclear power development today is on units with capacities of about 500 megawatts of electrical output each. Plans for even larger units of 1 000 electrical megawatts each are just quietly assumed. When we look toward the reactors for desalination of sea-water—one of the most remarkable future human benefits spilling from the cornucopia of nuclear energy—we consider unit sizes as large as 2 500 MW(e). But the other end of the spectrum also requires attention. Not all countries can use power in such large blocks. Hopefully, one of the outcomes of the large scale development of nuclear power will be the advent of economic power reactors in the smaller sizes more suited to many of the developing countries. As we have heard, nuclear reactors below the 500 megawatt size already appear capable of showing economic benefits in certain of these countries.

ECONOMICS OF NUCLEAR POWER

Let me turn now to some more detailed considerations. I would like to consider first some economic aspects of the reactor types developed in what I have described as the first phase. Table 2 attempts to give cost comparisons for the three presently developed types of nuclear power plants, as reported to the Conference. I feel a word of warning is necessary here since some in the audience will be tempted to compare the figures from one country with those of another. Without considering the specifics that go into making up these figures, it is very much like comparing apples and oranges. One should consider, for example, the influence on these estimates of such factors, varying among nations, as the cost of money, taxes, and the plant lives assumed in estimating costs. I might state it in another way, which I overheard during the Conference: these are the opinions upon which I base my facts.

As you know, the cost of power from any generating station, nuclear or conventional, is generally governed by four main factors: construction costs, operating costs, fixed or carrying charge rates, and system characteristics which determine the plant capacity factor. Except for the fixed charge rate, these subjects have been extensively discussed

Table 2. Economics of currently designed nuclear plants

(Data presented at Conference)

	Approximate construction cost—\$/kW	Approximate running cost mills/kWh
Canada (P/10)	250	1.3
France (P/37)	255	2.3
USSR (P/294)	255	[a]
UK (P/559)	280	2.3
USA (P/192, P/247)	140	2.8

[a] USSR nuclear power costs were presented in P/294, but these appear to be total power costs rather than running costs.

in various sessions of the Conference. It is perhaps unfortunate that more consideration was not given to fixed charges, since apparently much of the controversy over the relative merits of various reactor systems stems from different assumptions regarding this fixed charge rate. In fact, greater efforts toward international standardization of the bases for computing nuclear power costs would probably have been welcomed. The work which IAEA has done in this field represents a commendable start.

Technical and economic factors have restricted the number of reactor types that are well enough developed to be candidates at present for immediate large-scale power programs. The reported prospective construction costs for the three predominant reactor types in the world today are only about one-half the costs of the first large reactors.

These construction costs range from $140 to $280 per kilowatt, not including the value of fuel inventory. Running costs range from 1.3 to 2.8 mills per kilowatt hour. I have not attempted to combine construction and operating costs to arrive at total power costs due to the difference in fixed charge rates between countries. The significant fact is that those systems which tend to have high capital costs tend to have low running costs. Those countries which have concentrated on the development of reactors with low fuel costs have low fixed charge rates which tend to offset their higher capital costs. In fact, the lower carrying charges were one of the main reasons which made these lines of reactor development attractive. It speaks well for these reactor technologies that they have been able to become more competitive with other fuels in their own countries in spite of increases in some elements of the fixed charges such as the interest rate increases noted by both Dr. Lewis and Sir William Penney. This has been very severe in the case of the United Kingdom program where the rate of earnings used for economic assessment of reactor costs has risen from 4% in 1955 to 7½% at present.

All three of these reactor types still have considerable potential for economic improvement through increased unit size, through multiple unit stations, through large-scale production by replication of designs, and through steady engineering improvements of the type that have substantially reduced the cost of conventional stations over the years. The reported improvements by the United Kingdom in their initial 5 000 MW(e) national power program based on the magnox reactors are illustrative of this.

Experience has also demonstrated that many power reactors can operate safely at power levels considerably higher than their initial design ratings, thus substantially reducing unit costs. The Yankee reactor has had its power level increased from an initial 110 MW(e) to 175 MW(e). Reactors now in the design and construction stage still have this "stretch capability". For example, the Oyster Creek plant has a minimum capability of 515 MW(e) but, if the expected power density is achieved in the core, 640 MW(e) is possible. Soviet experience with the first 210-megawatt unit at Novovoronezh has made it possible to increase the capacity of the second unit, which is a modernized version of the first, to 365 megawatts or more. As experience accumulates, new plants will increasingly be rated initially closer to their ultimate capacity.

The reports have further indicated that there remains the possibility of substantial reductions in fuel cycle costs. The reductions to be achieved between the fuel cycle costs we have experienced up to now and future costs may be much greater than the 50% by which we have already reduced capital costs, although the amount of reduction will vary with reactor type. Fuel fabrication costs will be greatly reduced as we go on to develop improved fabrication techniques and increase the scale of the fabrication industry. Illustrative of this is the United Kingdom experience in fabricating almost two million magnox elements. The French reports on scaling up their fabrication efforts are also noteworthy. Increases in irradiation levels, which reduce fuel cycle costs, are also in prospect for all types of reactor fuels. The recent increase of the guaranteed irradiation level of the magnox fuel from 3 000 to 4 000 MWd/t illustrates the potentialities in this regard.

As far as the cost of fuel itself is concerned, possibilities for further reductions have also been reported. Natural uranium prices are currently well below the cost of the uranium used in the early cores of existing reactors. The widely quoted $6/lb figure is probably only an upper limit at present. Over a period of years, lower uranium prices will help the economics of reactors fueled with both natural uranium and enriched uranium. Utilization of increased percentages of the uranium material mined, as conversion ratios increase, will also tend to reduce costs. However, certain of these potential reductions in fuel cycle costs may require some concomitant increase in capital costs just as the choice of natural uranium fueled reactors necessitates higher capital costs to start.

Perhaps the most encouraging evidence that nuclear power costs are coming down lies in the projections of nuclear power growth given to this Conference. It appears quite certain that nuclear energy will play an increasing role in meeting the electrical power needs of many countries. The role of nuclear power will vary from country to country depending upon the extent and costs of their conventional resources. In this respect, the relative economics of nuclear power will be most important. The managers of the electric utility systems in all countries seem to insist, quite naturally, on economic competitiveness before they will engage in large scale nuclear power programs.

FUTURE OF NUCLEAR POWER DEVELOPMENT

The three types of power reactors which have already achieved economic status represent only a first step. Many reports on forthcoming converter reactors promise substantial improvements in economics and fuel utilization. While opinions may differ on the paths to pursue for the future, there is substantial agreement that we must develop improved converters to obtain these greater efficiencies. In looking toward ultimate future needs, there is also almost general agreement as to the need to develop breeder reactors although some nations like Canada support the opinion that breeder reactors may not be required for many years in the future, if at all. The general consensus, however, is evidenced by the program plans reported upon by the United Kingdom, the Union of Soviet Socialist Republics, France, Germany and the United States.

A variety of improved converter reactor types are presently under study and development in many parts of the world. Some of the potential advantages of these reactors include such properties as high conversion ratios, high specific power with resultant lower fuel inventory, high temperature and high thermal efficiency, larger single unit capacity, more efficient use of natural uranium, thorium and plutonium, and a potential contribution toward ultimate breeding systems. In some cases, these converter concepts are based on design variations and extensions and combinations of the technology of the proven reactor types. In other cases, they represent innovations in technology.

As an example, heavy water moderated reactors, long of interest to many countries, represent a class of reactors which has good long range as well as short range potential. Reported at the Conference were extensions of the heavy water moderated technology to designs which are under study and development, incorporating such coolants as gas, organic compounds, water and steam. The organic cooled, heavy water concept, being developed by Euratom in the ORGEL project, the OCDRE project in Canada, the DON project in Spain, the DOR project in Denmark, and the recently planned program in the United States in connexion with desalting all appear to offer considerable promise, as do the French and Czechoslovakian programs using gas cooling with a heavy water moderator and the United Kingdom work with steam cooling. It is clear from the scope of organic work planned that many countries have now mastered the handling of organics as coolants by establishing and maintaining satisfactory purity standards in the cooling system.

Other examples of the evolution of advanced converter reactors from the present types of large power reactors are the spectral shift reactor design (employing a variable mixture of light and heavy water) such as the Belgian-UK VULCAIN project, the Swedish designs for pressurized and boiling heavy water reactors, the seed and blanket pressurized water concept, and nuclear superheating. The experience in Sweden in achieving a very low heavy water leakage rate is very encouraging. The work in superheating appears to be particularly advanced in the USSR with the operation of the Beloyarsk power station.

Advanced versions of graphite moderated gas-cooled reactors are also being developed leading to high temperature, improved fuel cycle and higher conversion ratio performance. The AGR and DRAGON projects in the United Kingdom (the latter a broad multi-nation effort) and the HTGR in the United States represent principal efforts in this direction.

We find substantial development effort is also being undertaken with sodium-cooled reactors. The development of the sodium-cooled graphite-moderated reactor in the United States has as its prime objective an economic, high temperature large power reactor system; in addition it is also contributing a significant amount of sodium technology which is applicable to the sodium-cooled fast reactor systems. It is noteworthy that the Hallam Nuclear Power Facility in the United States, a reactor of this type, is the largest sodium-cooled reactor in operation today. Germany is developing the KNK reactor project which will use a sodium-cooled and zirconium hydride moderated reactor. The USSR program also indicates substantial development of sodium components.

Various reports indicate that emphasis on fast reactors has increased spectacularly in many countries during recent years. Germany, the United Kingdom, the United States and the USSR all have announced or reaffirmed their intentions to proceed with prototype fast reactors of several hundred MW(e) capacity. We have heard reports from the USSR and the United Kingdom on their operating experience with the BR-5 and Dounreay plants, respectively. The integrated power of Dounreay has reached a total of 9 080 MWd and its total electric power production is over 36 million kWh. Dounreay has been successfully demonstrated at full power and its continued use as a fuel test facility should contribute significantly to the United Kingdom's fast reactor program.

It was reported that the EBR-II at the US National Reactor Testing Station is now producing power. It is anticipated that this reactor, as well as the Enrico Fermi plant, will produce valuable information on fuels, components performance and systems reliability of fast breeders. The RAPSODIE fast reactor being constructed in France will give important data on physics behavior, including the kinetics of fast reactor cores. In Germany, an intensive evaluation is being made of the various coolants and systems which may be applied in fast reactor technology.

In the programs just described, major emphasis has been placed on the eventual use of the plutonium and uranium-238 cycle with which high breeding ratios appear feasible. Both metallic and ceramic fuels are being evaluated with regard to their potential for achieving high efficiency, low cost performance. This has led to the development of strong programs directed toward evaluation of the neutronics and the inherent safety of such fast reactor fuel systems.

On the fuel evaluation side, we find that a series of experimental fuel assemblies are being irradiated in the UK Dounreay reactor. Fuel material also has been irradiated to some 6% burnup in the USSR's BR-5. There are firm plans to carry out sample and fuel subassembly irradiations in the very near future in RAPSODIE, FERMI, EBR-II and in the fast flux loop in Belgium's BR-5. The United States is also building a fast test reactor, FARET, in which valuable physics measurements will be made and in which small cores can be tested at high power densities and to high burnups. The USSR also has announced plans for their 60 MW(e) reactor, BR-60, in which it hopes to demonstrate fuel burnups in excess of 10%.

To evaluate the safety of fast reactor systems, Doppler and sodium void coefficient measurements are under theoretical and experimental investigation in several countries. Conference papers and discussions indicate general agreement on Doppler coefficient contributions to reactor kinetics and safety—the coefficient will be negative, large and reliable. Experimental work is being carried on in the critical facilities: ZEBRA, VERA and QUAGGA in the United Kingdom, ZPR-III and ZPR-VI in the United States, BFS in the USSR and FR-O in Sweden. A number of additional critical facilities are planned for operation within the next five years—namely, MASURKA in France, SNEAK in Germany, and ZPPR in the United States. Another planned fast reactor project is the Southwest Experimental Fast Oxide Reactor, SEFOR, which is being undertaken in an international partnership of EURATOM, the Federal Republic of Germany, the Southwest Atomic Energy Associates (a group of American utilities), the General Electric Company and the USAEC. SEFOR will be used to measure Doppler and sodium temperature coefficients on mixed plutonium-uranium oxide cores under transient conditions.

Although the main effort in breeder reactor development is in the direction of sodium-cooled fast reactors, the reports here reflect that fast reactor systems which would use other coolants such as gas and steam are also being studied. During this Conference, a paper by the Swiss delegation describing a fast gas-cooled system and a paper on the evaluation of different coolant systems in Germany were presented.

Work in several countries which may lead to thermal breeder reactors utilizing the thorium and uranium-223 fuel cycle was also described. Three of the reactor concepts described which offer the potential of utilizing the important energy reserves now locked in thorium, and eventually of breeding, are the high temperature gas-graphite system, the heavy water system, and the seed and blanket pressurized light water system. The potential advantages for thermal breeding of fluid fuel reactors, such as the slurry oxide or molten salt systems, were also noted.

NUCLEAR FUEL CYCLE

Let me turn now to the manufacture of nuclear fuel, one of the most important technologies of nuclear power, where we find steady improvement through a diversity of approaches. These improvements have accounted for a slow, steady gain in fuel performance over the years, with operating temperatures and the heat output of each unit of fuel throughput becoming higher.

While the number of separate reactor concepts being pursued has narrowed somewhat in recent years, there are still many options as to the fuel cycle. Uranium metals are being used in low exposure natural uranium systems. For water cooled reactors, the presently favored and most thoroughly proven fuel material is uranium oxide. The results reported to this Conference indicate that this fuel will continue to be favored in these reactors because it can sustain high irradiation exposures. A number of papers suggest that carbide fuels appear quite promising for non-water reactors. Studies of other compounds such as nitride, sulfide, silicide, were also reported.

Stainless steel and zirconium alloys continue to be important cladding materials, although fuel designers are concerned about high temperature embrittlement under irradiation. Magnesium alloys have been serving well in low temperature gas cooled systems. For future applications ceramic fuel particles coated with carbon offer a good fuel for high temperature gas cooled reactors.

In Canada, typical fuels are natural uranium oxide clad in zirconium with fuel exposures estimated at 10 MWd/kg U. In France, the preferred fuel is natural uranium metal with magnesium alloy cladding with fuel exposures around 3½ MWd/kg U. In the USSR, the light water reactors use enriched uranium oxide clad in stainless steel alloys and will produce greater than 20 MWd/kg U. At the present in the United Kingdom, "adjusted" natural uranium metal is clad in magnesium alloy and produces 4 to 5 MWd/kg U. In the United States, a common fuel is UO_2 clad in stainless steel or zircaloy with exposure expectations of 16 to 25 MWd/kg U.

A number of fluid fuel concepts utilizing molten salt, molten plutonium and aqueous slurries are also being studied and developed. These concepts are very intriguing since they offer the promise of significant reductions in fuel cycle economics, but they pose formidable problems that are still to be solved.

In view of the excellent progress experienced in developing long endurance fuel and reducing the costs of the various unit operations required to support the fuel cycle, it now appears that the most economic fuel exposure for converter type reactors will be in the same neighborhood as a reasonable integrity lifetime of the fuels.

There were several reports on the final phase of the fuel cycle, spent fuel reprocessing, where there are a number of competing methods. At present, the aqueous solvent extraction process is the accepted means for recovery of nuclear fuels. Other recovery processes, such as pyrometallurgical and pyrochemical reprocessing are, however, advancing rapidly. In the end, the type of fuel will largely determine the most economic fuel recovery process.

As reported, the economic recycle of the bred fuels—plutonium and uranium-233—can now be clearly foreseen. Within a few more years, plutonium recycle should be demonstrated in large commercial power reactors and it will be an important step in assuring the economics of the complete fuel cycle. Already several countries such as Belgium and the United States have begun experiments in this direction. Similarly, recycle of uranium-233 will follow a few years later.

REACTOR SAFETY AND WASTE MANAGEMENT

An important factor in the development and application of the peaceful uses of atomic energy—as important as its economic and scientific impact—has been the continuing concern for public health and safety exemplified in the emphasis on reactor safety and the safe management of nuclear wastes.

The public has manifested concern in many countries over the safety considerations associated with the location, design, construction and operation of nuclear power plants. This is only natural in view of the increasing number of nuclear plants actually being operated, built or planned, and the desire on economic grounds to place these plants nearer to electric power needs.

Fortunately, safety has been a foremost consideration from the start in the development of nuclear reactors. The remarkable safety record which has been achieved by operating reactors is powerful and eloquent testimony to this fact and to the efforts and accomplishments of workers in this field throughout the world. For example, the United States has been operating reactors of various types for about twenty years—with an accumulation of over 1 200 reactor years of operating experience. In that time, there has been no known instance of injury or even inconvenience to a member of the public outside an immediate plant site that can be attributed to reactor operation or a reactor accident.

From the reports given at this Conference, it would appear that throughout the world a general reactor safety philosophy is developing for these nuclear reactor systems. The approach appears to be based largely on two related but separated and conservative paths. First, to prevent accidents, the reactor is generally designed conservatively, taking into account the kinetic or neutronic behavior of the system and the characteristics of the materials used in its construction, and also incorporation of redundant instrumentation and control systems made as fail-safe as possible. In addition, reactor operators are carefully trained and detailed plant operating procedures are carefully followed. Secondly, most power reactors are equipped with a variety of engineered safeguards and emergency systems to minimize the consequences of an accident should one somehow occur. For example, in some countries it is common practice to enclose the entire reactor system in a containment structure built to withstand considerable pressure and with a high degree of leak-tightness.

To support these policies, extensive nuclear safety research, development and test programs are conducted in almost all countries supporting reactor development programs. I believe we can be quite confident that these investigations, which cover a broad spectrum of subjects from reactor kinetics to fission product behavior and materials research, and in which a rather wide variety of scientific and technical disciplines are involved, will continue to contribute to nuclear energy's generally excellent safety record and that they will keep pace with the requirements of the industry as it develops.

The concern for nuclear safety does not cease with the continued safe operation of nuclear reactors. Their radio-active wastes must also be disposed of safely. Significant advances during the past years in the handling of radio-active waste products from nuclear energy operations, including power reactor installations, were reported on here by Czechoslovakia, France, India and the United States. There has been a strong impetus throughout the world for vigorous waste management research and development programs directed at further reduction in the quantities of radio-active materials being discharged to the environment.

As indicated in reports by France and the United States, the strict management and disposal of radioactive waste at nuclear power stations is not limiting the development of large scale and widespread nuclear power generation, and it may be noted also that during the past years, these waste handling operations have not resulted in any abnormal release of radio-activity to the environment. Radioactivity concentrations in power reactor plant effluents, with no environmental dilution, have been in the low range of 1-3% of the internationally accepted radiation protection standards.

The disposal of certain types of solid and liquid low-level waste effluents to the ground was reported to be safe and acceptable in many countries including Canada, the United States and the USSR. The growth of land burial or storage sites with its resulting economies, have essentially eliminated ocean disposal as an important waste management operation in many nations of the world with available land area.

More than fifteen years' experience in the United Kingdom, the United States and the USSR with the improving methods of handling highly radio-active liquid waste from fuel reprocessing by storage in special underground tanks has shown such storage to be a safe and practical interim measure. The long-term usefulness of this method is limited, however, by the long effective life of the waste (hundreds of years) and the comparatively short life of storage tanks, estimated at several decades. Accordingly, a number of countries are developing means to convert high level liquid waste to stable solids.

After high level liquid wastes are converted to solids, there still exists a requirement for permanent storage of these solid wastes. Man-made structures may not be adequate to last for the hundreds of years that must pass before the wastes become relatively harmless. Underground salt formations appear to offer an attractive alternative site for solids and concentrated liquid wastes because of their unique geologic characteristics. Salt formations are dry, impermeable, have good structural strength and thermal conductivity, and are not associated with usable ground water sources. Furthermore, they exist in many parts of the world. Future development work in several countries along this path will be watched with interest.

With continued attention to reactor safety and waste management, I firmly believe that we can achieve the potential benefits of nuclear power and at the same time protect or even improve our general standards of public health and safety. The increasing use of nuclear power may indeed help to lessen atmospheric pollution, a frequent result of the widespread use of fossil fuels.

ADVANCES IN ENERGY CONVERSION

To this point my remarks have been largely limited to the use of nuclear reactors to provide heat for the conventional generation of electricity. I turn now to the progress reported to this Conference in other energy conversion techniques, such as nuclear thermo-electric and thermionic conversion and magneto hydrodynamics which are opening new vistas for power generation.

The conversion of the heat of nuclear fission directly into electrical energy by means of the thermionic emission of electrons has been demonstrated as a practical concept in the short time since the last Conference. The potential of this concept is perhaps best indicated by the extent of the efforts reported by the United Kingdom, the USSR, France and the United States. Out-of-pile tests of converters with both uranium carbide and refractory metal emitters have shown life-times of thousands of hours. In-pile tests with both uranium carbide and uranium oxide fueled converters have operated for several hundreds of hours. Naturally the potential of these devices has stimulated materials development. As the technology of refractory metals is advanced to allow higher temperatures in reactors, the efficiency of thermionic devices increases to the point where there is more and more incentive to overcome the many remaining problems.

The generation of electric power using magnetohydrodynamic techniques is being actively pursued in a number of laboratories. Here again the high temperatures of the plasmas required pose serious materials problems although the use of an inert working fluid would reduce the severity of the materials problem. The closed cycle converter operated in conjunction with a high temperature gas-cooled nuclear reactor appears attractive. Proposals have been reported upon in this connection for reactors operating in the temperature range of 1 800-2 200 °C.

Generation of electric energy by the direct thermoelectric conversion of the decay heat of radioisotopes has become an established technology since the last Conference. The technology is now being demonstrated not only in space but also in a number of terrestrial applications, including weather stations, navigation buoys and lighthouses. The barge-mounted weather station powered by a 60-watt strontium-90 generator on exhibit here in Geneva is identical to a US station operating in the Gulf of Mexico. The USSR reports the successful operation of an automatic weather station in the middle part of their country powered by a 5 watt Ce^{144} fueled generator.

The direct thermo-electric conversion of the fission heat of a nuclear reactor has been demonstrated. The efforts in the USSR which culminated in ROMASHKA are of great interest. This uranium dicarbide (UC_2) fueled fast reactor, coupled to Si-Ge thermocouples, has been operating at about 1 800 °C and generating power at a level of several hundred watts since the middle of August.

The United States hopes to demonstrate in the spring of 1965, with a developmental orbital flight of SNAP 10A, a 500-watt reactor unit also employing thermo-electric power conversion. This uranium-235 fueled and zirconium-hydride moderated reactor with liquid metal coolant will weigh less than 1 000 pounds, including payload shielding. Such reactor units in larger sizes will permit future communication satellites to broadcast simultaneously several channels of television directly to individual homes.

It seems clear that reactor concepts such as SNAP and ROMASHKA, while receiving their impetus from the needs for space power, will find equally important roles as compact, reliable terrestrial power sources.

NUCLEAR DESALINATION OF WATER

As I indicated earlier, one of the more exciting new applications for nuclear reactors in the desalting of sea water. We have heard reports of the United States studies for combination power and desalting application and the studies by Israel, Tunisia and Mexico. The USSR and France have presented interesting data on reactors for process applications similar to the reactors that would be required for desalination. We are encouraged by these reports to expect that one or more combination nuclear power and desalting installations producing millions of gallons per day of fresh water will be constructed and in operation within the next four to eight years.

As the nations of the world develop and populations increase, the economic natural water sources are likely to become depleted, especially in some geographical regions. Other areas, already deficient in water, will need water for development to support larger populations. Thus, desalting of sea water by nuclear energy will become more and more important. What today is a matter of interest could well become tomorrow's necessity.

The studies that have been undertaken to date indicate that combination nuclear installations will be able in the next few decades to produce fresh water and electric power at costs which may be attractive for many municipal and industrial needs throughout the world. The water from these combination plants may even find economic potential for selected agricultural use when compared with other alternatives in specific situations.

The potential of nuclear energy for the combined production of power and desalinated water is not only a very fascinating peaceful use of the atom, but one which can provide tremendous benefits for all mankind. The availability of economic power and water could open new frontiers throughout the world for industrialization and increased living standards. To achieve these benefits, however, nations of the world must work together. We have witnessed a step in this direction just today in the IAEA panel meeting on desalting. During the Conference we also have heard of other steps such as the co-operative efforts between various nations to develop nuclear plants as a means for meeting future water and power needs. These steps are a commendable start.

PORTABLE NUCLEAR POWER PLANTS

Another current application of nuclear reactors is to supply power and heat in remote locations. We have heard a Soviet Union report on the 750 MW(e) ARBUS organic cooled and moderated package plant. This plant, which began operation in the summer of 1963, uses a carbon steel primary loop and pumps and auxiliaries available from the oil industry for lower costs, and consists of 19 packages each weighing not more than 20 tons. Soviet scientists have also described the 1 500 kW(e), TES-3, a pressurized water plant arranged on four large, tracked vehicles. United States scientists described their portable pressurized water reactors, using compact cores of UO_2-stainless steel cermet fuel, together with details of operating experience at several sites in the United States, the Arctic and the Antarctic. The success of these plants which generate up to 2 000 kW(e) in addition to a substantial quantity of space heat provides the technology which is applicable to any small nuclear power plant for remote installations, be it for mining, a scientific mission or for other needs.

MARITIME NUCLEAR PROPULSION

The hopeful outlook for the maritime application of nuclear power expressed in the 1958 Conference can now be supported by successful operating experience with two nuclear powered vessels. The USSR's icebreaker *Lenin*, during its nearly five years of operation, has demonstrated the advantages of nuclear power for this important service. The N.S. *Savannah*, the United States cargo-passenger vessel, is now completing its second European voyage and is also meeting expectations.

Two other countries—West Germany and Japan—already have firm projects for construction of their first nuclear powered ships. Other countries such as Norway, Sweden, Belgium and the United Kingdom, are carrying on development in preparation for future projects, and the USSR announced during the Conference that it expects to build two new nuclear icebreakers, with the first one coming into operation in 1971.

Thus, with successful operating experience amounting to well over 100 000 miles for the two existing ships and with new potentially economic projects already under way or planned, we can have confidence in the ultimate success of maritime nuclear propulsion throughout the world.

PEACEFUL NUCLEAR EXPLOSIVES

The United States Plowshare program for developing peaceful uses of nuclear explosives has received considerable attention. Despite the facts that this program is in an early stage of development and that many data are needed before useful projects can be undertaken, the potential for use of nuclear explosives in excavation, mining, recovery of gas and oil and as a research tool appears promising. Significant suggestions for methods of international collaboration and participation have been proposed by delegates from a number of nations. It is hoped that through such international support and cooperation nuclear weapon technology can be converted into a valuable research and engineering tool for the benefit of all mankind.

RESEARCH AND HIGH FLUX REACTORS

Although nuclear power has been the major focus of interest at this Conference, there has been considerable discussion of research and high flux reactors and their associated programs and of the applications of radioisotopes in the physical and life sciences.

Conference papers suggest that the uses of newer research reactors fall plainly into three main kinds of activity: first, there is the continuing examination of radiation effects on materials for the construction, moderation and fueling of reactors. Second is the more fundamental and better controlled kind of physical research made possible by reactors designed to meet more specific research needs. A good example of this is the work reported on pulsed reactors. The third area is the production of radioisotopes for medical therapy, for tracer uses, and now for the production of relatively large quantities of transplutonium elements in both the United States and the USSR.

My personal bias is evident when I say that the prospect of performing basic and exploratory research on gram quantities of californium isotopes, hundreds of milligrams of berkelium, milligrams of einsteinium and up to a milligram of fermium produced in these reactors is one of the most exciting to which we have been exposed in decades.

The shift from all-purpose to specialized research reactors is most clear when one considers the construction of high flux reactors for either materials testing or isotope production. In operation, or shortly to be in operation, are the HFIR, HFBR and ATR in the United States, the MP, MPR and SM-2 in the USSR, and the PÉGASE in France.

The desire for higher neutron fluxes has stimulated technological developments which have produced fluxes higher by an order of magnitude, or more in some cases, than those found in present power reactors, thus paving the way for further improvements in power reactors. Such major advances include the development of fuel elements and cores able to operate at very high power densities and heat fluxes.

We have also learned how to specially tailor the flux in experimental areas, and through past experience have come to appreciate the need to carefully coordinate the design and construction of the reactor with our research needs. The new knowledge has resulted in such notable experimental facilities as fuel element testing loops in the USSR MR reactor and the French PÉGASE reactor, the high temperature gas cooled loop in the United Kingdom PLUTO reactor, the liquid hydrogen cold sink in the French high flux beam reactor and the liquid hydrogen moderator chamber in the British DIDO reactor.

RADIOISOTOPES

More than thirty papers at this Conference were devoted specifically to radioisotopes, their applications and the methods by which they are produced or separated. If I were to include papers on subjects of a closely related nature, such as high flux reactors, stable isotopes, and the productive utilization of ionizing radiation, the number would increase substantially.

It is clear that some technology associated with isotopes can now be found in virtually every scientific and engineering field. It is also one outgrowth of the atomic age that can be employed by all countries, regardless of size or state of technological advancement.

In my judgment, an outstanding technical accomplishment of the past few years—well represented in papers presented here—has been the effort to produce, separate and purify radioisotopes in quantities sufficient to permit their use as sources of thermal and radiation power. Several countries have reported major progress in this area. Another area of outstanding achievement has been the use of radioisotopes in medicine; this is the domain of what I have called "the Humane Atom".

From the scientific viewpoint, the widespread establishment of neutron activation analysis as a standard technique for measurement of trace quantities of almost every element in the periodic table represents a contribution of immeasurable value to medicine, agriculture and the physical sciences. In fact, its application has been extended even to law enforcement.

Ionizing radiation—whether the source be radioisotopes, machines, or reactors—is finding a place in the processing of organic chemicals, plastics and other materials, in sterilization of medical supplies, and in the preservation of foods.

CONTROLLED THERMO-NUCLEAR REACTIONS

The disclosure of previously classified research on controlled thermo-nuclear reactions was one of the main features of the 1958 Geneva conference. We were then in an age of innocence for this intriguing field of research, which can lead to the extraction of an inexhaustible supply of energy from the oceans. The papers presented here show that we have learned a great deal in the intervening years. Plasma physicists now know well the hard scientific and engineering realities of suspending, squeezing and holding in space gases with temperatures of the order of those found in the stars. They have learned that the prospects for an easy engineering short-cut to controlled fusion are not bright. They have demonstrated, to the satisfaction of themselves and the nuclear community, that controlled fusion is one of the most difficult scientific and engineering problems ever encountered.

The sobering experience of the last six years should not, however, blind us to the truly significant progress that has been made. An important and exciting new area of fundamental science in plasma physics has grown up. I shall mention but three of the many evidences of the maturing of plasma physics. One is the increasing sophistication of the field, represented in part by the development of a new language which is getting beyond the comprehension of the rest of us in the nuclear field. The second is the sheer size of the effort, as represented by the general increase in the number of scientists in controlled fusion research, the increased investment in scientific facilities by governments, and the expanding literature. The number of scientific papers per year on plasma physics has increased about 45 per cent since 1959, as have the number of workers in the field. A rough count indicates that work is now going on with 10 major experimental devices in the USSR, 14 in the United Kingdom and Western Europe, 4 in Japan and Australia, and 10 in the United States.

The most important indicator of growth, however, lies in the scientific results of these years, contained in papers presented here. Whereas in 1958 plasma scientists were only on the verge of producing fusion reactions with thermal neutrons truly attributable to the reaction, a number of laboratories today regularly produce plasma with ion-energies exceeding the so-called minimum ignition temperature.

A usable controlled fusion reaction would require nuclear reactions of adequate duration, temperature, and density of plasma. Today, one machine may best approach the production of the required temperature, another the required duration of nuclear reactions and another the desirable density of plasma, but no one machine is capable of meeting all three requirements. The aim now—and it is a long-range one—is to achieve reactions combining all of these factors satisfactorily in a single machine.

An important foundation of knowledge has been erected on one of the most important problems of controlled fusion, namely plasma stability. The pioneering work of Ioffe in the Soviet Union on the confinement of plasma in a region where the pressure of the magnetic field is at a minimum, the so-called Minimum-B confinement, is to be admired. It is also encouraging to learn of the many new experiments under way to measure the limits of plasma stability under varying conditions, such as the MTSE in the United Kingdom, DECA in France, and the DCX-2 in the United States.

There is a growing ability to predict plasma behavior. Numerous good checks between experiment and theory have been achieved—for example, in the PHOENIX experiments in the United Kingdom, and in the Levitron and ALICE experiments in the United States. Such agreements which did not exist in any laboratory results in 1958, are a strong indication of the growing maturity of plasma science.

We cannot be absolutely sure that controlled thermo-nuclear power can be developed, although the general feeling at the Conference is that it will be accomplished at some time, perhaps before the end of the century. Certainly the benefit—essentially unlimited power for the earth's population for all time—is one we cannot overlook. Indeed, I agree with the view expressed by some delegates that the approximately one hundred million dollars spent world-wide each year in the nuclear fusion field is too low an investment for research with such vast potential benefit.

EXHIBITS

A word should be said about the many fine scientific exhibits displayed here in Geneva in connexion with this Third Conference. Also I am sure many of you were impressed, as I was, by the excellent quality of the scientific films prepared for this Conference by many of the countries. These will certainly be a lasting contribution. The many people involved in these exhibits and films should be congratulated for their excellent efforts.

CONCLUSION

In my closing remarks, I should like to depart again from the form of the technical progress summary. I wish to review some of the human implications, especially in an international context, of what has been said here. The degree of international co-operation in the development of this coming major energy resource in the last decade is surely unusual, and perhaps unique, in world history. We can point to these conferences, to the work of the International Atomic Energy Agency, the variety of co-operative programs among nations, and to the nuclear assistance programs of a number of nations. Important specific projects are the Norway-Poland-Yugoslavia Project, the DRAGON Project, the SEFOR Project, and the Halden Project. Close at hand is CERN, one of the outstanding examples of international co-operation in science, which many of us have had an opportunity to visit during this Conference.

The Conference has demonstrated many reasons why international co-operation must be continued and strengthened. The free flow of information, not only in science but also at the more restrictive technological level, is the key to the most rapid technical progress for all people.

This international collaboration practised so successfully in nuclear energy gives further strength to the thesis that science can serve as a common ground between all nations of the world. A uranium or plutonium atom knows no nationality. Through international conferences such as this, and other broader and more intensive programs of exchange and collaboration, science may be a leading factor in resolving the differences which still remain between countries.

The Conference has also dramatized the fact that practical achievement of material well-being for the peoples of the developing nations rests upon this structure of close international co-operation. The Conference has again made us aware of the relative shortages of fossil fuels and hydroelectric potentials in many of these nations. For these nations to reach and maintain living standards presently found in the developed countries by the end of the century will require nuclear energy on a large scale. Indeed, we see the possibility that through nuclear power the developing nations may partially circumvent the long years of the Industrial Revolution and greatly telescope the time required to enter the Scientific Revolution upon which so many of the developed nations have already embarked.

Such a hope will be illusory, however, without a solid foundation consisting of cadres of scientists, engineers and technicians as well as facilities for productive work. Secretary-General U Thant of the United Nations reminded us that "the development of certain scientific institutions and the training of at least a small number of scientists in some of the advanced disciplines is by no means a luxury for any of the new nations".

Technologically advanced nations and the International Atomic Energy Agency have already made progress in training and in establishing science centres in the developing nations. Much more needs to be done by a number of the developed nations. We need to find ways, especially through science centres, to enable trained scientists and engineers of high calibre to do meaningful work in their own countries. We have found that they otherwise migrate to advanced centres of science abroad.

It is clear that these efforts should not be limited to nuclear science and technology. The nuclear field, however, has much more to offer than nuclear power. The breadth and attractiveness of nuclear science and technology make the field an excellent focal point for a start in broader research and development. We are all aware of a number of good examples of such beginnings with the nuclear field.

If we are to implement the major conclusion of this Conference—that nuclear power will become an increasingly powerful force in the world's work—it will be necessary to evolve as rapidly as possible an appropriate world body of nuclear law. Considerable progress has been made in the development and application of appropriate safeguards under the aegis of the International Atomic Energy Agency. As Dr. Sigvard Eklund, Director General of the IAEA, told us, it is important to have accepted an "international safeguard system *now* when the number of power reactors is still small". The future growth of the international atom must be paralleled by the future growth of an effective safeguards system.

By the turn of the century, our Conference suggests, more than half of the world's electricity will be generated by nuclear energy. Nuclear energy is, therefore, basic to the hope of the peoples of the world for a good life. If the major future energy base of the world continues to evolve in an environment of international development and law, nuclear energy can be an important unifying force in a world of peace, security and human well-being.

ABSTRACT - RÉSUMÉ - АННОТАЦИЯ - RESUMEN

Etats-Unis d'Amérique

Résumé des travaux de la conférence

par G. T. Seaborg

Je commencerai par des remarques de caractère général portant d'abord sur les besoins mondiaux d'énergie et sur la place qui revient à l'énergie nucléaire parmi les autres moyens de faire face à ces besoins, et ensuite sur les trois phases du développement de l'électricité nucléaire qu'envisagent certains d'entre-nous.

La Conférence a mis en pleine lumière le fait que pendant la quarantaine d'années qui s'écouleront avant la fin de ce siècle l'approvisionnement en énergie devra augmenter dans des proportions gigantesques pour répondre aux besoins mondiaux. Dans les pays développés, c'est la marche accélérée de la Révolution scientifique qui l'exige. C'est aussi une nécessité impérieuse que de mettre les techniques modernes à la portée des pays en voie de développement. Comme le rappelait le Secrétaire général U Thant dans le discours qu'il a prononcé à la séance d'ouverture: "Le thème principal de la présente Conférence est l'énergie d'origine nucléaire; et c'est là un problème clé pour le développement à long terme de plus de la moitié du monde. Pour que la consommation d'électricité par habitant dans les régions en voie de développement puisse se comparer un jour à ce qu'elle est aujourd'hui dans les plus importants pays industrialisés, le supplément d'énergie nécessaire à cette fin serait si considérable que les immenses réserves de combustibles fossiles et d'énergie hydroélectrique de notre globe ne seraient que peu de chose en comparaison...”

Le D^{r} Bhabha, de l’Inde, a remarqué qu’il n’y a pas d’énergie aussi coûteuse que l’absence d’énergie.

Quelles sont les conclusions de la Conférence en ce qui concerne les avantages offerts par l’électricité nucléaire au regard de ces besoins énergétiques? La Conférence a montré que la rentabilité de l’énergie d’origine nucléaire est en train de devenir une réalité, mais ses avantages ne sont pas seulement d’ordre économique. Ils permettent aux pays de se servir avec sagesse de leurs réserves de combustibles fossiles comme de matières premières irremplaçables et non comme de sources de chaleur. Le Président Emelyanov a dit à la séance d’ouverture: “Les matières premières pour l’industrie chimique, pour la fabrication de matériaux plastiques, de tissus, de cuir artificiel et d’autres produits analogues sont le gaz naturel, le pétrole et le charbon. Le combustible organique est une matière première pour l’industrie chimique. Si l’on continue à consommer le naphte au même rythme que maintenant, tout le pétrole sera bientôt brûlé et la chimie perdra ses sources les plus importantes de matières premières.”

Quelles raisons nous donne la Conférence de croire en l’avenir de l’électricité nucléaire? L’indication la plus marquante des progrès accomplis est peut-être l’accroissement de la puissance nucléaire installée dans le monde: en 1955, elle n’était que de 5 mégawatts; en 1958, elle atteignait 185 mégawatts. Aujourd’hui, en 1964, nous approchons de 5 000 mégawatts et les perspectives sont excellentes. La puissance nucléaire installée totale dans le monde atteindra près de 25 000 mégawatts en 1970 et 150 000 à 250 000 mégawatts en 1980.

Comme M. Tape, de la Commission de l’énergie atomique des Etats-Unis, l’a fait observer: “Au cours des cent prochaines années, l’énergie nucléaire pourrait bien, comme l’ont fait autrefois successivement le bois, le charbon et les hydrocarbures, assurer plus de la moitié de la production nationale d’énergie.”

Les indications que l’on trouve dans les mémoires techniques du fait que l’énergie d’origine nucléaire est sortie de la période de préparation sont confirmées par des discussions privées qui témoignent de l’apparition de la concurrence commerciale. Or, cette apparition est en elle-même un signe manifeste de réussite du point de vue économique; je veux croire, d’ailleurs, qu’elle n’a pas marqué trop profondément les débats de la Conférence. La concurrence — quelquefois agressive — accompagne inévitablement le développement économique. Son rôle est important, car elle fait baisser les prix. Il est peut-être opportun de rapporter cette remarque d’un participant selon laquelle il est parfois indispensable de faire appel à des procédés agressifs si l’on veut convaincre les financiers et les ingénieurs des services publics trop prudents de la valeur d’une innovation.

On observera que dans nos projections du développement de l’électricité nucléaire, nous n’avons pas émis l’hypothèse d’une réussite dans le domaine de la fusion thermonucléaire contrôlée ou de l’avènement de quelque source d’énergie encore inconnue. Si un tel événement n’est pas impossible, il n’est pas encore prévisible. Mais si la fusion entrait dans le domaine des choses réalisables et si elle devenait rentable, je suis sûr que nous aurions le temps de modifier nos plans.

Le deuxième groupe de mes remarques d’ordre général concerne les réacteurs tels que nous les voyons aujourd’hui et tels que nous espérons les voir dans l’avenir. Pour un grand nombre de participants à cette conférence, le développement de l’électricité nucléaire présente trois phases.

La première de ces phases, atteinte vers l’année dernière, a consisté à rendre économiquement compétitifs trois types de réacteurs: le réacteur refroidi par un gaz et ralenti au graphite, le réacteur ralenti et refroidi à l’eau lourde et le réacteur ralenti et refroidi à l’eau légère.

La deuxième phase sera celle de la mise au point des types perfectionnés ou avancés de réacteurs convertisseurs, y compris les réacteurs presque surgénérateurs. Il existe une large gamme de types différents de tels réacteurs, ralentis à l’eau lourde, au graphite, à l’eau légère ou même grâce à une combinaison variable d’eau lourde et d’eau légère. On espère que cette phase du développement de l’électricité nucléaire permettra de mieux utiliser le combustible, de préparer plus rapidement le combustible des surgénérateurs et de produire l’énergie à moindre frais qu’avec les réacteurs d’aujourd’hui. Toutefois, comme on continuera à perfectionner les types de réacteurs qui sont actuellement rentables, ceux-ci deviendront probablement des concurrents de plus en plus redoutables pendant presque toute la période durant laquelle les convertisseurs avancés seront mis au point et utilisés.

La troisième phase, qui se confondra dans une certaine mesure avec la précédente, est celle de la mise au point des réacteurs surgénérateurs. On a beaucoup discuté au cours de cette conférence des réacteurs surgénérateurs à neutrons rapides, utilisant le plutonium et l’uranium 238 dans leur cycle de combustible. Mais on n’a peut-être pas assez parlé des surgénérateurs à neutrons thermiques utilisant le thorium et l’uranium 233. L’un comme l’autre, ces deux types de réacteurs doivent permettre de multiplier au moins par 10 l’utilisation comme combustible de nos réserves d’uranium et de thorium puisqu’ils produiront plus de matières fissiles qu’ils n’en consommeront. En un mot, ils constituent pour nous la clé qui libérera l’énergie emmagasinée dans l’uranium 238 et le thorium 232, nucléides qui ne sont pas fissiles, mais que l’on trouve en très grande abondance sur la terre.

Il importe de noter que tous les participants ne sont pas unanimes pour envisager ces trois phases comme une progression partant des réacteurs actuellement rentables pour passer aux convertisseurs perfectionnés qui permettent des économies encore plus grandes et à la réalisation, à peu près simultanée, d'un programme à long terme de réacteurs surgénérateurs. Certains participants pensent que la phase intermédiaire des convertisseurs est inutile et que les programmes de développement de l'énergie nucléaire des divers pays devraient passer directement à la phase des réacteurs surgénérateurs. Mais il semble que les incertitudes qui jettent encore de l'ombre sur les perspectives économiques à long terme des réacteurs surgénérateurs agissent fortement, pour de nombreux pays, en faveur de la mise au point de convertisseurs perfectionnés. D'autres participants encore pensent qu'il ne convient pas, pour l'instant, de gaspiller des efforts appréciables pour la mise au point de réacteurs surgénérateurs, puisque les types actuels de réacteurs et les convertisseurs perfectionnés pourront fournir suffisamment d'énergie pendant encore de nombreuses décennies. S'il devenait possible, comme l'a signalé le Royaume-Uni, de produire de l'uranium à partir de l'eau de mer à des prix ne dépassant pas 20 dollars par livre de U_3O_8, cette façon de voir se trouverait considérablement renforcée.

La Conférence a montré très clairement que le but visé par toutes les nations était de produire de l'électricité nucléaire en abondance et à des prix économiquement acceptables. Nous nous rapprochons de ce but par plusieurs chemins et il est heureux que l'on ait envisagé différentes solutions. Il est probable que la base de la production mondiale d'électricité nucléaire consistera pendant encore quelque temps en plusieurs systèmes différents. Il est peu vraisemblable que l'on arrive à un point d'arrêt brutal marquant la fin de l'utilité d'un type de réacteur. Il est aussi peu vraisemblable que l'on généralise l'utilisation d'un système perfectionné, quel qu'il soit — convertisseur ou surgénérateur —, s'il n'est pas économiquement rentable. Ainsi, à mon avis, nous ne verrons pas utiliser un grand nombre de réacteurs surgénérateurs si leur technologie n'est pas modifiée de façon à les rendre économiquement compétitifs. Et l'on peut prévoir des cas où des réacteurs surgénérateurs ne pourraient devenir rentables que si le prix du combustible nucléaire était amené à un niveau suffisamment élevé.

Les discussions de la Conférence ont montré que la production d'électricité nucléaire s'oriente aujourd'hui vers l'installation de groupes développant une puissance unitaire de quelque 500 mégawatts électriques.

On admet sans sourciller des projets portant sur des puissances unitaires encore plus élevées, à savoir 1 000 mégawatts électriques. Lorsque nous pensons aux réacteurs qu'il faudra construire pour dessaler l'eau de mer — l'un des progrès les plus remarquables que la corne d'abondance de l'énergie nucléaire offre à l'humanité — nous envisageons des puissances unitaires atteignant 2 500 mégawatts électriques. L'autre extrémité de la gamme mérite également qu'on s'y intéresse. Tous les pays ne sont pas en mesure d'utiliser l'énergie nucléaire en si grandes tranches. Il faut espérer que l'un des résultats de l'expansion générale de l'électricité nucléaire sera l'apparition de réacteurs de puissance rentable mais de dimensions plus petites, comme en ont besoin la plupart des pays en voie de développement. Nous avons entendu dire que les réacteurs nucléaires de moins de 500 mégawatts paraissent déjà capables de présenter des avantages économiques dans certains de ces pays.

Dans mes remarques finales, j'aimerais m'écarter à nouveau de la forme habituelle du résumé technique. Je voudrais examiner ce qu'implique pour l'humanité — et particulièrement sur le plan international — ce qui a été dit à la Conférence. Le degré de coopération internationale qui s'est établi pour le développement de cette source de plus en plus importante d'énergie au cours de la dernière décennie est certes rare, il est peut-être même unique dans l'histoire du monde. On peut mentionner à ce propos les conférences, l'activité de l'Agence internationale de l'énergie atomique, le grand nombre de programmes de coopération entre divers pays et les programmes d'assistance en matière nucléaire d'un certain nombre d'autres. Parmi les projets proprement dits, celui de la Norvège, de la Pologne et de la Yougoslavie, le projet DRAGON, le projet SEFOR et le project de Halden sont importants. Tout près d'ici, le CERN, qu'un bon nombre d'entre nous ont eu l'occasion de visiter au cours de cette conférence, est un exemple remarquable de coopération scientifique internationale.

La Conférence a montré les nombreuses raisons qui commandent de poursuivre et de renforcer la coopération internationale. La clé du progrès technique le plus rapide pour tout le monde est la libre circulation de l'information, non seulement en matière de science, mais aussi au niveau — plus restreint — de la technique.

Cette coopération internationale, pratiquée avec tant de succès dans le domaine de l'énergie nucléaire, renforce la thèse selon laquelle la science peut servir de terrain commun de rencontre pour toutes les nations du globe. L'atome d'uranium, ou l'atome de plutonium, ne connaît aucune nationalité. Grâce à des conférences internationales semblables à celle qui vient d'avoir lieu, grâce à l'expansion et à l'intensification des programmes d'échanges et de coopération, la science peut devenir un élément de premier ordre dans l'élimination des divergences qui existent encore entre les pays.

La Conférence a également mis en évidence le fait que l'aboutissement pratique au bien-être matériel des peuples des pays en voie de développement doit s'appuyer sur une telle structure d'étroite coopération internationale. La Conférence nous a de nouveau rappelé la pénurie relative de combustibles fossiles et de réserves hydroélectriques d'un grand nombre de ces pays. Pour atteindre vers la fin de ce siècle et conserver les niveaux de vie que l'on observe actuellement dans les pays développés, il leur faudra disposer de grandes quantités d'énergie d'origine nucléaire. En réalité, nous entrevoyons la possibilité pour les pays en voie de développement d'éviter en partie, grâce à l'énergie nucléaire, les longues années qu'a duré la Révolution industrielle et de raccourcir considérablement la période qui précédera le moment où ils pourront, comme l'ont déjà fait de si nombreux pays industrialisés, s'engager dans la Révolution scientifique.

Cependant, un tel espoir ne serait qu'illusion s'il ne s'appuyait sur une base solide, constituée de cadres de savants, d'ingénieurs et de techniciens ainsi que d'installations permettant un travail productif. Le Secrétaire général des Nations Unies, U Thant, nous a rappelé que "la création de certaines institutions scientifiques et la formation d'un petit nombre au moins de spécialistes de quelques-unes des disciplines les plus avancées ne sont nullement un luxe pour aucune des nouvelles nations".

Les pays à technologie développée et l'Agence internationale de l'énergie atomique ont déjà avancé dans cette voie en préparant des spécialistes et en créant des centres scientifiques dans les pays en voie de développement. Il y a beaucoup plus à faire pour nombre d'autres pays développés. Il nous faut trouver les moyens, notamment, grâce aux centres scientifiques, de permettre à des savants et à des ingénieurs hautement qualifiés de faire un travail utile dans leur propre pays. Nous avons constaté que si une telle possibilité fait défaut, ils émigrent vers les centres scientifiques de l'étranger.

Il est évident que ces efforts ne doivent pas être limités à la science et à la technologie nucléaires. Mais ces deux domaines ont à offrir bien plus que de l'électricité nucléaire. Leur étendue et leur intérêt en font des points de départ excellents pour d'autres recherches et d'autres progrès. Nous connaissons tous quelques bons exemples de tels débuts dans le domaine nucléaire.

Si nous voulons mettre en œuvre la principale conclusion de cette conférence, à savoir que l'énergie d'origine nucléaire deviendra une force de plus en plus puissante dans l'activité du monde, il est nécessaire de constituer aussi rapidement que possible un système mondial adéquat de droit nucléaire. Des progrès considérables ont été faits sous l'égide de l'Agence internationale de l'énergie atomique dans l'élaboration et l'application de garanties appropriées. Comme nous l'a dit M. Sigvar Eklund, Directeur général de l'AIEA, il est important que l'on ait accepté "un système international de garanties *maintenant* alors que le nombre de réacteurs de puissance est encore faible". L'expansion future de l'atome international doit avoir pour parallèle le développement d'un système de garanties efficaces.

Comme nous le permet de supposer cette conférence, vers la fin du siècle, plus de la moitié de l'électricité mondiale sera produite au moyen de l'énergie nucléaire. L'espérance des peuples du monde en une vie meilleure s'appuie donc sur l'énergie nucléaire. Si la principale base énergétique d'avenir dans le monde continue à se développer sur le terrain du progrès international et du droit international, l'énergie nucléaire peut devenir une force unificatrice importante dans un monde de paix, de sécurité et de bien-être de l'humanité.

Соединенные Штаты Америки

Резюме о работе конференций

Гленн Т. Сиборг

Разрешите мне начать с общих замечаний, относящихся в первую очередь к мировым потребностям в энергии и к тому значению, которое должна занять атомная энергетика для обеспечения этих нужд, и, во-вторых, с того, что некоторые из нас считают тремя фазами развития ядерной энергетики.

На конференции неоднократно подчеркивался тот факт, что в течение остатка века миру требуется огромнейшее увеличение доступной энергии. Ускоряющийся темп научной революции в развитых странах потребует огромных новых энергетических ресурсов. В то же время мы также обязаны поднять развивающиеся страны на орбиту современной технологии. Генеральный Секретарь Организации Объединенных Наций У Тан напомнил нам в своей вступительной речи: «Основной темой настоящей Конференции является ядерная энергетика, именно она является ключевым вопросом для перспективного развития большей половины мира. Если современное потребление электроэнергии на душу населения в развивающихся странах довести до уровня потребления, характерного для основных индустриальных стран, то потребуется такое дополнительное количество энергии, что даже огромнейшие земные резервы ископаемого топлива и гидроэлектрической энергии окажутся ничтожными».

Д-р Баба из Индии сказал: «Нет более дорогостоящей энергии, как отсутствие энергии».

К какому решению пришла Конференция относительно преимуществ использования ядерной энергии для покрытия потребностей в энергии? Конференция показала, что экономичная ядерная энергетика находится на пути становления, но преимущества ее развития выходят за рамки экономики. Они позволяют странам разумно использовать свои ресурсы ископаемого топлива в качестве незаменимого сырья, а не в качестве источника тепла. Председатель Емельянов отметил это в своей вступительной речи следующим образом: «Сырьем для химической промышленности для изготовления пластических материалов, тканей, искусственной кожи и прочего являются природные газы, нефть и уголь. Органическое топливо является сырьем для химической промышленности. Если потреблять нефть в таких же темпах, как это имеет место теперь, то нефть скоро будет сожжена и химия лишится важнейших источников сырья».

Посмотрим, какие основания дает нам Конференция поверить в будущее атомной энергетики. Возможно, наиболее впечатляющим свидетельством прогресса является рост установленной ядерной мощности в мире — от 5 *Мвт* в 1955 до 185 *Мвт* в 1958 году и почти 5.000 *Мвт* в 1964 году. Прекрасны и прогнозы на будущее. В 1970 году общая мировая мощность ядерной энергетики составит около 25.000 *Мвт*, а в 1980 году она увеличится до 150.000—200.000 *Мвт*.

Как заметил член Комиссии по атомной энергии Соединенных Штатов Тейп, «в следующем столетии ядерная энергия сможет, как это сделали в свое время дерево, уголь и жидкие углеводороды, обеспечить половину потребной стране энергии».

Утверждения технических докладов о том, что ядерная энергия стала «совершеннолетней», подтверждаются дискуссиями в кулуарах, отражающими начало коммерческой конкуренции.

Это само по себе является убедительным подтверждением экономического значения этого дела, и я хотел бы думать, что это не ложилось тяжелым бременем на Конференцию. Однако конкуренция — иногда и агрессивная — неизбежно сопровождает экономическое развитие. Она играет значительную роль в понижении цен. Возможно, уместно отметить замечание одного из делегатов, в котором подразумевалось, что агрессивные методы иногда необходимы для того, чтобы убедить консервативных финансистов и инженеров-энергетиков в значении новых достижений.

Следует также заметить, что наши проекты развития ядерной энергетики не предусматривают положительного решения вопроса о промышленном использовании энергии управляемых термоядерных реакций или любого другого неизвестного до сих пор источника энергии. Решение этой проблемы не находится на горизонте, но это может произойти. Если реакция синтеза получит практическое разрешение и будет экономичной, я уверен, что мы будем иметь время для изменения наших планов.

Предметом второй группы общих замечаний являются реакторы, такие, какие существуют сегодня, и такие, какими они станут в будущем. Многие из делегатов этой Конференции видят три фазы в развитии ядерной энергетики.

Первой фазой, которая была достигнута примерно в прошлом году, является освоение трех типов экономически выгодных реакторов: реактор с графитовым замедлителем и газовым охлаждением, реактор с замедлением и охлаждением тяжелой водой и реактор с замедлением и охлаждением обычной водой.

Второй фазой развития ядерной энергетики является разработка улучшенных или усовершенствованных реакторов-конвертеров, включая почти реакторы-размножители. Эти реакторы составляют целую гамму типов, включая реакторы с тяжеловодным замедлителем, графитовым замедлителем, замедлителем из обычной воды и даже типы реакторов, в которых используются переменные замедлители — тяжелая и обычная вода. Эта фаза развития ядерной энергетики обещает лучшее использование топлива, более быструю подготовку топлива для реакторов-размножителей и, возможно, даже более низкую стоимость энергии, чем современные реакторы. Однако следует признать, что постоянное усовершенствование современных типов реакторов, очевидно, позволит добиться их экономической конкурентоспособности в течение большей части периода времени, когда будут разрабатываться и использоваться усовершенствованные реакторы-конвертеры.

Третьей фазой прогресса в ядерной энергетике, которая, возможно, будет частично совпадать со второй фазой, будет развитие реакторов-размножителей. На этой Конференции мы прослушали большое количество выступлений о реакторах-размножителях с использованием топливного цикла Pu — U^{238}. Вероятно в меньшей степени, чем они того заслуживают, обсуждались реакторы-размножители на тепловых нейтронах, основанные на использовании топливного цикла Th — U^{233} Оба эти типа реакторов-размножителей обещают увеличить на один порядок величины или более использование топлива урана и тория, так как они позволяют произвести больше делящихся веществ, чем сами потребляют. Короче говоря, они являются ключом для извлечения энергии, запасенной в неделящихся, но имеющихся в изобилии изотопах U^{238} и Th^{232}.

Необходимо отметить, что не все делегаты согласны с тем, что эти три фазы могут следовать по восходящей линии от ныне существующих экономических реакторов к усовершенствованным конвертерам, дающим большую экономию, и далее к некоторому совместному поиску долгосрочных программ развития реакторов-размножителей. Некоторые делегаты считают, что нет необходимости в промежуточной фазе разработки реакторов-конвертеров и что программы развития ядерной энергетики соответствующих стран должны быть направлены непосредственно на разработку реакторов-размножителей. Но неопределенности, которые все еще связаны с долгосрочным экономическим прогнозом реакторов-размножителей, вероятно, будут основной причиной для текущего и ближайшего будущего развития усовершенствованных конвертеров для многих стран. Напротив, многие делегаты считают, что не следует в настоящее время направлять основные усилия на развитие реакторов-размножителей, так как ныне существующие типы реакторов и улучшенных конвертеров могут обеспечить в изобилии энергию для многих грядущих десятилетий. Если, как это было высказано на этой Конференции делегацией Великобритании, будет возможно производить уран из морской воды по ценам не более 20 долларов за фунт U_3O_8, то эта позиция будет значительно усилена.

Конференция ясно показывает, что целью всех стран является получение в изобилии экономичной ядерной энергии. Мы подходим к решению этой задачи различными путями и, вероятно, хорошо, что проводятся альтернативные исследования. По-видимому, в будущем ядерная энергетика в течение некоторого времени будет базироваться на различных системах. Вероятно, мы не найдем резко определенной точки, когда один из типов реакторов перестанет быть полезным. Более того, маловероятно, чтобы какая-то из усовершенствованных систем — конвертер или размножитель — будет широко использоваться, если она не станет экономически выгодной. По моему мнению, реакторы-размножители никогда не найдут широкого применения, например, если технология не будет развита до экономически конкурентоспособной стадии. И можно представить себе условия, при которых бридеры могут стать экономически выгодными, только если цены на топливо будут достаточно высоки.

Материалы Конференции показывают, что в настоящее время основное внимание уделяется разработке крупных станций электрической мощностью 500 *Мвт* каждая. Рассматриваются планы сооружения даже более крупных электростанций электрической мощностью 1000 *Мвт*. Когда идет речь о реакторах для опреснения морской воды — одна из замечательных выгод, которую получит человечество из рога изобилия ядерной энергии — имеются в виду станции мощностью 2 500 *Мвт* (эл.). Но другой конец спектра также требует внимания. Не все страны могут использовать энергию, производимую такими крупными блоками. Можно надеяться, что одним из результатов развития большой энергетики будет появление экономически выгодных энергетических реакторов меньшей мощности, приемлемых для многих развивающихся стран. Как мы здесь слышали, ядерные реакторы мощностью меньше 500 *Мвт* уже могут оказаться экономически выгодными в некоторых из этих стран.

В заключение я хотел бы отвлечься от итогов технического прогресса. Мне хотелось бы рассмотреть кое-что из того, что было здесь сказано, имеющее общечеловеческое значение, в особенности в международном смысле. Масштабы международного сотрудничества в развитии этого основного энергетического источника будущего в последние десятилетия являются действительно необычными и, возможно, единственными в своем роде в истории человечества. Мы можем указать на эти конференции, на работу Международного агентства по атомной энергии, на многообразие программ сотрудничества между странами и на ядерные программы помощи ряда стран. Конкретными проектами, имеющими большое значение, являются проект Норвегия — Польша — Югославия, проект DRAGON и проект SEFOR, проект Халленского реактора. К ним относится также CERN — один из замечательных примеров международного сотрудничества в науке, — который многие из нас имели возможность посетить во время Конференции.

Конференция выявила много причин, по которым следует продолжать и усиливать международное сотрудничество. Свободный поток не только научной, но и более узкой технической информации является ключом к наиболее быстрому прогрессу всех народов.

Это международное сотрудничество, осуществленное с успехом в области ядерной энергии, указывает на то, что наука может служить общей основой для сближения между странами мира. Атом урана или плутония не знает национальности. С помощью таких международных конференций, как эта, и благодаря широкому и более интенсивному развитию обмена и сотрудничества наука могла бы быть ведущим фактором в разрешении трудностей, которые все еще существуют между странами.

Конференция также подчеркнула тот факт, что практическое достижение материального благополучия народов развивающихся стран зависит от тесного международного сотрудничества. Конференция еще раз напомнила нам об относительном недостатке ископаемого топлива и гидроэлектрических ресурсов во многих из этих стран. Чтобы в этих странах достигнуть жизненного уровня, существующего теперь в развитых странах, к концу этого столетия потребуется использовать атомную энергию в широком масштабе. В действительности, именно благодаря развитию ядерной энергетики мы видим возможность, чтобы развивающиеся страны хотя бы частично сократили те долгие годы промышленной революции и значительно приблизили необходимое им время для вступления в эпоху научной революции, в которую многие из развитых стран уже вступили.

Однако такая надежда будет иллюзией без надежной основы, состоящей из научных кадров инженеров и техников, а также возможностей для производительного труда. Генеральный Секретарь Организации Объединенных Наций У Тан напомнил нам, что «открытие определенных научных институтов и подготовка по крайней мере небольшого количества ученых в области некоторых современных наук ни в коем случае не является роскошью для любой из молодых стран».

Высокоразвитые страны и Международное агентство по атомной энергии уже достигли некоторого прогресса в обучении и в создании научных центров в развивающихся странах. Еще больше необходимо сделать при помощи развитых стран. Мы должны найти пути, в особенности с помощью научных центров, чтобы дать возможность квалифицированным ученым и инженерам выполнять значительную работу в их собственных странах, так как в противном случае они перейдут на работу в развитые научные центры за границей.

Ясно, что эти усилия не должны ограничиваться лишь областью ядерной науки и техники. Однако ядерная наука в целом может дать больше, чем ядерная энергетика. Широта и заманчивость ядерной науки и техники делают ее замечательной стартовой площадкой для еще более крупных исследований и развития. Нам известен целый ряд замечательных примеров таких начинаний в ядерной области.

Если мы хотим сделать основной вывод этой Конференции — что ядерная энергия станет все возрастающей силой международной деятельности, то будет необходимо создать как можно скорее соответствующий международный орган ядерного права. Значительный прогресс достигнут в развитии и применении соответствующих систем гарантий под эгидой Международного агентства по атомной энергии. Генеральный директор МАГАТЭ д-р Сигвард Эклунд сообщил нам, что очень важно принять «систему международных гарантий именно сейчас, когда количество энергетических реакторов еще невелико». Дальнейшее развитие международного атома должно идти параллельно с будущим ростом эффективных систем гарантий.

Из обсуждений на Конференции следует, что в конце столетия более половины электроэнергии в мире будет производиться с помощью ядерной энергетики. Следовательно, ядерная энергия является надеждой народов мира на лучшую жизнь. Если основная будущая база энергетики мира будет продолжать развиваться в духе международного развития и права, ядерная энергия может быть важной объединяющей силой в мире мира, безопасности и благополучия человека.

Estados Unidos de América

Resumen de la Conferencia

por G. T. Seaborg

Empezaré por hacer algunas observaciones generales, primero acerca de las necesidades mundiales de energía y la función de la energía nuclear en la satisfacción de estas necesidades, y segundo acerca de lo que algunos de nosotros consideramos que son las tres fases del desarrollo de la energética nuclear.

La Conferencia ha dramatizado el hecho de que el mundo necesitará durante el resto de este siglo enormes aumentos de la energía disponible. El ritmo acelerador de la Revolución Científica en los países desarrollados exigirá nuevos y enormes incrementos de energía. Al mismo tiempo, necesitamos urgentemente colocar las naciones en desarrollo en la órbita de las técnicas actuales. Según nos recordó el Secretario General, U Thant, en su declaración en la sesión de apertura: “El tema principal de esta Conferencia es la energía nuclear, un problema fundamental para el desarrollo a largo plazo de más de la mitad del mundo. Si el consumo diario de electricidad *per capita* en las regiones en vías de desarrollo se compara con el que se observa en los países más industrializados, la cantidad de energía adicional necesaria será tan vasta que empequeñecerá incluso las inmensas reservas de la tierra en combustibles fósiles y energía hidroeléctrica.”

El Dr. Bhabha de la India observó que “no hay energía tan costosa como la falta de energía”.

¿Qué conclusiones parecen haberse extraído en la Conferencia con respecto a las ventajas de la energía nuclear para hacer frente a estas necesidades de energía? La Conferencia ha demostrado que la energía nuclear a precio ventajoso está llegando a su mayoría de edad, pero sus ventajas van más allá de la mera economía. Permiten a las naciones administrar prudentemente sus recursos de combustibles fósiles más como materias primas irreemplazables que como fuentes de calor. Como observó el Presidente de la Conferencia, Sr. Emelyanov, en su discurso de apertura: “Las materias primas para la industria química, para la fabricación de materiales plásticos, de tejidos, de cuero artificial, están constituidas por los gases naturales, el petróleo y el carbón. El combustible orgánico es una materia prima para la industria química. Si se sigue consumiendo petróleo al mismo ritmo que ahora, pronto se habrá quemado todo el que tenemos y la química perderá su fuente más importante de materias primas.”

Veamos ahora de qué modo la Conferencia nos da motivos para creer en el futuro de la energía nuclear. El indicio más impresionante del progreso alcanzado quizá sea que la potencia nuclear instalada en el mundo ha pasado de sólo 5 MW en 1955 a 185 MW en 1958 y a casi 5 000 MW en 1964. Las previsiones para el futuro son también excelentes. En 1970 la potencia nuclear total instalada en el mundo será de 25 000 MW aproximadamente y para 1980 esta cifra total habrá aumentado hasta 150 000 ó 200 000 MW.

Según puso de relieve el Comisario de Energía Atómica de los Estados Unidos, Sr. Tape, “en el próximo siglo la energía nuclear puede perfectamente proporcionar más de la mitad de la producción nacional de energía, como lo ha hecho anteriormente la madera, el carbón y los hidrocarburos fluidos".

Los documentos técnicos dan fe de que la energía nuclear ha llegado a su mayoría de edad, fe que se ha visto confirmada por las discusiones de pasillo que reflejan el comienzo de la competencia comercial en esta esfera. Esto constituye en sí un serio indicio de éxito económico y quiero creer que tal hecho no ha importunado excesivamente a la Conferencia. Sin embargo, la competencia (a veces agresiva) acompaña inevitablemente al desarrollo económico y desempeña una importante función en la disminución de los costos. Quizá sea conveniente resaltar la observación de un delegado que afirmaba que en ocasiones se necesitaba recurrir a procedimientos agresivos para convencer a financieros conservadores e ingenieros de empresas públicas del valor de los nuevos descubrimientos.

Debe hacerse notar que nuestras proyecciones del desarrollo de la energía nuclear no presuponen la aparición de la fusión termonuclear controlada o de cualquier fuente de energía ahora desconocida. No se prevé tal acontecimiento, pero puede ocurrir. Si la fusión se hace realidad y es barata, estoy seguro que habrá tiempo de modificar nuestros planes.

El tema de mi segundo grupo de observaciones generales se refiere a los reactores tal como los conocemos hoy y como esperamos que sean en el futuro. Muchos de los delegados de esta Conferencia consideran que la energética nuclear atraviesa tres fases.

La primera fase (alcanzada en el pasado año aproximadamente) ha sido hacer económicamente competitivos tres tipos de reactores: el reactor moderado por grafito y refrigerado por gas, el reactor moderado y refrigerado por agua pesada y el reactor moderado y refrigerado por agua natural.

La segunda fase será la puesta a punto de los reactores convertidores perfeccionados o modernizados, incluidos los reactores casi-reproductores. Estos reactores son de diversos tipos: los moderados por D_2O, por grafito o por H_2O e incluso los reactores que utilizan una moderación variable de D_2O y H_2O. Esta fase del desarrollo de la energética nuclear promete mejorar la utilización del combustible, preparar el combustible para los reactores reproductores a un ritmo más rápido y, en potencia, la producción de energía a un costo incluso inferior al de los reactores actuales. Sin embargo, debe reconocerse que el constante perfeccionamiento de los tipos actuales de reactores hará probablemente que sigan siendo unos competidores cada vez más fuertes durante la mayor parte del período de puesta a punto y en servicio de los convertidores avanzados.

La tercera fase, en cierto modo concurrente, del progreso nuclear, es el desarrollo de los reactores reproductores. En esta Conferencia se ha discutido ampliamente acerca de los reactores reproductores de neutrones rápidos que utilizan el ciclo de combustible de plutonio y uranio-238. Se ha dado quizá menos importancia que la que merecen a los reactores reproductores con neutrones térmicos alimentados a base del ciclo de combustible torio y uranio-233. En todo caso, estos reactores rèproductores dejan prever un aumento de un orden de magnitud y más del uso como combustibles de nuestras reservas de uranio y de torio, ya que producirán más material fisible que consumen. En esencia, estos reactores representan la llave que nos permitirá liberar la energía almacenada en los núclidos no fisibles, pero muy abundantes, uranio-238 y torio-232.

Importa resaltar que no todos los delegados coinciden en que se puedan ordenar estas tres fases de modo que, empezando por los reactores que son económicos ahora, se llegue a convertidores perfeccionados que incluso mejoren esta economía y y de aquí quizá simultáneamente a emprender un programa a más largo plazo de instalación de reactores reproductores. Algunos delegados han considerado que no es necesario pasar por la fase intermedia del convertidor y que los programas de desarrollo nuclear de los respectivos países deben pasar directamente a la fase de los reactores reproductores. Pero las dudas todavía asociadas a las perspectivas económicas a largo plazo de los reactores reproductores parecen proporcionar razones sólidas para que muchos países pongan a punto convertidores perfeccionados. En cambio, otros delegados han considerado que por ahora no deberían consagrarse esfuerzos especiales a los reactores reproductores, puesto que los tipos actuales de reactores y los convertidores perfeccionados podrían proporcionar energía abundante durante muchos decenios. Si, tal como ha informado la delegación del Reino Unido en la Conferencia, fuera posible extraer el uranio del agua del mar con un costo no superior a 20 dólares la libra de U_3O_8, quizá quedaría considerablemente reforzada esta opinión.

La Conferencia ha demostrado claramente que el objetivo de todas las naciones es producir energía nuclear abundante y barata. Nos aproximamos a esta meta por caminos diferentes y el que se efectúen exploraciones alternativas constituye un feliz acontecimiento. Parece probable que durante algún tiempo la base de la energía nuclear en el mundo la formarán varios sistemas diferentes. No es probable que lleguemos a un punto en el que un tipo de reactor deje bruscamente de ser útil. Además, tampoco es probable que llegue a adoptarse ampliamente un tipo perfeccionado de convertidores o reproductores si no resulta barato. En mi opinión, nunca contemplaremos, por ejemplo, el empleo generalizado de los reactores reproductores si no se hace avanzar la tecnología a la fase económicamente competitiva. Y podemos concebir condiciones en que los reactores reproductores sólo podrían resultar económicos si se aumentara suficientemente el precio del combustible.

Estas actas confirman que, hoy, se insiste en que el desarrollo de la energética nuclear necesita centrales de unos 500 MW(e), dándose por sentado con toda tranquilidad la ejecución de planes para la instalación de centrales incluso mayores de 1 000 MW eléctricos cada una. Cuando hablamos de los reactores para desalinización de agua del mar (uno de los mayores beneficios que puede deparar al hombre en el futuro la energía nuclear) situamos el tamaño de las centrales en los 2 000 MW(e). Pero la otra cara del problema también requiere atención. No todos los países pueden consumir energía en magnitudes tan enormes. Afortunadamente, uno de los resultados del desarrollo en gran escala de la energía nuclear será la instalación de reactores de potencia baratos, de tamaño más reducido y más apropiados para muchos de los países en desarrollo. Según hemos escuchado, en algunos de estos países se empieza ya a considerar que los reactores nucleares de menos de 500 MW de potencia pueden proporcionar ventajas económicas. En mis observaciones finales, desearía examinar algunas de las consecuencias para el hombre de lo que se ha dicho en esta Conferencia, especialmente dentro de un contexto internacional. El grado de cooperación internacional en el desarrollo de esta nueva e importante fuente de energía en el último decenio es seguramente un acontecimiento insólito y quizá único en la historia mundial. Podemos señalar estas Conferencias, el trabajo del Organismo Internacional de Energía Atómica, los distintos programas de cooperación entre las naciones y los programas de asistencia nuclear a algunas de aquéllas. Entre los proyectos concretos importantes figuran el proyecto de Noruega, Polonia y Yugoslavia, el proyecto DRAGON, el proyecto SEFOR y el proyecto HALDEN. Cerca tenemos el CERN, uno de los ejemplos más destacados de la cooperación internacional en el campo de la ciencia, que muchos de nosotros hemos podido visitar durante esta Conferencia.

La Conferencia ha demostrado de múltiples formas por qué debe continuar y fortalecerse la cooperación internacional. El libre intercambio de informaciones, no sólo al nivel científico sino al nivel más limitado de la técnica, es la clave para que todos los países realicen progresos técnicos con la mayor rapidez posible.

Esta cooperación internacional en materia de energía nuclear practicada con tanto éxito refuerza aún más la tesis de que la ciencia puede servir de base común de las relaciones entre todas las naciones del mundo. Un átomo de plutonio o de uranio no tiene nacionalidad. A través de Conferencias internacionales como ésta y de otros programas más amplios e intensos en materia de cooperación y de intercambio de informaciones, la ciencia puede ser un factor principal de superación de las divergencias todavía existentes entre los países.

La Conferencia también ha dramatizado el hecho de que el logro práctico del bienestar material de los pueblos de los países en desarrollo descansa en esta estructura de estrecha cooperación internacional. La Conferencia ha vuelto a infundir en nosotros la conciencia de la escasez relativa de combustibles fósiles y de recursos hidroeléctricos en muchos de estos países. Para alcanzar y mantener a finales de siglo niveles de vida similares a los existentes actualmente en los países desarrollados, aquellos países necesitarán energía nuclear en gran escala. Ciertamente, creemos en la posibilidad de que, a través de la energía nuclear, las naciones en desarrollo puedan evitar parcialmente el largo período que duró la Revolución Industrial y acortar considerablemente el tiempo que necesitarían para entrar en la era de la Revolución Científica, en la que han entrado ya muchas de las naciones desarrolladas.

Sin embargo, tal esperanza será ilusoria si no se asienta sobre bases firmes constituidas por cuadros de hombres de ciencia, ingenieros y técnicos y por instalaciones para realizar un trabajo productivo. El Secretario General de las Naciones Unidas, U Thant, nos recordó que “el establecimiento de un cierto número de institutos científicos y la formación de un pequeño número, cuando menos, de científicos en algunas de las disciplinas avanzadas no constituye en modo alguno un lujo para ninguna de las nuevas naciones”.

Técnicamente, las naciones avanzadas y el Organismo Internacional de Energía Atómica han hecho ya progresos en materia de formación y de creación de centros científicos en las naciones en desarrollo, pero las naciones desarrolladas deben todavía hacer mucho más. Necesitamos encontrar métodos, especialmente a través de los institutos científicos, que permitan a hombres de ciencia e ingenieros con grandes calificaciones efectuar un trabajo útil en sus propios países, pues hemos comprobado que, de lo contrario, se marcharán a trabajar en institutos científicos avanzados de otros países.

Es evidente que estos esfuerzos no deben limitarse a la ciencia y a la técnica nucleares. Sin embargo, la ciencia nuclear puede ofrecer muchas más cosas que la energía nuclear. La envergadura y la atracción de la ciencia y de la técnica nucleares hacen de esta esfera un excelente punto de partida para iniciar investigaciones y desarrollos más amplios. Todos conocemos unos cuantos y buenos ejemplos de tales comienzos en el campo nuclear.

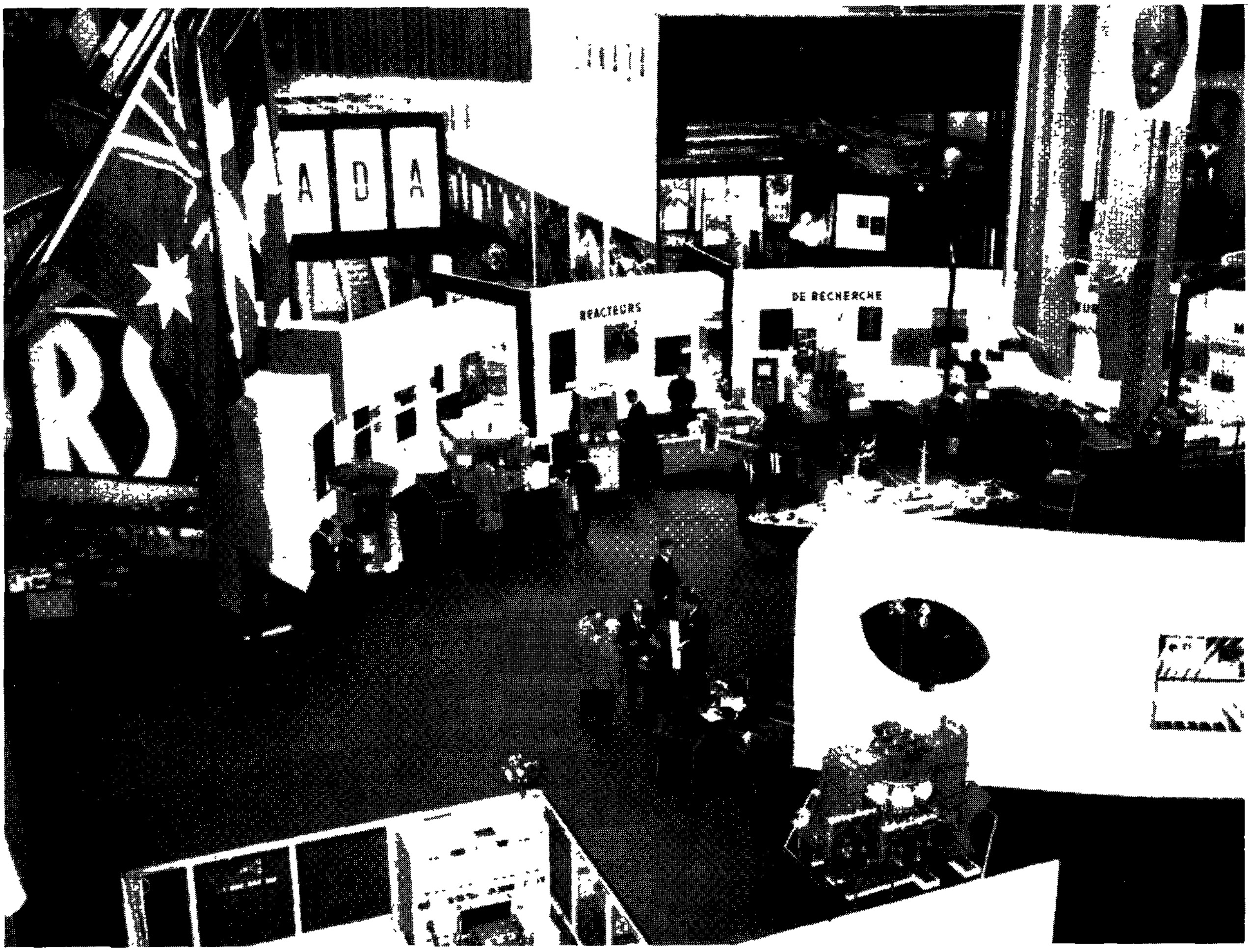
Si vamos a aplicar la principal conclusión de esta Conferencia, a saber: que la energía nuclear se convertirá en una fuerza cada vez más poderosa para llevar a cabo los trabajos de nuestro mundo, será necesario elaborar lo más rápidamente posible un cuerpo de leyes nucleares apropiado y de ámbito mundial. Se han hecho ya progresos considerables en el desarrollo y aplicación de salvaguardias adecuadas bajo la égida del Organismo Internacional de Energía Atómica. Como nos dijo el Dr. Sigvard Eklund, Director General del OIEA, es importante haber aceptado un "sistema internacional de salvaguardias *ahora*, cuando todavía el número de reactores de potencia es pequeño". El desarrollo futuro del átomo internacional debe ir acompañado del futuro desarrollo de un sistema eficaz de salvaguardias.

Según se desprende de la Conferencia, a la vuelta de este siglo más de la mitad de la electricidad producida en el mundo será generada mediante la energía nuclear. Por tanto, ésta constituye la esperanza de una vida mejor para todos los pueblos del mundo. Si la base principal de la energía mundial en el futuro sigue evolucionando en un ambiente de desarrollo y de legislación a escala internacional, la energía nuclear puede ser una fuerza importante de unificación en un mundo de paz, de seguridad y de bienestar humano.

The
Governmental Scientific
Exhibition

Main entrance to the Palais des Expositions, Geneva

The *interior* of the Exhibition Hall



NARRATIVE OF THE EXHIBITS

By arrangement with the local authorities, the Palais des Expositions, situated in the heart of the city of Geneva, was rented to house the exhibits of the eighteen countries taking part in the Governmental Scientific Exhibition which was organized in conjunction with the Conference. Some 33 000 m^2 of the total floor area of this building were reserved, of which 7 627 m^2 were taken up by the national exhibits, the remaining space providing the necessary foyers and passageways, exhibit storage, a covered car park, reception areas, delivery points and the administrative offices. A mobile fire picket, first-aid post, restaurant and bars were also installed. The Swiss customs authorities made the Exhibition area a free zone to facilitate the expeditious and convenient clearance of exhibitors' consignments on entry and exit.

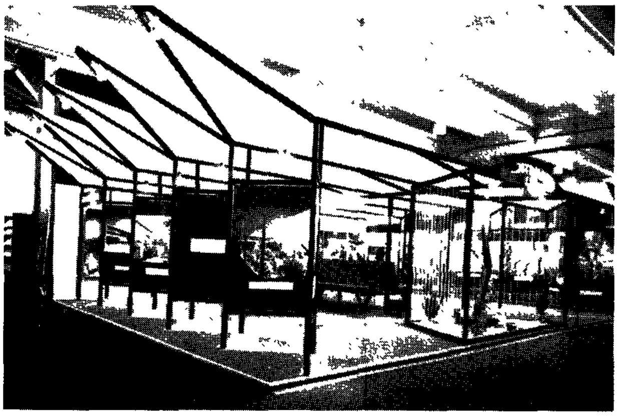
The technical preparations for the Exhibition, the provision of common services to the exhibit stands and day-to-day administration were entrusted by the United Nations to the Geneva "Atoms for Peace" Foundation, whose Secretary-General headed a Technical Administration appointed and equipped for this purpose, working under general United Nations supervision. The entire costs of the hire of the building, common services and administration were met by the exhibiting governments in proportion to the amount of stand space occupied by each.

The Scientific Exhibition was opened to participants in the Conference on the afternoon of Sunday, 30 August, when the Secretary-General of the United Nations, accompanied by senior officers of the Headquarters Staff and of the European Office, the President of the Conference, members of the Scientific Advisory Committee, the Director General of IAEA and members of his staff and the Scientific Secretariat, civic dignitaries of the State of Geneva, and members of the Conference Secretariat made an informal tour of the exhibits. The Exhibition remained open until 10 September, the general public being admitted on most afternoons. Altogether, some 23 000 people visited the Exhibition. IAEA also mounted a pictorial panel display illustrating its present and future activities, together with an exhibit of its technical publications in the Palais des Nations. No commercial exhibition was held as in 1958. National exhibits were designed to illustrate the main theme of the Conference, i.e., the technology of nuclear power in general and the development of nuclear reactors for the generation of electrical power in particular. They were also closely related to the papers presented to the Conference by their respective delegations. The Exhibition was linked to the Conference meetings and film screenings in the Palais des Nations by a special transport service running between the two buildings.

AUSTRALIA

The exhibit was presented by the Australian Atomic Energy Commission to illustrate photographically some of the progress being made in its current research programme. This comprises mainly a study of the technical and economic feasibility of a high-temperature, gas-cooled, beryllium oxide moderated power reactor, for which an all ceramic pebble-bed type core is being investigated, with the fuel elements consisting of spheres of beryllium oxide, approximately one-inch diameter, containing uniformly dispersed fissile and fertile materials. Commercial plutonium oxide and thorium oxide are being considered for the fuel cycle.

Entrance to the Australian stand



General view of the Australian stand

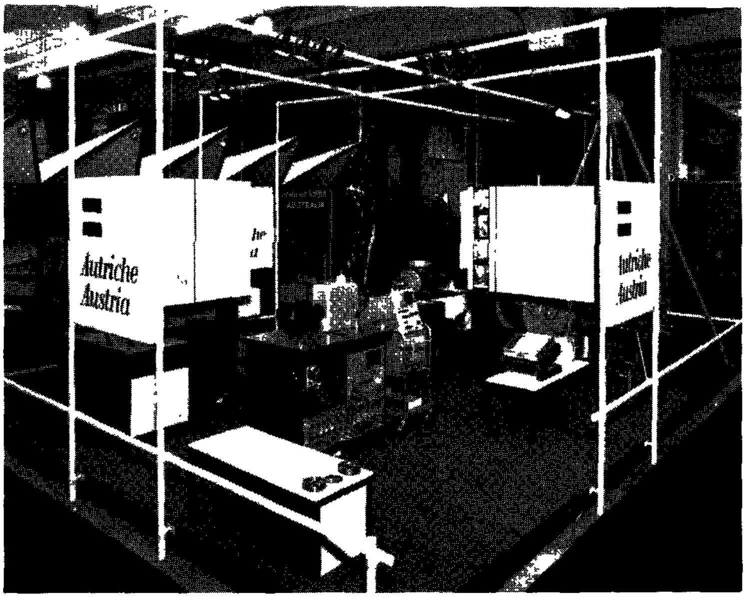
A major part of the Commission's programme has been concerned with materials research, particularly in the testing and fabrication of irradiated and unirradiated materials. This work has now reached an advanced stage.

Large colour and black and white photographs showed some of the related research facilities at the Commission's Research Establishment at Lucas Heights, near Sydney, New South Wales; and related electron micrographs, in some cases enlarged up to 390 000 times the original specimen, gave some of the results which have been obtained in experiments using beryllium oxide.

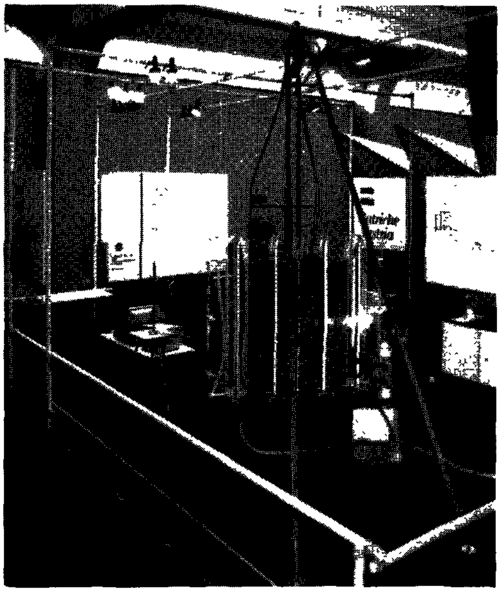
A photo mural, 30 ft by 16 ft, indicated the full layout of the AAEC Research Establishment in Australia, where the exhibit was designed and the photographic enlargements prepared.

AUSTRIA

Among exhibits shown on the Austrian stand were two pieces of apparatus of special interest. One consisted of gamma spectroscopy equipment using a cooled semi-conductor detector in a Compton coincidence arrangement with 18 keV (full width at half maximum) energy resolution for the non-destructive measurement of spent fuel burn-ups based on the intensity of the caesium-137 gamma line. Measurement accuracy is expected to be within 15 per cent of the actual burn-up. The other was a device for the measurement of the velocity and direction of flow of underground water streams in well-defined depths down to 300 m. The latter device requires only a single bore hole, 2 to 3 inches in diameter, and it has proved its worth during three years of field service.



General view of the Austrian stand, showing in the foreground mobile equipment for burn-up measurement



Austrian exhibit of a device to measure velocity and direction of the flow of underground streams

Other items included a megarad irradiation equipment for liquids and gases with strontium-90-titanate foils protected by 0.075 mm stainless steel used as an irradiation source, thus providing a very compact device which requires only a minimum amount of shielding; and a model of one of the six forced circulation steam generators for the OECD high-temperature gas-cooled reactor project DRAGON, a compact design featuring multi-start helical coils and an integrated combined by-pass and isolation valve. There were also semi-finished and finished products of molybdenum, tantalum, niobium and tungsten (shielding blocks for irradiation sources, tubes and sheets).

BELGIQUE

La participation belge à l'Exposition scientifique gouvernementale avait pour but de mettre l'accent sur certains aspects des activités nucléaires en Belgique, en ce qui concerne notamment la conception et la construction des réacteurs, la plupart des opérations du cycle de combustibles, l'étude de matériaux nucléaires, la construction d'équipements spécialisés et l'utilisation des radioéléments.

Le stand belge comportait notamment:

Une maquette du Centre d'étude de l'énergie nucléaire (CEN, Mol), donnant une idée d'ensemble des laboratoires, et notamment des quatre réacteurs de recherche (BR1, BR2, BRO2 et VÉNUS) et de la centrale pilote de puissance [BR3, réacteur à eau pressurisée, 11,5 MW(e)].

Une maquette de BR2, le réacteur d'essais de matériaux, dont la conception originale et le flux de neutrons très élevé (de l'ordre de 10^{15} n/cm^2 s) font actuellement un des outils d'essais les plus modernes du monde. Ses performances permettent, entre autres, l'essai de combustibles au taux de combustion poussé et l'étude des dégâts radiatifs dans les matériaux les plus divers.

Un ensemble de panneaux, diapositive animée, maquettes, relatifs au projet anglo-belge de développement du réacteur VULCAIN. Ce réacteur [20 à 50 MW(e)], qui est basé sur le principe de la modération variable et sur une disposition extrêmement compacte du cycle primaire, est destiné à des applications terrestres et maritimes.

Un aperçu des activités d'Eurochemic, société européenne pour le traitement chimique par la méthode aqueuse des combustibles irradiés, dont le siège social est établi à Mol et dont la Belgique fait partie.

Un aperçu des recherches entreprises depuis 1956 en vue de développer la technologie du plutonium et plus particulièrement les oxydes mixtes UO_2-PuO_2.

Des échantillons d'éléments de combustible pour réacteurs d'essais des matériaux et pour réacteurs de puissance. A cette occasion, certaines techniques particulières en soudage, coextrusion, rétreint, etc., étaient illustrées par des exemples.

Des appareillages de mesure des radiations et des radioisotopes.

Un échantillonnage d'activités dans le cadre du traitement d'UF_6 enrichi et appauvri; dans le domaine de l'uranium naturel étaient notamment exposés des sels et des métaux sous forme de lingots, billettes, barres, plaques, tubes et sphères. On pouvait en outre remarquer des boutons d'uranium métal permettant désormais de produire de petits lingots d'uranium dans des conditions très économiques, grâce à un procédé de transformation directe d'UF_6 en UF_4.

Des équipements divers pour réacteurs, tels que: une vanne de circuit primaire pour réacteur PWR et un système de commandes de barres de contrôle.

Translation

BELGIUM

The Belgian participation in the Governmental Scientific Exhibition was aimed at emphasizing certain aspects of nuclear activities in Belgium, in particular the design and construction of reactors, most of the operations in the fuel cycle, the study of nuclear materials, the construction of specialized equipment and the utilization of radio-elements.

The Belgian stand included the following:

A model of the Nuclear Energy Study Centre (CEN, Mol), giving a general idea of the laboratories and particularly of the four research reactors (BR1, BR2, BRO2 and VÉNUS) and of the Pilot Power Station [BR3 pressurized water reactor, 11.5 MW(e)].

A model of BR2, the material test reactor, whose original design and very high neutron flux (of the

Le stand de la Belgique, montrant le Centre de Mol et un prototype de bateau doté d'un réacteur VULCAIN

The Belgian stand, showing the Mol Centre and a model of the rear section of a prototype ship equipped with a VULCAIN reactor

Vanne en acier inoxydable pour le circuit primaire de la centrale SENA

Stainless steel valve for the primary circuit of the SENA reactor

Cellule destinée au programme de développement des combustibles au plutonium et une diapositive animée du réacteur VULCAIN

A glove box used in the plutonium fuel development programme and an animated flow diagram of the VULCAIN reactor order of 10^{15} n/cm^2 s) make it at present one of the most modern testing instruments in the world. Its performance permits, *inter alia*, of testing fuels with a high burn-up and of studying radiation damage in the most varied materials.

A series of panels, an animated slide, and models connected with the Anglo-Belgian project for the development of the VULCAIN reactor. This reactor [20-50 MW(e)], which is based on the principle of variable moderation and on an extremely compact arrangement of the primary circuit, is intended for land and sea applications.

A survey of the activities of Eurochemic, European company for the chemical treatment of irradiated fuels by the aqueous method, the headquarters of which are at Mol and of which Belgium is a member.

A survey of the research undertaken since 1956 with a view to developing plutonium technology and particularly UO_2-PuO_2 mixed oxides.

Samples of fuel elements for material test reactors and power reactors. In this connexion, certain special techniques of soldering, co-extrusion, contraction, etc., were illustrated by examples.

Apparatus for measuring radiation and radioisotopes.

A sample of activities in connexion with the treatment of enriched and depleted UF_6 ; in the case of natural uranium, there were exhibits of salts and metals in the form of ingots, billets, rods, plates, tubes and spheres. Using the method of direct conversion of UF_6 to UF_4 , buttons of uranium which are shown can be economically produced and from them small uranium ingots can be made.

Sundry equipment for reactors, such as a primary loop valve for a PWR reactor and a drive system for control rods.

CANADA

The development of economic nuclear power in Canada was the dominant theme of the Canadian exhibit.

A diagrammatic panel showed the preliminary design of the Pickering Generating Station, a million-kilowatt (electrical) station to be built on the shore of Lake Ontario, near the easterly boundary of metropolitan Toronto. The Pickering station will have two CANDU-type reactors, one of which will go into operation in 1970, and the other the following year. Like the CANDU reactor in the Douglas Point Nuclear Power Station, the Pickering reactors will use natural uranium for fuel, heavy water for moderator, and heavy water for coolant.

The nuclear power section included a model of the Douglas Point Nuclear Power Station as a whole; a one-eighth scale model of the CANDU reactor; and an actual section of a CANDU pressure tube, showing details of the end fitting, the end shielding, and fuel bundles in place. The Douglas Point station, which is being built on the shore of Lake Huron, will have an electrical output of 200 000 kW.

The Nuclear Power Demonstration Station (NPD) —the 20 000 kW (electrical) prototype for Canadian power reactors—was represented in the exhibit by a large cutaway model of the station as a whole, a section of an actual pressure tube and panels of photographs. NPD went into full-power operation in June 1962. The station was built as a co-operative project of Canadian Nuclear and Electronics Industries and the Hydro-Electric Power Commission of Ontario. Like the CANDU reactor, the NPD reactor has horizontal pressure tubes, a heavy-water natural uranium system, and on-power bi-directional fuelling which is carried out by two remotely-controlled fuelling machines.

A large preliminary architect's drawing gave details of the Rajasthan Atomic Power Project. This station, practically a duplicate of the Douglas Point station, is being built by the Government of India near Rana Pratap Sagar in Rajasthan State. Canadian nuclear power industrial interests are responsible for the design of the nuclear portion of the station, which is to go into operation in 1969 with an electrical output of 200 000 kW.

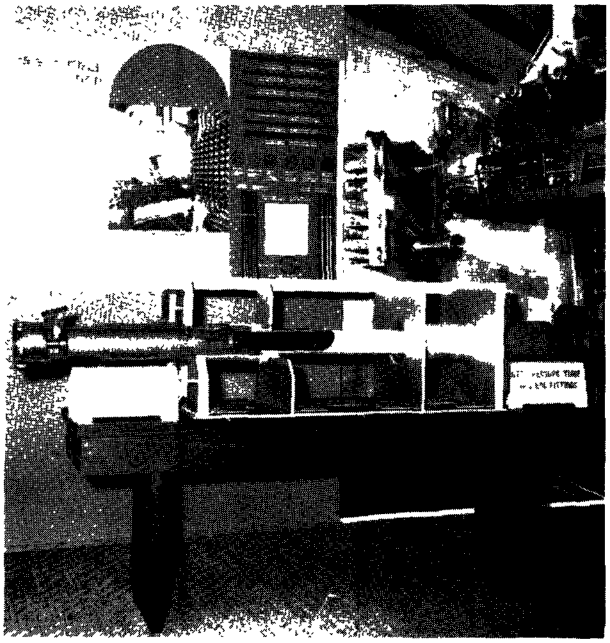
Fuel development in Canada was shown with sections of NRX and NRU fuel rods, and actual fuel bundles of the NPD and the Douglas Point stations. Other sections of fuel indicated the various lines of development being followed in Canadian fuel production. Also illustrated were specimens of industrial design and development work of various fuel manufacturers.

Canadian interest in the heavy-water moderated and organic cooled type of power reactor was demonstrated by a detailed scale model of the Whiteshell Reactor No. 1 (WR-1). This engineering test reactor is being constructed near the newly-built town of Pinawa, Manitoba, about 65 miles north-east of Winnipeg. WR-1, a highly flexible test reactor for advanced power reactor concepts, has pressure-tube type fuel channels that can be grouped and fed with different coolants. The reactor will be used to carry out large-scale experiments on fuel channel designs and fuelling systems. It will have a heat output of 40 000 kW when it goes into operation in 1965, with initial use of only 37 of the 55 fuel channels.

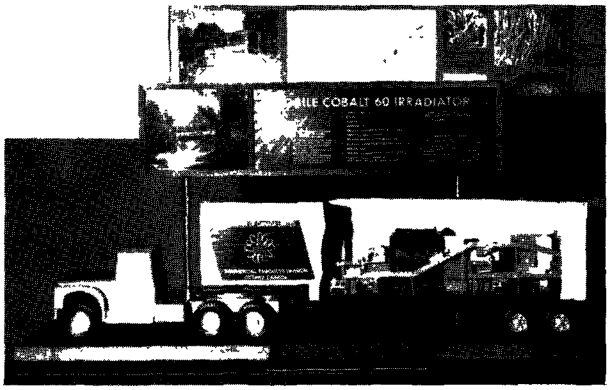
Among exhibit items showing Canadian work on advanced power reactors was an engineering scale model of the Advanced Water Systems Loop in the NRU reactor at the Chalk River Nuclear Laboratories. Flow diagrams showed systems for testing various types of cooling: pressurized water, boiling water, fog and steam.

Canadian uranium resources, whose known reserves represent about 37% of the total among those countries that have published reserve statistics, were shown by tables, a resources map, and samples of the vein-type ore from the Beaverlodge area

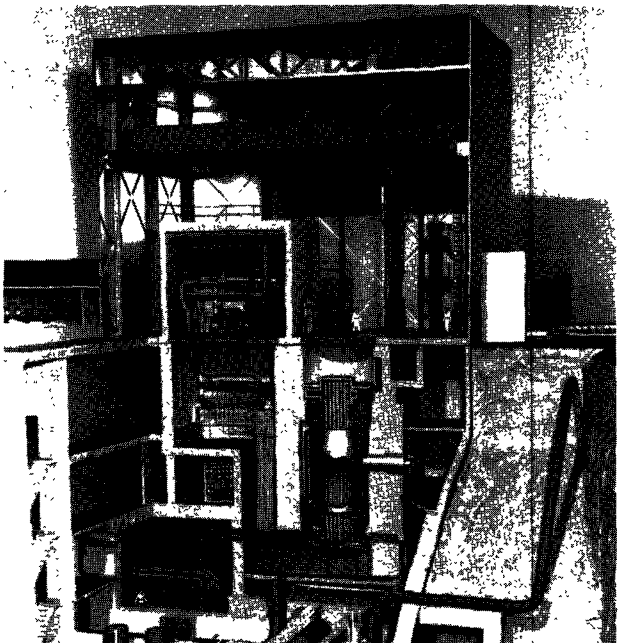
Scale model of the CANDU reactor of the Douglas Point Nuclear Power Station, in the nuclear power section of the Canadian exhibit



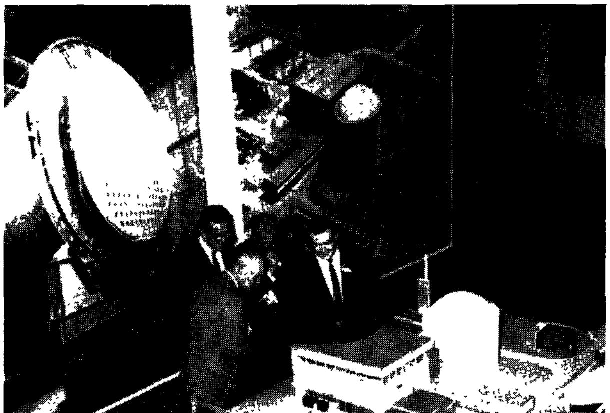
Section of an NPD reactor pressure tube showing the end fitting, end shielding and fuel bundles in place



A display of irradiators, including a model of the truck-mounted cobalt-60 irradiator used for the processing of potatoes



Model of the Whiteshell Reactor No. 1 (WR-1) at Pinawa, Manitoba



Model of the 200 000 kW(e) Douglas Point Nuclear Power Station, with a picture of the calandria (left background)

(Saskatchewan), the conglomerate-type ore from the Elliot Lake area, and the pegmatitic-type ore from the Bancroft area (Ontario). Also displayed were a variety of the products of uranium refining at Port Hope, Ontario.

The long-term dimensional stability of the metals used in reactor components is one of the factors that has to be considered when the design stresses for these components are set. The exhibit showed details of a machine developed to obtain creep data for metals under irradiation in reactors. Two such machines have been operated successfully in the NRX reactor.

Research activities were illustrated by panels of photographs and diagrams on studies of solids by means of thermal neutron inelastic scattering, kinetics of fission measured by time-of-flight experiments, and studies associated with an electromagnetic isotope separator used to separate isotopes, either to study their nuclear properties or to provide an energetic beam of carrier-free radio-active atoms for tracer studies and range measurements.

Practical applications of radio-active isotopes, developed by commercial enterprise in Ottawa, were shown by an actual Theratron cancer therapy machine and by models of a variety of irradiators for research and industry. Irradiator models using cobalt-60 sources included a Gammacell, into which are inserted small samples for gamma irradiation, and a Gammabeam, which is used in a shielded room to irradiate batches of material placed around the unit.

A small-scale model depicted the truck-mounted irradiator which has travelled to various warehouses in eastern Canada to irradiate potatoes on a trial basis. An animated model of a commercial-scale, conveyor-type irradiator showed a plant in use for the sterilization of medical supplies, and being built for large-scale irradiation of potatoes.

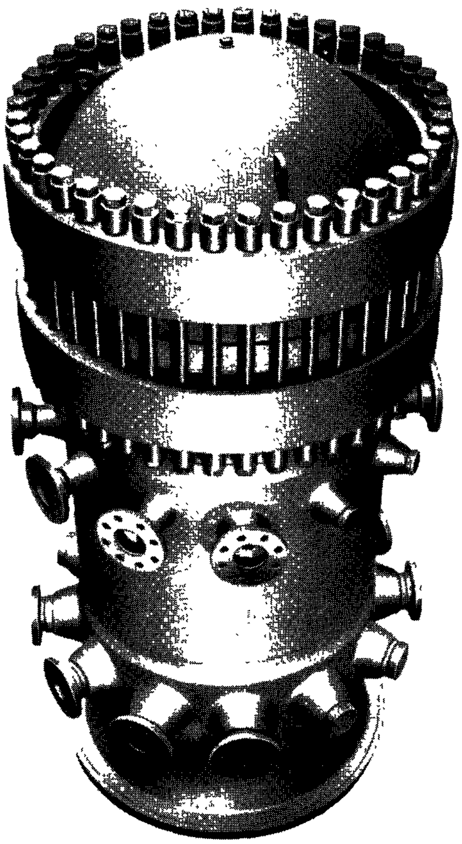
CZECHOSLOVAKIA

The main theme of the Czechoslovak exhibit dealt with the 150 MW(e) power station which is under construction at Bohunice, in Slovakia, and included the following exhibits:

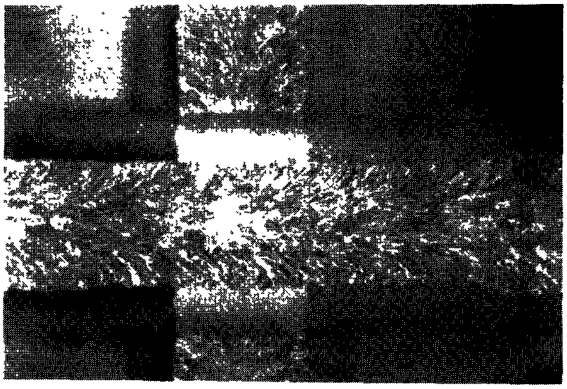
(1) A full-scale model of the upper ring of the pressure vessel of the first Czechoslovak power reactor, made by the Power Department of the Skoda Works at Plzeň (Pilsen). The pressure vessel itself is a vertical cylinder with a hemispherical bottom and removable cover. The vessel is made of special carbon steel and varies in thickness from 150 to 300 mm. Its total weight is given as 600 tonnes.

(2) Full-scale specimens of the electric-slag and electric-arc welded joints of the pressure vessel.

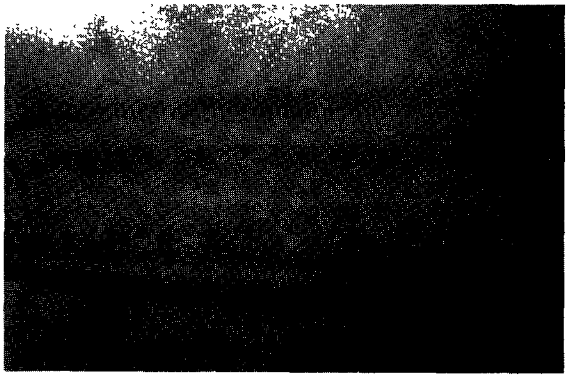
(3) Full-scale samples of selected parts of the pressure vessel subjected to destruction on the 6 000 tonne capacity tensile machine installed at Plzeň.



Pressure vessel of the first Czechoslovak nuclear power reactor at Bohunice



Pressure vessel electric-slag welded joint



Pressure vessel electric-arc welded joint

(4) Microsamples of the pressure vessel material.

The exhibits illustrated Czechoslovakia's capacity for development of its nuclear power industry. The Czechoslovak nuclear power programme is based on natural-uranium fuelled, heavy-water moderated, gas-cooled reactors. The demonstration prototype, 150 MW(e) HWGCR, is under construction, and the completion of the first Czechoslovak nuclear power plant will be of key importance to the further development of the nuclear power industry. The basic scientific and technical problems of all sections of the station have been solved.

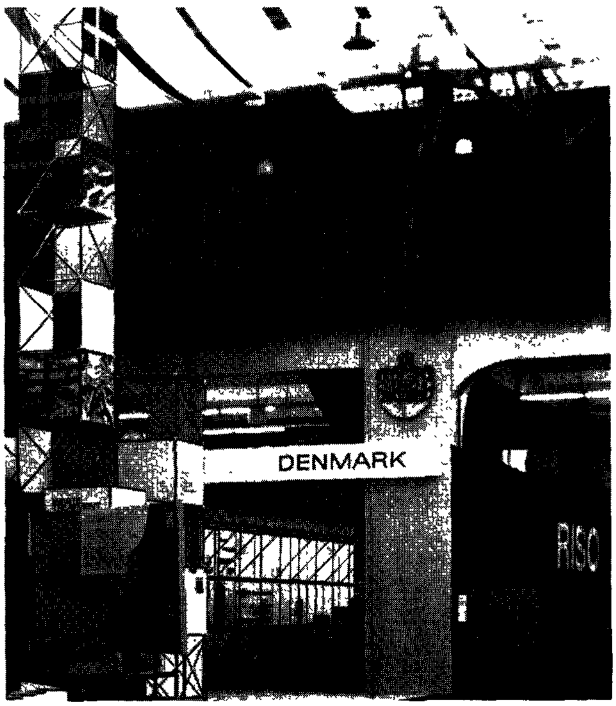
Experience gained in the research and design of the first power plant, and further studies which have been undertaken, suggest that this type of reactor and the general concept of its installation are progressive and capable of further development.

DENMARK

The Danish exhibit occupied an area of 132 m^2 and contained a variety of specimens and models. In the field of health physics were displayed an automatic sample changer designed for the measurement of β-activity of solid samples, the detector being a gas-flow anti-coincidence Geiger counter with a very low background; a fully transistorized hand-and-clothes monitor designed for checking persons on leaving radio-active areas; a compensated ionization chamber designed for food monitoring in disaster situations, the instrument needing a minimum of maintenance and being easy to operate by relatively unskilled personnel; and a portable contamination monitor for the measurement of contamination on surfaces and on objects, the instrument being transistorized, battery and mains operated. Isotopes were represented by a set of sealed radio-active α, β and γ sources for educational use, the sources being strong enough to demonstrate the most important properties of radioactive radiation, while still being so weak that the National Health Service has approved them for general distribution.

Neutron counting was illustrated by a model of a thermal neutron counter using the He^3 (n,p) H^3 reaction for measuring neutron density in a thermal beam. A method of waste treatment was shown in a plan of the Risö waste treatment plant, together with a model of the special Rolf Andersen evaporator used for decontamination of radio-active effluent. The exhibit also included a model of the High Power Density Rig which has been designed in co-operation with the OECD DRAGON Project for irradiation of fissile materials in Pluto-type reactors.

Metallurgy occupied a major position in the presentation of exhibits, which comprised an apparatus for creep-burst testing of tubes at elevated temperatures under internal pressure, and some samples of blended aluminium powder products. There were also samples of welded end caps on SAP-materials used as fuel-element cladding. As well as exhibits, there were different photographs from Risö departments showing certain specialized work such as the cutting of spent fuel-elements, work in hot cells, and so forth. A cinema showed the film "A New Reality", which is the Danish contribution to a series of educational science films produced with the support of the OECD. On the basis of Niels Bohr's theories, the Danish film illustrates, among other things, through experiments with models and light, the revolution in man's conception of nature that has been brought about by atomic physics. Statens Filmcentral (The Danish Government Film Office) produced "A New Reality" for Dansk Kulturfilm in co-operation with the International Council for Educational Films and with the support of the Carlsberg Foundation.



A general view of the Danish stand, showing, among other exhibits, plans of the Riso waste treatment plant

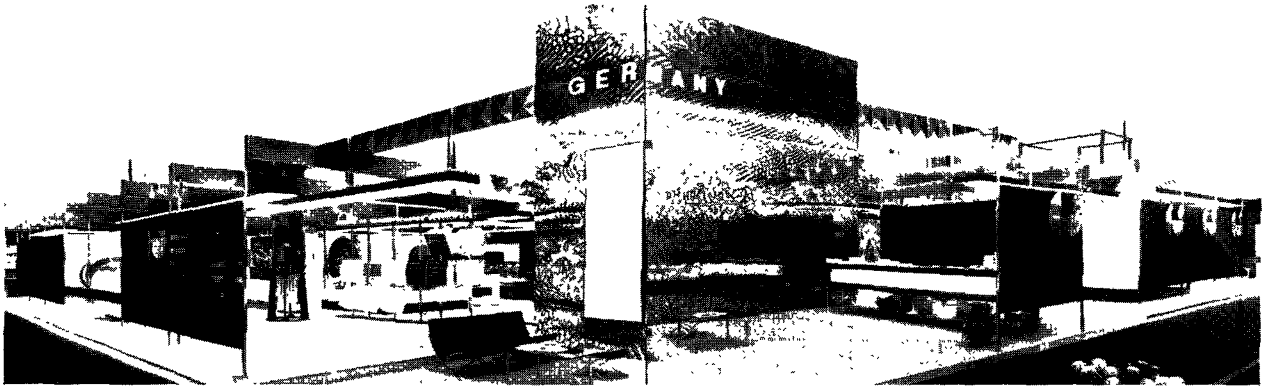
FEDERAL REPUBLIC OF GERMANY

The German exhibit occupied an area of 607 m^2. It portrayed the activities of the Federal Republic in relation to the topics of the Conference, and was divided into four sections: Nuclear Power Development; Nuclear Research Centres and Institutes; Research Reactors, Isotopes and Nuclear Engineering; and technical information.

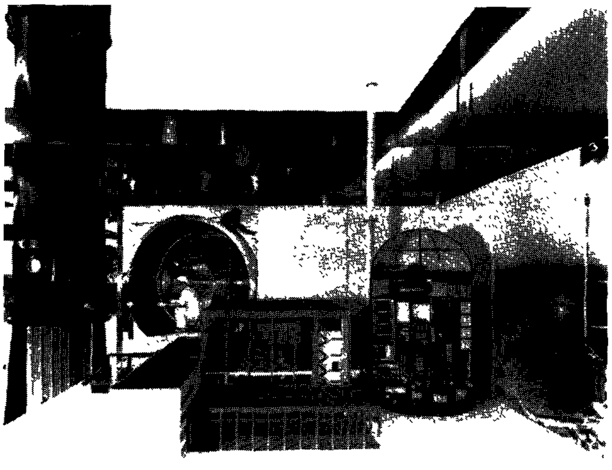
The first section dealt with the development of power reactors and their components. At the entrance a schematic graph illustrated the trends in

German reactor development: light-water moderated, heavy-water moderated, graphite-moderated, gas-cooled reactors (including the pebble-bed reactor as a special variant), and sodium-cooled reactors. The vertical grouping reflected the chronological sequence: proven reactors—advanced reactors—breeders. The model of a 237 MW(e) nuclear power station and its pressure vessel gave an idea of a so-called dual-cycle boiling-water reactor which is characterized by a comparably high efficiency and excellent controllability. This reactor is being built at Gundremmingen on the upper Danube and will supply electric power at a competitive price from 1966 onward. The core consisting of 368 fuel elements will contain 45 tons of uranium with a 2.17 per cent enrichment. The specific power thus amounts to 17.8 kW per kg of uranium.

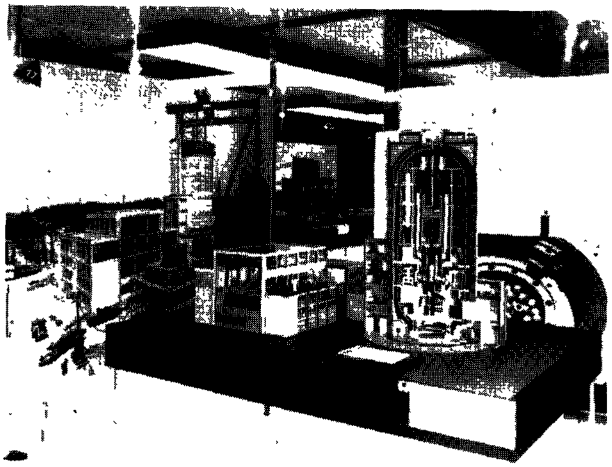
An example of an advanced light-water reactor was the integrated 25 MW(e) superheat reactor model evaporating the water at a pressure of 70 atm.



General view of the Federal Republic of Germany's stand

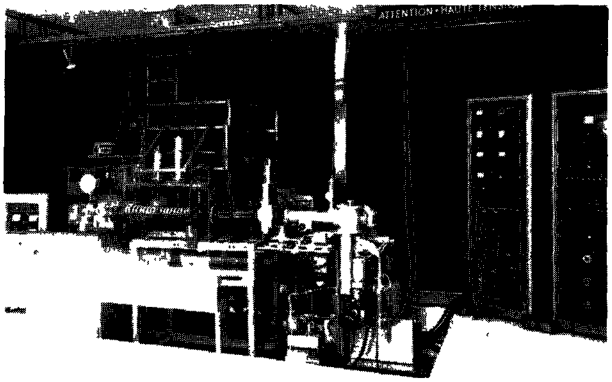


Model of the Gundremmingen Nuclear Power Station and 237 MW(e) boiling water reactor



Cutaway model of the 15 MW(e) pebble bed reactor

Part of the exhibit showing models of apparatus at the Karlsruhe Nuclear Research Centre



Travelling-wave plasma accelerator used in the Julich Fusion Research Programme abs. by means of combined boiling water-superheat fuel elements in a single pressure vessel. The active part of a superheat test element demonstrated the perfect alignment of the welded shell tubes, which make for a uniform coolant flow. The range of heavy water reactors was represented by two models, a 50 MW(e) pressure vessel reactor and a 100 MW(e) pressure-tube reactor. The former, a multipurpose reactor, is nearing completion at the Karlsruhe Nuclear Research Centre. The fuel elements consist of UO_2 pellets in Zircaloy cannings; the D_2O-cooled and moderated core, whose output is mainly controlled by adjusting moderator temperatures, contains 242 fuel elements. The 100 MW(e) pressure tube reactor will be operated in a prototype nuclear power station; it is planned to use a heavy-water moderated pressure-tube core and CO_2 as a coolant. Compared with the pressure vessel reactor, only the vertical tubes of this reactor, which contain the fuel elements and through which the cooling gas passes, are exposed to the operational pressure of some 60 atm. abs., whereas the large moderator tank sustains an internal pressure of only a few atmospheres. The cooling gas temperature is about 550 °C, so that steam may be generated under conditions similar to those in modern conventional power stations, i.e. 530 °C. at 105 atm. abs. The advanced pressurized water reactors include the marine reactor designed for the nuclear-powered merchant ship *Otto Hahn* which is under construction. The pressure vessel does not only contain the core but also the steam generator and the primary coolant circuit—as shown by a model from which a segment of 120° was cut to show the reactor and protection against collision. The 10 000 shaft horsepower turbines will propel the ship at over 15 knots. Designed for 500 days of full load operation, the core contains 2.95 tons of uranium with a 3.6 per cent enrichment.

A cut-away model of a 15 MW(e) experimental power station under construction at Jülich was displayed having a high-temperature reactor of the pebble-bed type, the fissile and/or fertile material of which is embedded in graphite spheres of 6 cm diameter. Core, steam generator and coolant gas blowers are all housed in a double-wall container. An original test stand demonstrated the refuelling, flow processes and the circulation of 80 000 spheres at a scale of 1:7.5 together with a preset course and evaluation. Another model showed how contaminated reactor components are removed by a handling machine.

Another 20 MW(e) experimental nuclear power station, now being designed, was represented by models of the sodium-cooled and zirconium-hydride moderated reactor, of an original-size fuel element with central and outer moderator portion, and of the complete power station. Important for fast breeder development, it will be set up near the Karlsruhe Nuclear Research Centre.

Also on show were samples of fuel and fuel elements, graphite and boron carbide shapes, a hot channel with fuel element of the 100 MW(e) pressure tube reactor, an experimental pressure vessel made of seamless forged rings and provided with electrical measurement equipment, two multi-layer pressure vessels on which rupture tests had been performed with a rupture pressure of more than 1 000 atm. gauge, a deep-dished base of 7 000 kg weight having a wall thickness of 13 cm including 6 mm high-quality steel plating and a diameter of 250 cm and, finally, tubes and pipes for circuit systems, heat exchangers and cannings made of chrome-nickel steels, Iconel and Hastelloy C.

Another section showed the development of fast breeder reactors at Karlsruhe. The construction of a 200 MW(e) prototype breeder will follow extensive neutron physics experiments with fast systems, which were illustrated by five models of the three assemblies: a flexible unmoderated and unreflected assembly of uranium in the form of a pulsed fast sub-critical experiment (SUAK), a "coupled" fast thermal reactor (STARK) and a fast zero power assembly (SNEAK) with plutonium as a fuel. Operational models of a fast scram rod for fast reactors, and of efficient neutron flash tubes represented further development under the fast breeder programme in association with Euratom and the American SEFOR Project—an example of international co-operation. Models of the European Transuranium Institute built at Karlsruhe as part of the Joint Euratom Research Centre were further examples. Research work in the field of nuclear physics at the Jülich Research Establishment was demonstrated by experimental models attached to the reactor FRJ-2 (type DIDO). Plasma physics activities were demonstrated by a travelling-wave plasma accelerator, shown in operation including its measurement equipment, and a model of the 600 kJ compression experiment and diagrams, etc., of some research projects of the Institute of Plasma Physics at Garching, near Munich. The Munich research reactor disposes of a particularly efficient low-temperature irradiation facility (4.5 °K) in its core, a model of which was exhibited. The Hahn Meitner Institute of Berlin had on display a device for the separation of isotopes by countercurrent ion electromigration in aqueous solution. As a counterpart to distillation in a column, a method of preparative crystallization in column for purification and separation was shown, rendering it possible, for example, to separate high-purity *p*-terphenyl used for reactor moderation from isometric compounds.

The third section was centred around the 0.1 W Siemens training reactor SUR-100, which was in operation combined with a pile oscillator for measuring absorption characteristics of materials. Another model illustrated a German design for research reactors, a 1 MW(th) tank-type reactor developed especially for measurement and calibration purposes.

Panels and actual equipment portrayed the use of radioisotopes in medical therapy and diagnostics; the labelling, transportation and dumping of sand into the sea by helicopter; and the control of seepage water at a dam by means of radiohydrometric tests. A gas-tight "master-slave" machine and a heavy-duty manipulator with a lifting capacity of 1 ton, together with the associated viewing equipment for work done in hot cells, were seen in operation. The possibility of processing metallic and ceramic fissionable material under a vacuum and in a defined atmosphere of protective gas, respectively, was demonstrated by melting and sintering furnaces. There was also equipment for assembling energy converters under exactly controllable conditions.

FRANCE

Le programme de la présentation française paraissait se définir logiquement à partir du thème essentiel de la Conférence: la mise au point des réacteurs destinés à la production d'électricité.

Il s'agissait de mettre en évidence l'étendue et la solidité de l'expérience acquise par la France qui, poursuivant son programme de construction de centrales nucléaires, développe ses connaissances et ses moyens dans les domaines les plus variés, et par conséquent de regrouper, à l'intérieur d'une même zone, les recherches effectuées et les appareillages mis au point pour l'étude de chaque type de réacteur.

En introduction figurait une reconstitution de la manipulation qui avait permis à Frédéric et Irène Joliot-Curie en 1934 de découvrir la radioactivité artificielle. A proximité immédiate, la mise en évidence de la réaction inverse, en utilisant un ensemble d'appareillages modernes, faisait ressortir l'importance des moyens utilisés pour une expérience analogue trente ans plus tard.

Les réacteurs, thème central de la présentation, étaient répartis entre les trois zones suivantes: réacteurs de recherche, réacteurs destinés à la production d'électricité, et RAPSODIE, réacteur expérimental régénérateur à neutrons rapides.

Autour de la maquette de SILOÉ, pile piscine entrée en service en 1963 au Centre de Grenoble, et destinée aussi bien à des recherches technologiques sur les matériaux irradiés qu'à des recherches fondamentales, étaient groupés différents dispositifs d'irradiation.

La présentation, à côté de PÉGASE, pile entrée en service en 1963 au Centre de Cadarache, d'éléments combustibles spéciaux destinés à être irradiés dans les boucles de ce réacteur, permettait de faire ressortir les facilités qu'il donne pour les essais de combustibles. Enfin, était exposée la maquette d'OSIRIS, pile expérimentale à hauts flux de neutrons, en cours de construction au Centre de Saclay.

A côté de ces réacteurs de recherche se trouvaient réunis différents appareils électroniques récemment mis au point et notamment du matériel entièrement transistorisé destiné au contrôle des réacteurs.

Les réacteurs de la filière uranium naturel-graphite-gaz occupaient la partie centrale de l'exposition. Tout d'abord était donnée une vue d'ensemble des centrales EDF, reproduites dans leurs sites de Chinon et de Saint-Laurent-des-Eaux. Le rapprochement des maquettes des caissons en béton précontraint d'EDF3 et d'EDF4 mettait ensuite en évidence, pour ce dernier réacteur, l'adoption des échangeurs incorporés. Enfin, une maquette d'ensemble d'EDF4, montrant notamment le mouvement de la machine de chargement, soulignait le développement des connaissances acquises dans la construction des réacteurs à uranium naturel. Cet effort constant de perfectionnement ressortait également de l'examen des différents modèles d'éléments combustibles, depuis ceux qui avaient été élaborés pour G2 jusqu'au projet d'élément combustible annulaire refroidi intérieurement et extérieurement.

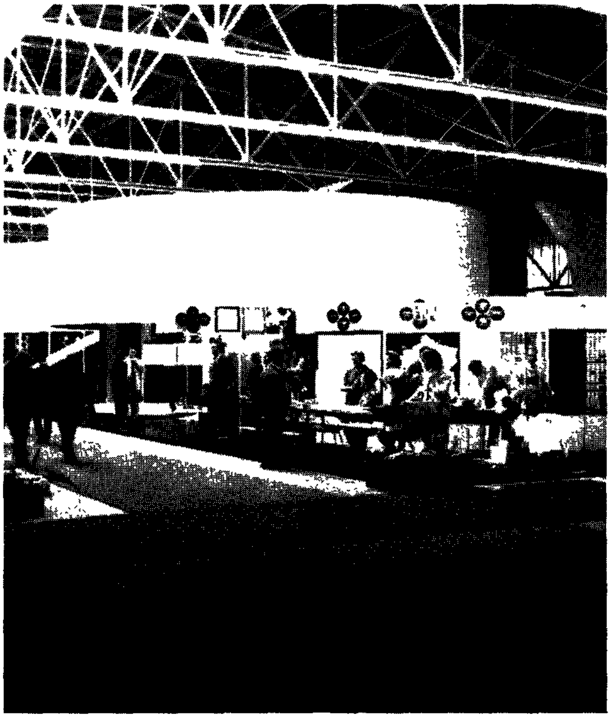
Autour de la maquette d'EL4, centrale nucléaire expérimentale en construction sur le site EDF des monts d'Arrée, la présentation des études effectuées sur le bioxyde et sur le carbure d'uranium, sur les modérateurs organiques, sur les éléments combustibles du premier jeu et sur les structures, permettait également de percevoir l'importance de l'expérience acquise à partir des travaux et des recherches en cours sur les réacteurs à eau lourde.

De même, dans le secteur consacré à RAPSODIE, pile expérimentale à neutrons rapides refroidie au sodium fondu, dont la construction s'effectue à Cadarache en association avec EURATOM, un aperçu était donné de l'ensemble des travaux déjà entrepris pour l'étude de cette filière: recherches sur les combustibles, mesures neutroniques par exemple.

Il convenait de rappeler, à cette occasion, que cette orientation de l'effort français vers la production, à partir des techniques actuellement dominées, d'électricité d'origine nucléaire ne faisait pas négliger pour autant des perspectives plus lointaines. Une maquette de TYPHÉE illustrait les études sur la conversion directe de l'énergie.

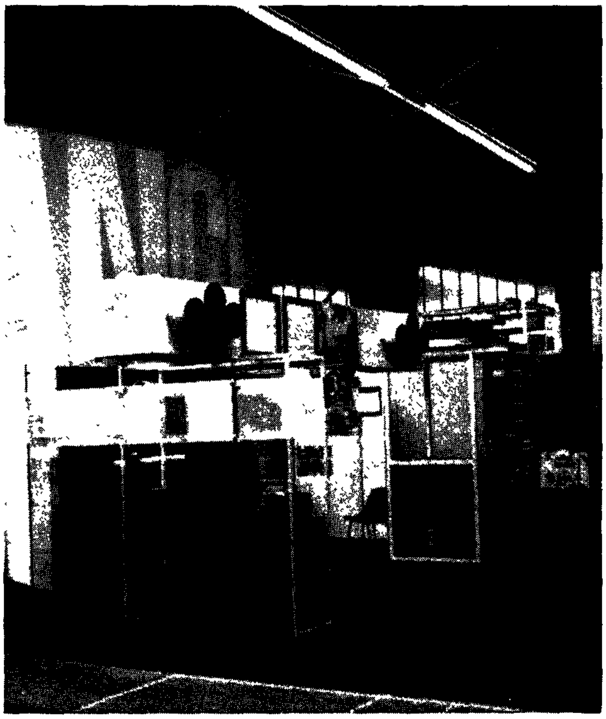
Enfin, la dernière partie de l'exposition était consacrée au traitement des combustibles irradiés et des produits de fission, au traitement de l'uranium enrichi et au traitement des effluents.

La présentation, destinée essentiellement à illustrer la participation française à la Conférence, poursuivait deux objectifs: offrir un témoignage concret des efforts poursuivis par la France dans le domaine de la production d'électricité d'origine nucléaire, établir ou approfondir les contacts avec les autres pays. Il semble bien que le matériel présenté constituait pour les ingénieurs français présents sur le stand de la France un support suffisant pour que ces deux buts aient pu être atteints.



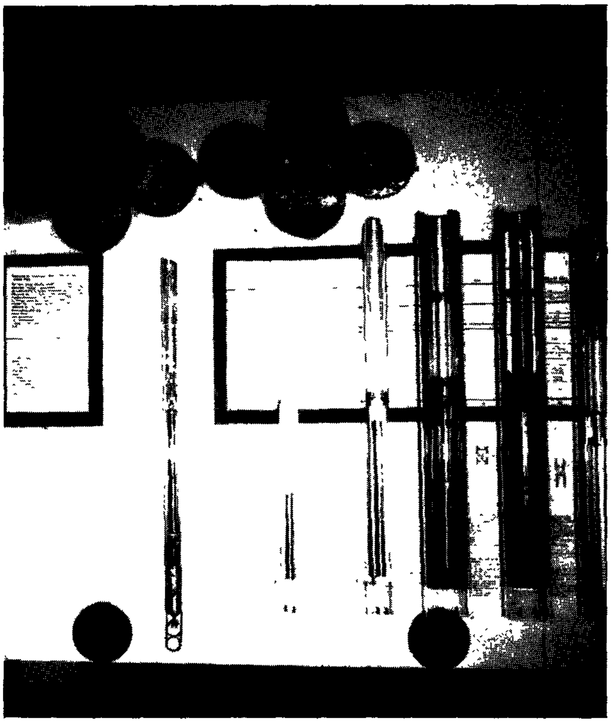
Vue d'ensemble du stand français. Au premier plan, le bureau d'information

General view of the French exhibit, with the information desk in the foreground



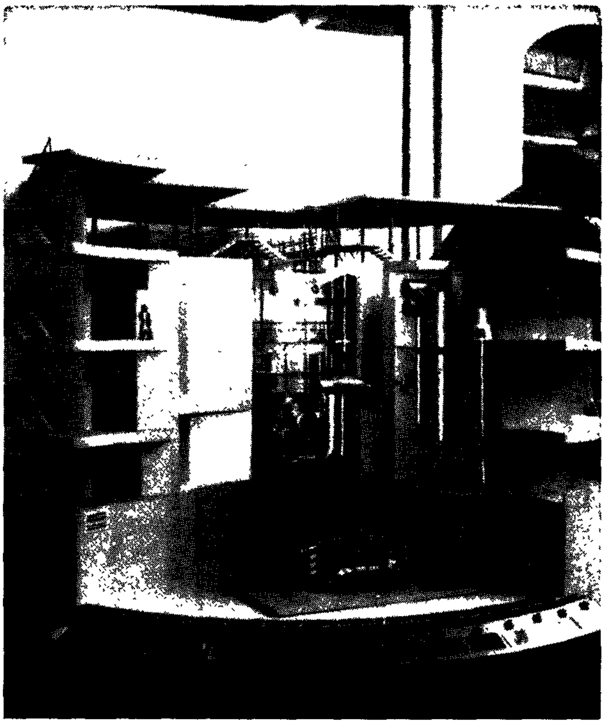
Reconstitution de l'expérience qui a permis en 1934 à Frédéric et Irène Joliot-Curie de découvrir la radioactivité artificielle

Reconstruction of the experiment which led Frédéric and Irène Joliot-Curie to the discovery of artificial radio-activity in 1934



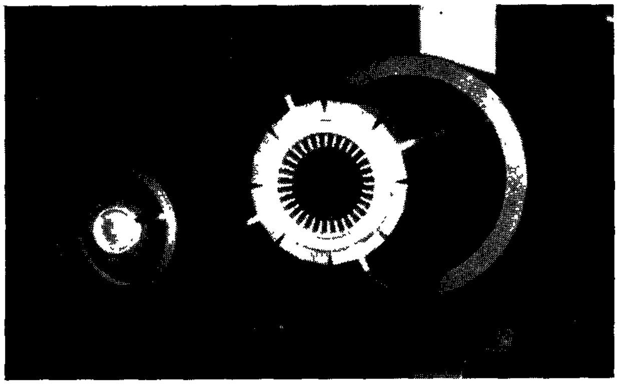
Evolution des éléments combustibles de la série uranium naturel-graphite-gaz

Development of fuel elements of the natural uranium-graphite-gas type



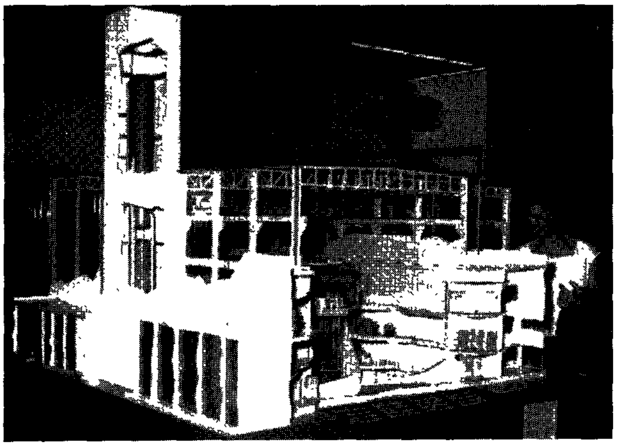
Maquette de la pile OSIRIS en construction au Centre de Saclay

Model of the OSIRIS reactor undergoing construction at the Saclay Centre



Chemises en graphite pour éléments combustibles types EDF3 et annulaire

Graphite sleeves for the EDF3 and annular types of fuel elements



Maquette du réacteur PÉGASE *entré en service en* 1963 *au* Centre de Cadarache

Model of the PÉGASE reactor, in operation at the Cadarache Centre since 1963

Maquette des caissons en béton précontraint des réacteurs EDF3 et EDF4

Models of the pre-stressed concrete pressure vessels for the EDF3 and EDF4 reactors

Translation

FRANCE

The French exhibit appeared to be logically based on the main theme of the Third International Conference on the Peaceful Uses of Atomic Energy —namely, the development of reactors for the generation of electric power.

Its purpose was to demonstrate the range and depth of the experience gained by France, which, in carrying out its programme of nuclear power plant construction, is extending its knowledge and capabilities in the most widely varying fields. It therefore set out to bring together, in a single section, the research undertaken and the equipment developed for the study of each type of reactor.

The first exhibit was a reconstruction of the experiment which led to the discovery of artificial radio-activity by Frédéric and Irène Joliot-Curie in 1934. Immediately beside it, the demonstration of the reverse reaction with the use of modern apparatus brought out the scale of the equipment used for a similar experiment thirty years later.

Reactors, which formed the central feature of the display, were divided into three main groups: research reactors, power reactors and RAPSODIE, an experimental fast neutron breeder reactor.

The model of SILOÉ, the "swimming pool" reactor which came into operation in 1963 at the Grenoble Centre and which is intended both for technological research on irradiated materials and basic research, was surrounded by a display of various irradiation devices.

Special fuel elements were shown in conjunction with the model of PÉGASE, the reactor which came into operation in 1963 at the Cadarache Centre. These elements, which were designed for irradiation in the loops of this reactor, demonstrated the facilities which it offers for fuel tests. Lastly, there was a model of OSIRIS, the experimental high-flux neutron reactor now under construction at the Saclay Centre.

Next to these models of research reactors was a display of various items of electronic equipment that have recently been developed, including completely transistorized equipment for reactor control.

The central part of the exhibit was occupied by gas cooled, graphite moderated, natural uranium reactors. First, a general view was given of the EDF nuclear power stations at Chinon and Saint-Laurent-des-Eaux. Juxtaposed models of the pre-stressed concrete vessels of the EDF3 and EDF4 power stations demonstrated the adoption of incorporated heat exchangers for the latter reactor. Lastly, a general model of EDF4, illustrating, *inter alia*, the operation of the loading mechanism, demonstrated the growth of scientific knowledge in the construction of natural uranium reactors. This constant effort at improvement was also illustrated by the different types of fuel elements, from those developed for the G2 reactor to the design for an annular fuel element cooled internally and externally.

The valuable experience gained from current work and research on heavy water reactors was similarly illustrated by the studies displayed around the model of EL4, the experimental nuclear power station now under construction at the Electricité de France site in the Arrée hills. These studies related to uranium dioxide and uranium carbide, organic moderators, fuel elements for first loading, and structures.

The section devoted to RAPSODIE, the experimental fast neutron sodium cooled reactor now being constructed at Cadarache in association with EURATOM, also provided an over-all view of the work already undertaken in connexion with the study of this type of reactor: research on fuels, neutron measurements, etc.

It should be noted that, although the main emphasis of the exhibit was on the French effort to produce electricity from nuclear sources by means of already known techniques, attention was also given to future developments. Studies on the direct conversion of energy were illustrated by a model of TYPHÉE.

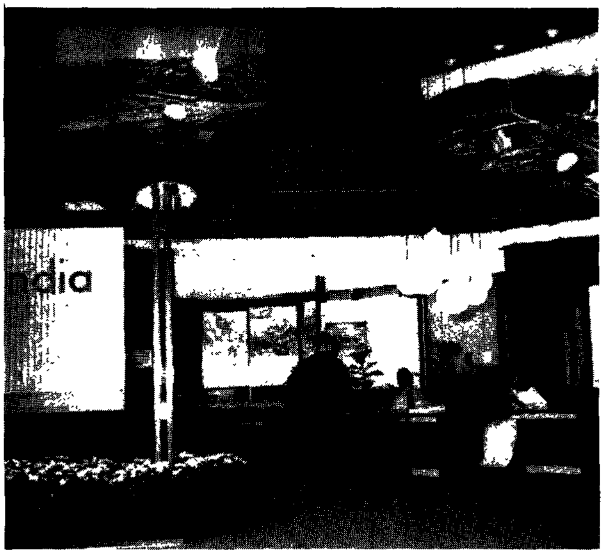
The last section of the exhibit dealt with the treatment of irradiated fuels and fission products, as well as of enriched uranium and effluents.

The exhibit, which was mainly intended to illustrate the part played by France in the Conference, had two main objectives—to provide concrete evidence of the work being done by France in the field of nuclear power generation, and to establish or strengthen contacts with other countries. The equipment on display certainly provided the French engineers at the stand with sufficient material to achieve these two objectives.

INDIA

The Indian Pavilion covered an area of 300 m^2. The exhibits consisted of photographs, electronic instruments, sections of various types of fuel elements, charts and maps, and they were directly related to the scientific papers submitted to the Conference.

One panel of photographs showed the fabrication of UO_2 fuel elements. On display also was a 19-rod cluster type fuel element for ZERLINA (UO_2 canned in aluminium), a cutaway section of test fuel elements (UO_2 canned in Zircaloy), a section of the fuel elements used in CIR and ZERLINA, a section of thorium metal and thorium oxide sintered pellets in different sizes and shapes. Another panel described the deposition of, and corrosion on, the aluminium cladding of CIR fuel rods. Other photographic panels illustrated papers entitled "Release of fission gases in reactor coolants under normal operation", "Utilization of reactors CIR and APSARA for studies in nuclear physics and for isotope production", and scientific papers relating to the heavy water plant at Nangal and the plutonium plant at Trombay. Another panel showed the north site of the Atomic Energy Establishment at Trombay, and the Canada-India reactor.



A general view of the Indian stand

Another view of the Indian stand

Electronic equipment and instruments were also on display, designed and fabricated at the Atomic Energy Establishment, Trombay, which were used for experimental assemblies in connexion with papers on the utilization of research reactors at Trombay, gamma energy release rates from fission products shortly after fission, and the ratio determination of U^{235} and U^{238} in uranium samples. Some of these electronic instruments are in current use in the plutonium plant at Trombay. Beneficial mutations showing the higher yield obtained at the

Trombay Establishment with the application of radiations on rice and peanuts were also illustrated.

Important features of the scientific papers dealing with atomic power were depicted by:

(*a*) A table showing the cost of nuclear power as compared to the cost of delivering power from local coal fuel stations, pit head coal stations + EHV transmission and oil stations in Bombay, Delhi, Kotah (Rajasthan) and Madras regions;

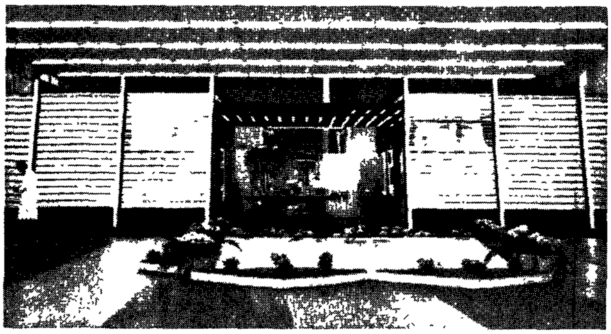
(*b*) A map of India showing principal hydro resources, coal fields, hydro, thermal and nuclear stations and transmission lines.

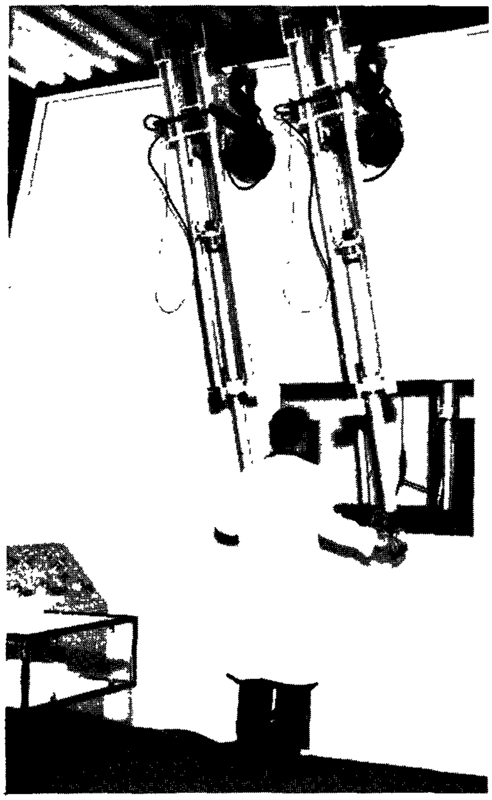
ITALY

The Italian pavilion was organized by the Italian National Committee for Nuclear Energy (CNEN) in partnership with the Italian State Agency for Electricity (ENEI) and some prominent firms in the field of industry and electronics. The major feature of the Italian stand was an apparatus known as MASCOT-1, a transistorized, remotely-handled manipulator consisting basically of two units, one called the Master, providing housing and operator, and the other the Slave, performing the movements and linked to the Master by electrical transmission. MASCOT-1, a prototype built at the CNEN laboratories of the Nuclear Study Centre of Casaccia, near Rome, is being improved for application to a MASCOT-type standard equipment.

Prototypes of natural uranium fuel elements for gas reactor cores produced in the CNEN laboratories were also exhibited, together with several types of equipment for the automatic control of reactors. These facilities are transistorized units forming part of an extensive programme of study on the development of reactor control systems. CNEN also displayed operational equipment for the catalytic reduction of uranyl nitrate into tetravalent uranium nitrate, developed and built by the Industrial Chemistry Division at Casaccia.

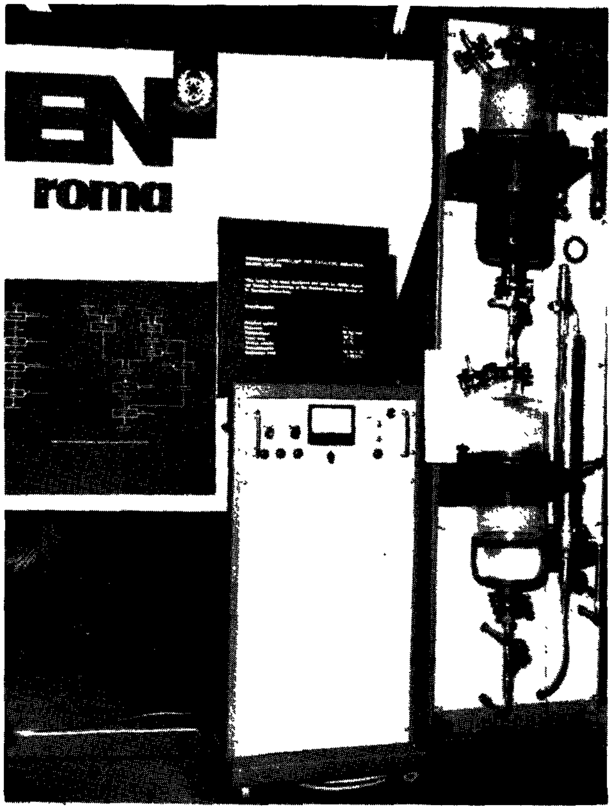
A plant for the re-processing of irradiated thorium fuels and for the refabrication of new fuels was also on view. This plant, now under construction at Rotondella, in southern Italy, showed a pellet-



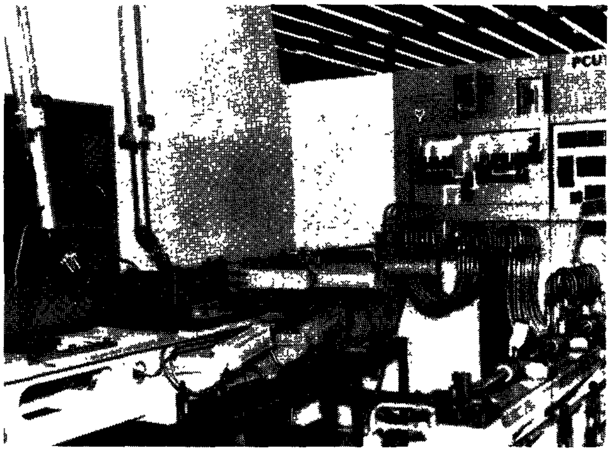


An assembly of hot cell manipulators in operation

The Italian "MASCOT-1" remote control manipulator



Catalytic reduction of uranium nitrate apparatus



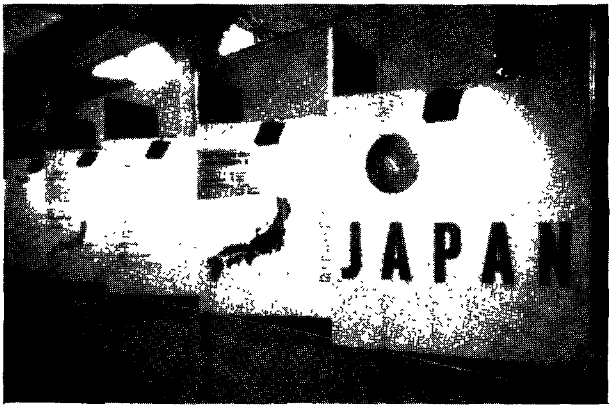
Uranium-Thorium Cycle Programme PCUT fuel assembly and pellet loading machines

loading machine and a fuel element assembly machine designed and built in Italy, and operated throughout the Exhibition. These operations are remotely controlled on account of the high degree of radioactivity involved in the process.

In the industrial nuclear energy section, a prototype of fuel elements for pressurized water reactors and a prototype of control mechanisms for control rods of an organic moderated reactor envisaging working temperatures of up to 320 °C and pressures up to 30 kgf/cm^2 were exhibited. This section included a display of commercially produced nuclear spectrometry instruments, one exhibit being an analyser with 4 096 channels possessing a simultaneous measurement and printing capability, while another electronic device shown was a new CP-1B automatic sample switcher for low background gamma spectrometry. ENEI's chief contribution to the Italian exhibit consisted of panels giving details of the three Italian nuclear power stations.

JAPAN

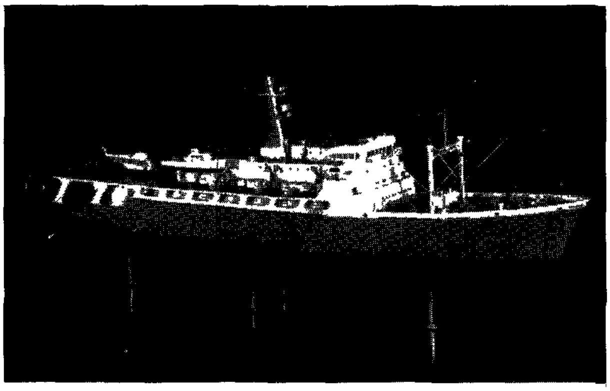
The Japanese exhibit was divided into three parts, designed to illustrate the general aspects of research and development of atomic energy in Japan. One series of pictorial panels illustrated the main establishments, including fifteen reactors, shown on a map of Japan; the structure of the research and development organization, shown on a chart which indicated the central role played by the Japan Atomic Energy Research Institute (JAERI), the Atomic Fuel Corporation (AFC) and the Japan Nuclear Ship Development Agency (JNSA) in atomic energy research and development, and in which a number of universities, national research institutes, atomic industrial groups and power concerns, together with nine electric power companies, are also co-operating. Another panel showed the uranium resources of Japan and the production and refinement of nuclear materials carried out by the AFC. The fourth introduced the building schedule of the first nuclear ship (the basic design of which was completed by JNSA) and the training programme of its crew. The last panel of this group showed the activities of the Japan Atomic Industrial Forum (JAIF) which was established to promote atomic industries and is made up of some 700 private enterprises.



Pictorial panels of the Japanese exhibit

Another group of six panels on the other side of the stand showed the contribution made by industrial firms to the development of atomic energy in Japan.

Aerial view of the Tokai Atomic Energy Centre



Model of Japan's first nuclear ship

The back of the stand was taken up with an aerial view of the Tokai Atomic Energy Centre, a colour picture indicating that half the reactors in Japan are concentrated in this area, together with the many research and service facilities concerned.

In the middle of the stand, colour films were displayed by means of a fluorescent projector and portrayed the activities of the National Institute of Radiological Sciences, the Institute of Plasma Physics, the Radiation Breeding Laboratory gamma-field, the Takasaki Establishment of JAERI (radiation chemistry centre) and the latter's first Japanese made reactor. Other films showed the work of the central laboratories of five major atomic industrial groups.

At the entrance to the exhibit a model (scale 1 : 100) of the first Japanese nuclear ship was set up. This nuclear powered vessel is an oceanographic survey ship of about 6 700 tons and has a light-water reactor with a power output of 35 MW.

NETHERLANDS

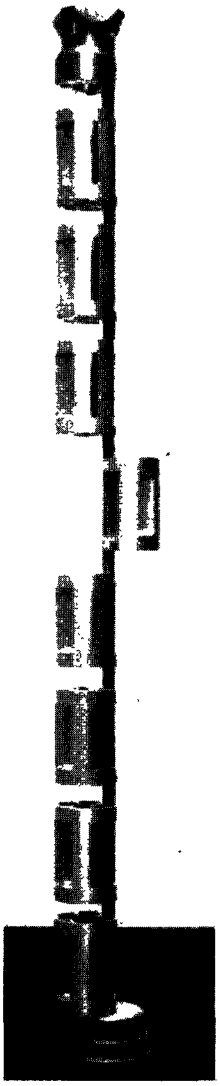
The Netherlands Exhibit occupied an area of just over 400 m^2 and gave an up-to-date general view of the nation's nuclear research and development programme. Fields of interest included plasma physics, mass separation, a pilot plant for the production of fuel particles, hydrodynamic experiments in boiling water loops, neutron irradiation experiments, activation analysis, nuclear science in agriculture, the NERO ship propulsion project and scientific equipment manufactured by the Dutch nuclear industry. The entrance to the stand depicted the theme "Energy and research in the Netherlands", the country in which windmills have for centuries been the main source of energy to keep its low-lying land dry and inhabitable.

A working alternating pinch device contributed by the FOM Institute for Plasma Physics demonstrated progress made in obtaining conditions of stability in a plasma confined by means of well-programmed magnetic fields. The same institute showed a model of an experiment in which high temperature hydrogen plasma is created by injection of H^+ ions with an energy of 10 keV into a strong 20 kilogauss cusp-shaped magnetic field. Instabilities and particle loss are being examined. A panel diagram showed the working of the isotope separator installed at the Institute for Nuclear Research (IKO) in Amsterdam. The instrument is used in the preparation of radio-active beta and gamma ray spectroscopy.

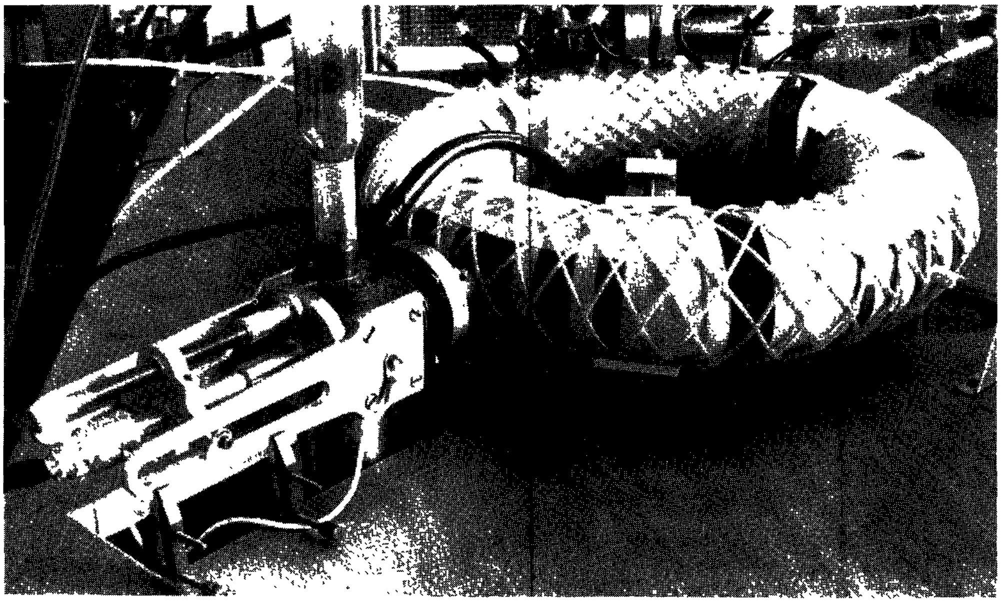
A pilot plant working on the Sol-Gel process produced ThO_2-UO_2 spherical fuel particles with a diameter of 5 μ. Fuel particles of this size are used in the KEMA aqueous homogeneous suspension reactor in Arnhem, but particles of a diameter in the millimeter range can be made if required. A glass model (at atmospheric pressure) of an experimental high pressure boiling water loop adequately equipped for measuring pressure, flow-rate, void fraction and temperatures demonstrated hydraulic instabilities occurring at applied high-heat fluxes. These instabilities are the subject of heat transfer studies at the Technological University of Eindhoven. A panel showed a cross-section drawing of the actual 40-atmosphere test loop complete with detecting, recording and signal analysing equipment.

The 20 MW High Flux Reactor, of which a model was exhibited, is owned by the European Atomic Energy Community (Euratom) and forms part of its research establishment at Petten. The reactor is operated by the Netherlands nuclear energy organization, Reactor Centrum Nederland (RCN), and used jointly by Euratom and RCN. Both parties co-operate with other organizations in the execution of nuclear physics experiments and irradiation experiments on fissile and non-fissile materials. With the help of cutaway models, Reactor Centrum Nederland demonstrated these experiments with fissile and non-fissile materials which are either packed in capsules or inserted in in-pile loops. Models to scale of out-of-pile auxiliary equipment were shown as well as an actual radioisotope production facility. A model of the crystal structure of

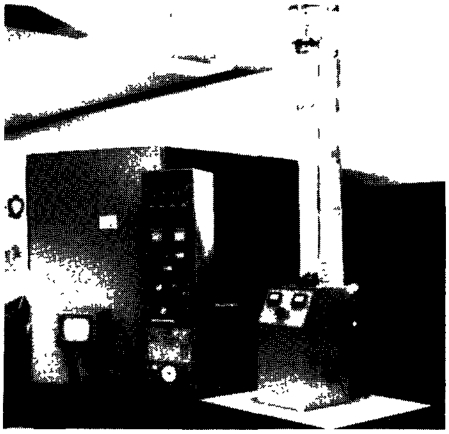
A general view of the Netherlands exhibit



A Netherlands radio-isotope production aid for insertion in a reflector element



Alternating pinch device from the FOM Institute for Plasma Physics



Glass loop used in Dutch hydrodynamic and heat transfer experiments

A section of the Netherlands pilot plant for the production of ThO_2-UO_2 fuel particles for the KEMA aqueous homogeneous suspension reactor

U_3O_8 based on results obtained from neutron diffraction experiments was also to be seen.

Other panels showed a method of non-destructive determination of the material composition of ancient and valuable objects by means of activation analysis with 26-MeV deuterons from the cyclotron of the Institute for Nuclear Research in Amsterdam, and the neutron activation analysis of white lead found in the white pigment of authentic old master paintings. From this analysis, carried out by the Reactor Institute in Delft, it was found that the impurity composition present in white lead changed through the ages.

The Institute for Atomic Sciences in Agriculture (ITAL) at Wageningen exhibited a model of their biological agricultural reactor. This 100-kW swimming-pool type reactor was designed by Reactor Centrum Nederland and constructed by the Netherlands nuclear industry. The thermal neutron flux (1 m above floor level) in the irradiation room situated below the reactor was measured and found to be 5.10^6 n/cm^2 s. A show-case with coloured photographs illustrated the original control sample and mutants of the African violet after X-ray irradiation of the leaf petioles with 4 000 roentgens.

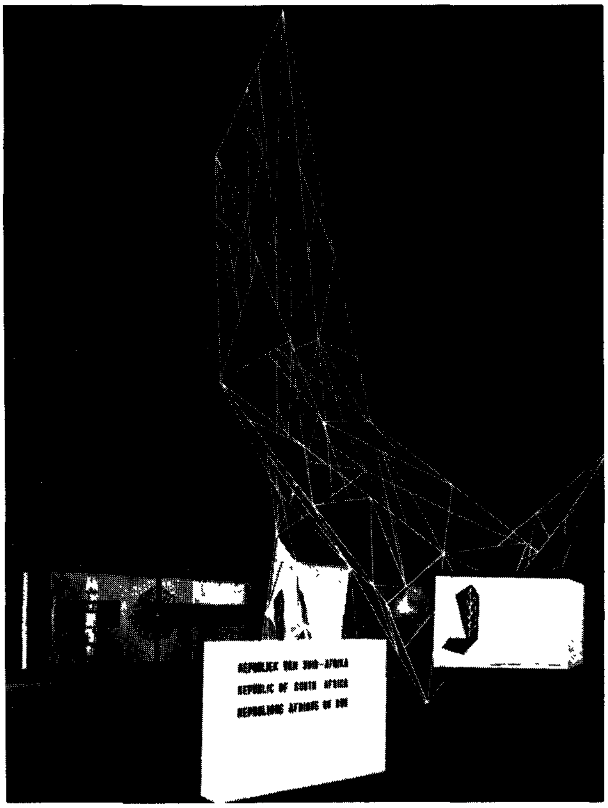
The Netherlands nuclear ship propulsion development programme NERO was presented against a background panel of the Amsterdam harbour in the seventeenth century, symbol of a traditionally seafaring nation. A large plastic model of the complete 67-MW reactor installation occupied a central position. Further exhibits pertaining to the development programme consisted of the actual test section of the 150-atmosphere 300 °C high-pressure water loop for studying hydrodynamic behaviour and heat transfer, a model of a complete fuel assembly, together with models showing power distributions in these assemblies as measured in the critical facility KRITO at the Petten research centre. In addition there was a full-scale ejector, one of the 36 to be located round the reactor core, a novelty in the re-circulation system. An automatic welding chamber, used in connexion with welding research for this programme, demonstrated the welding of end caps on fuel canning tubes. The NERO development programme is a Reactor Centrum Nederland project carried out in association with Euratom. The Technological Universities of Delft and Eindhoven and Dutch nuclear industry also participate.

All scientific equipment exhibited was of Dutch manufacture and included automatic sample changers, scalers, a transistorized spectrum stabilizer, a proportional counter for counting tritium in the gaseous phase, and a neutron generator tube for the production of 14-MeV neutrons from the DT-reaction. A large 60 cm long and 2 m wide tuning fork mounted on a revolving platform drew much attention. This instrument was developed in the Netherlands in co-operation with CERN in Geneva. It forms a variable capacitor, vibrating at 55 c/s, modulating the carrier frequency of the CERN synchrocyclotron. A model of a cyclotron symbolized the fact that complete units are now available in the Netherlands, manufactured on a factory basis. Another interesting model of the nuclear steam generators used in the SENN reactor near Naples gave an indication of Dutch contribution abroad.

SOUTH AFRICA

The exhibit mounted by the Republic of South Africa occupied a total surface area of some 130 m^2 and was designed in the modern idiom to symbolize the progress of a virile young country in the field of nuclear energy. This theme was presented by a central lattice-work spire, 12.5 m high, constructed of tubular aluminium and sheets of glass fibre on which was mounted the emblem of the South African Atomic Energy Board.

Enclosing the exhibit on three sides were the display boxes, faced externally with ivory coloured plastic mouldings representing in stylized form the fusion process and the application of nuclear energy to medicine, agriculture, industry and in fundamental research. Facing inwards were graphic illustrations of the uranium mining industry, the growth of the national nuclear research centre at Pelindaba, and the activities undertaken there including research



A general view of the Republic of South Africa stand in the fields of power-reactor engineering, chemistry, physics and metallurgy.

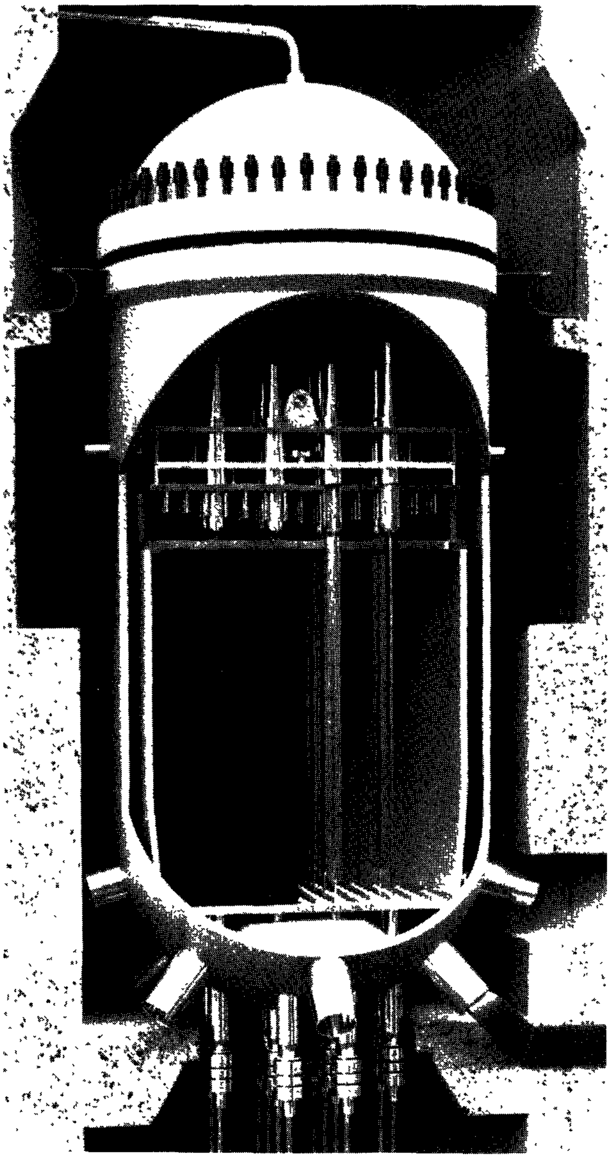
Two examples of significant advances in the fields of extraction metallurgy and radioisotopes pioneered by South African scientists occupied a third of the total display space and proved a source of considerable interest to visitors. The former consisted of an animated flow diagram of the recently-developed process for the production of nuclear-grade uranium compounds direct from the ore at little or no additional cost, corresponding to the pilot plant currently operating at the Buffelsfontein gold mine in the Transvaal. The second—also a flow diagram—provided an outline of a low cost ion selective extraction process for the extraction of radio-active caesium from fission product wastes for use as a radiation source. The method and the exchange resin used resulted from a collaborative effort between a South African scientist and the staff at AERE, Harwell.

SWEDEN

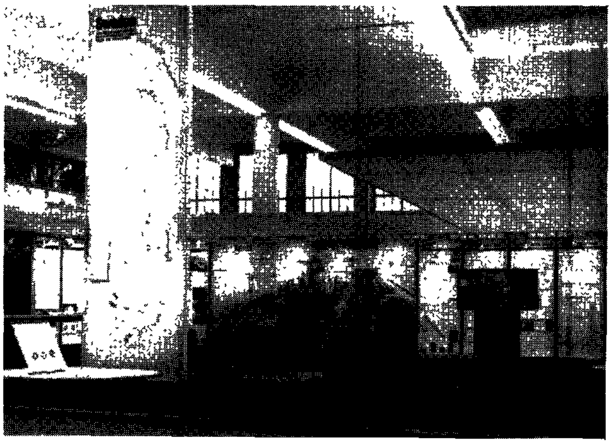
Under the heading "Swedish Heavy Water Reactors", the Swedish stand of over 200 m^2 portrayed the Swedish power supply system, with recent studies related to the potential development of various power sources during the coming decades, in the form of power reactors, reactor fuels and nuclear research. The exhibits were in the main linked to the Swedish conference reports, and were divided into six different sections.

The first consisted of a map of Sweden illustrating the system of power distribution and giving the information that (*a*) 95% of Sweden's electricity is based on hydroelectric power, produced mainly in the north of the country, with a *per capita* consumption of 5 300 kWh per annum; (*b*) there are no domestic sources of fossil fuels; and (*c*) the total energy consumption increases by about 3% *per annum*, and electricity consumption by about 6%. Diagrams showed the main results of a study made in 1962 of potential Swedish electrical power production in the 1970s. Of an estimated power production total of some 20 000 MW in 1980, nuclear power is expected to contribute 4 000 MW.

The second section contained coloured photographic representations of the Agesta Nuclear Power Station, which has been in operation since July 1963, including details of its building, commissioning and operation, with special reference to pressure vessel manufacture, leakage testing of pipe joints on site, welding and inspection of heat exchanger tubing, control rods with hydraulic drives (portrayed by a cutaway control rod), fuel handling, control equipment, three phases of reactor physics (start-up and low-power experiments, experimental equipment, and long-term experiments), and the tightness of D$_2$O systems.



A cut-away model of the pressurized heavy water reactor



A general view of the Swedish exhibit

The Marviken Nuclear Power Station (Sweden's second), a 140/200 MW boiling heavy water reactor now under construction, formed the third sector containing a reactor mock-up, scale 1 : 25, with a flow diagram as its background. The highlights of this presentation were heavy water in a direct cycle turbine plant, natural circulation, on-load refuelling, fuel cycle (showing sections of a fuel assembly), nuclear superheat, pressure suppression and pressure vessel design.

The fourth sector was devoted to a study of the Pressurized Heavy Water Reactor (PHWR), a 350-MW project which has been placed on the international market at a fixed price by a Swedish industrial firm. It consisted of a reactor mock-up similar in scale and background to the Marviken. It dealt chiefly with core heat transfer, moderator exchange and film cooling, plant control, core design (with sections of fuel assembly, disclosed), and the development potential.

Sector V dealt with reactor fuels, and demonstrated the Swedish production of UO_2 powder, the manufacture of UO_2 pellets, and the fuel assemblies for the Agesta Nuclear Power Station, together with section specimens of all three.

The last section of the exhibit described facilities possessed by the Studsvik research establishment, and some typical experiments such as the materials testing and research reactor R2, shielding research, heat engineering, reactor physics, fast neutron physics, hot chemistry, thermo-luminescence dosimeter, the butyl rubber suit and, finally, the research reactor R1 which has been in operation for ten years.

SWITZERLAND

Displayed in an area of some 300 m^2, a selection of about 50 objects or subjects, which have been developed or studied by official research institutions or industrial firms, presented a short survey of most of the activities undertaken in Switzerland, either to support the national reactor development programme or the construction of foreign power reactor prototypes, and generally to help research in the nuclear sciences. The underlying intention was to show that Switzerland possesses the industrial background necessary to establish itself in world competition in the nuclear field. A detailed description of the exhibits on the Swiss stand can be found in *New techniques*, 6, No. B4, 1964.

The Swiss reactor development programme centers around the development of heavy water moderated pressure tube reactor systems, cooled either with gas or light water steam. It includes the construction of an underground experimental power plant with CO_2 cooling, situated at Lucens (north of Lausanne), which will start operating in 1966 with a power of 7 MW(e) and which will serve as a technological demonstration of the reactor concept and for the testing of several types of fuel elements; and the implementation of a programme of experimental and theoretical studies with the aim of establishing a basis for the selection of the most interesting variant for the construction of a prototype.

Reactor research was mainly represented by the Swiss Federal Institute for Reactor Research (EIR), Würenlingen, which disposes of a swimming-pool research reactor (SAPHIR), a heavy water moderated research and material testing reactor (DIORIT), a sub-critical heavy water moderated installation (MINOR), and a hot laboratory. The Institute, which assumes a major role in the neutronic and technological research required by the reactor development programme and helps private industry to establish power reactor projects, showed the following amongst its exhibits:

The in-pile loop KASIMIR, which will be used in DIORIT for fuel testing in reactor operating conditions;

The contribution to the DRAGON fuel irradiation programme in the reactor DIORIT;

A neutron time of flight installation for an energy range below 10 eV and some typical results;

A gamma spectrometer with absolute gain stabilisation of a factor of about 1 000;

A gamma-compensated ionisation chamber with dynamic and variable compensation;

A remotely controlled and hydraulicly operated manipulator for underwater handling of fuel elements and irradiation rigs;

A remotely controlled high precision lathe, and a multi-purpose tensile strength testing machine used in the hot cells of the Institute.

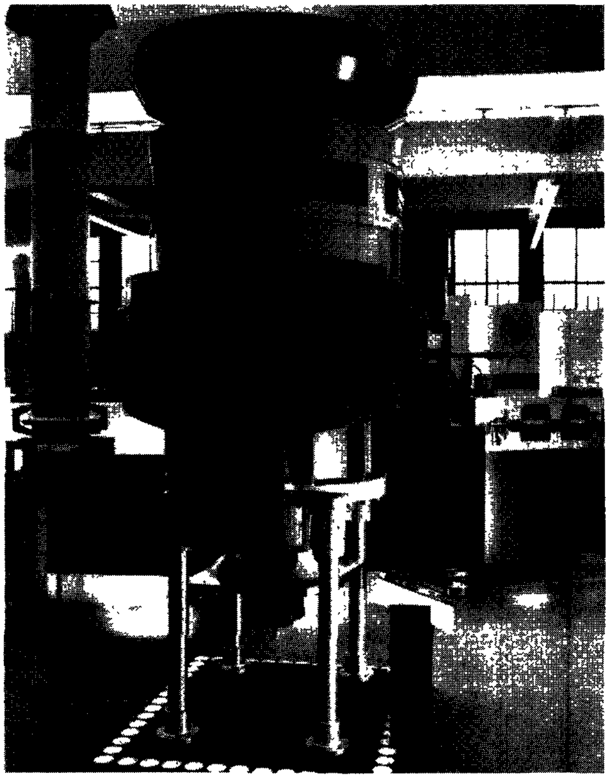
Private industry contributed to the sector on research with a hermetically sealed helium blower designed for the in-pile loop mentioned in the preceding paragraph, advances in electron beam welding of Zircaloy for reactor pressure tubes, an electron beam welding plant, and a vacuum melting furnace for laboratory work. The Nuclear Engineering Laboratory of the Ecole polytechnique, University of Lausanne also contributed to this sector by showing an entirely selfmade, very flexible suspension of the fuel rods for its light water critical assembly, allowing two continuous degrees of freedom for the rods.

The construction of the experimental power station at Lucens was undertaken two years ago by the National Society for the Promotion of Industrial Atomic Techniques, a private organization grouping interested Swiss firms. This project constitutes the first step of an industrial programme which should result in the near future in starting the operation of large nuclear power plants in Switzerland. Among the equipment developed for the Lucens station, and exhibited by the National Society, were shown a complete fuel element with its connecting head to the fixed pipe system, a control rod with drive,

A remotely controlled, high-precision, multi-purpose tensile strength testing machine and other exhibits

More Swiss exhibits, including a rack of the in-pile loop KASIMIR and related hermetically sealed helium blower

Plans showing the experimental power station and containment at Lucens and other equipment



More apparatus for the Lucens Experimental Power Station

Various specimens of laboratory equipment

A corner of the stand devoted to developments in electronic equipment

Exhibits in the field of ionizing radiations one of two main heavy water moderator circulation pumps which do not require shaft seals, a fuel transfer flask and a charge machine, one of the two CO_2-blowers developed for the primary coolant circuit, and a special system of cavern containment. Besides its own reactor programme, Swiss industry was given the opportunity to show some of the components it has developed either for power reactor prototypes or research centers, especially abroad, such as one of two blowers provided for the pebble-bed reactor in Jülich, Germany, the charge-discharge machine built for the DRAGON reactor at Winfrith, England, a D_2O-rectifying column, and a process for the economical production of heavy water.

The detection and utilisation of ionising radiations constitute a very dynamic field of development in the electronic industries of Switzerland and the Principality of Liechtenstein. A great variety of electronic instruments were shown, illustrating the achievements attained in the dosimetry of radiations and in the field of basic nuclear research. New developments in ion sources, accelerator tubes, irradiation cells and special nuclear monitors for medical purposes, and the control of dust and fire were also illustrated.

In the field of plasma research, the Plasma Physics Research Laboratory was set up in Lausanne after the second PUAE Conference as a result of the great interest stimulated by this Conference in Swiss scientific circles. This laboratory showed photographs of some of the apparatuses developed and some results obtained by heating and stabilising plasmas by means of high-frequency electromagnetic fields. Private interests also displayed specimens of new ancillary components such as an ultra-high vacuum pumping unit, a cycloid mass spectrometer for vacuum systems and circuits for special magnets.

In the domain of uranium survey, the Committee for the investigation of nuclear fuel and rare elements in Switzerland, at Berne, illustrated on a map, and by photographs, the results of the systematic research and radiometric survey of uranium mineralization which have been carried out during the past few years. Average U-contents, from some hundreds up to a thousand ppm, have been found in some of the samples. No large scale prospecting work entailing digging, mining and drilling has as yet been carried out, so that the economic value of the U-mineralization so revealed remains unknown.

Finally, a section of the display, organised by the Library of the Federal Institute of Technology, was devoted to the methods of dissemination of information employed in Switzerland in the field of nuclear techniques and sciences. The Swiss Association for Atomic Energy in Berne, in collaboration with the Delegate of the Federal Council for Atomic Energy Matters, displayed their handbook on Atomic Energy and Radiation Protection in Switzerland.

СОЮЗ СОВЕТСКИХ СОЦИАЛИСТИЧЕСКИХ РЕСПУБЛИК

Выставка Советского Союза отражала достижения советских ученых и инженеров в области мирного использования атомной энергии. На выставке, размещенной на площади более 1000 *м*², демонстрировались оживленные модели атомных электростанций транспортных и транспортабельных атомных энергетических установок, установок для термоядерных исследований, а также две действующие термоядерные установки и электронные приборы, применяемые в различных областях науки и техники. Большое количество фотографий, диаграмм и графиков, отражавших работу и характеристики действующих атомных установок, являлись основой для обсуждения вопросов, интересовавших специалистов разных стран. Экспонаты выставки иллюстрировали и дополняли доклады советских ученых на конференции. В специальном кинозале на выставке демонстрировались 24 научных кинофильма, подготовленных к конференции Государственным комитетом по использованию атомной энергии. На выставке были организованы консультации советских ученых и инженеров и встречи их с делегатами других стран.

Выставка включала следующие основные разделы: (1) атомная энергетика; (2) исследовательские ядерные реакторы; (3) термоядерные исследования; (4) применение атомной энергии в различных областях науки и техники.

В центре выставки был установлен 6-метровый макет ледокола «Ленин», который завершал осенью 1964 года свою пятую навигацию, пройдя более 100.000 миль в тяжелых условиях Арктики. Макет позволял видеть принципиальную схему атомной энергетической установки мощностью 44.000 л. с., фотографии и специальная киноустановка показывали ледокол и его экипаж в плавании.

Макет Белоярской атомной электростанции имени И. В. Курчатова демонстрировался с целью показать устройство и принцип работы первой в мире атомной электростанции с ядерным перегревом пара, 1-й блок которой мощностью 100 *Мвт* дает энергию с весны 1964 года. Полномасштабные макеты верхней крышки реактора, графитовых блоков и рабочего канала давали наглядное представление об их размерах и конструкции. Этот комплекс макетов и фотографии вызывали большой интерес у специалистов.

Макет Нововоронежской атомной электростанции в масштабе 1 : 25 позволял понять работу станции и взаимодействие ее узлов. Реактор первого блока этой станции достиг критичности и станция вводилась в строй.

В Советском Союзе ведется широкий фронт работ по созданию атомных электростанций с реакторами на быстрых нейтронах с расширен-

Общий вид стенда СССР

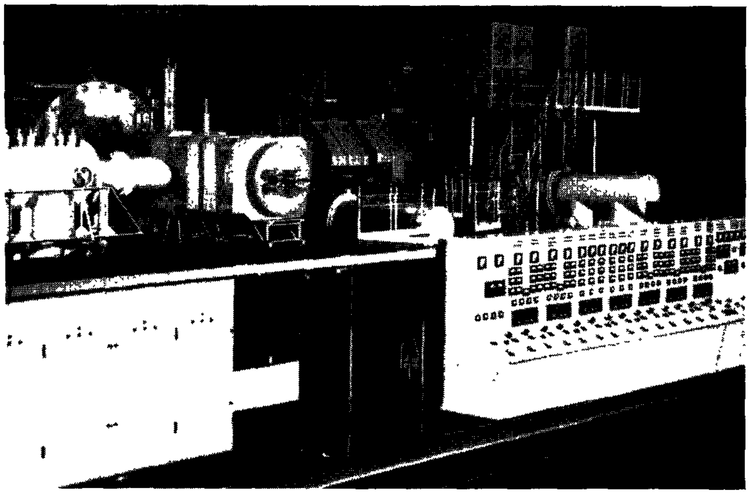
General view of the USSR stand

Модель транспортабельной атомной энергетической установки ТЭС-3 на советской выставке

Model of the TES-3 mobile atomic power plant

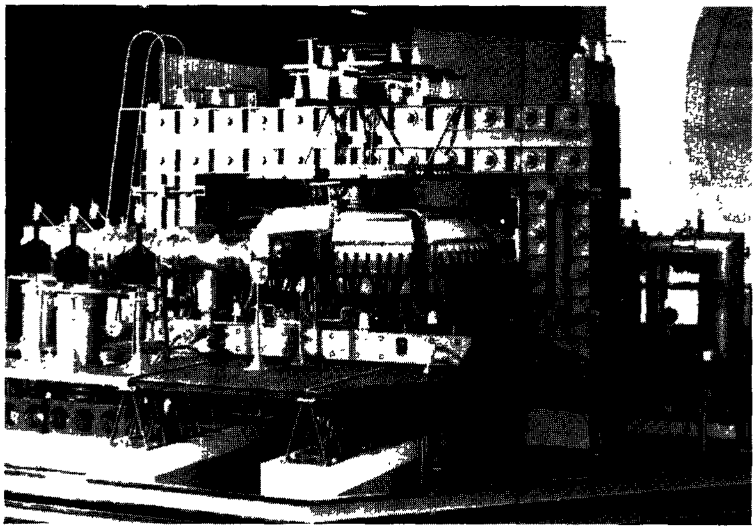
Советская термоядерная установка УН-3

The USSR thermonuclear installation UN-3



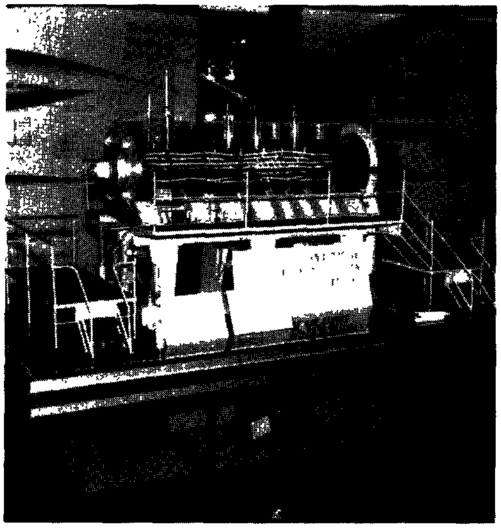
Модель советской термоядерной установки «Огра-II»

A model of the Soviet Ogra-II thermonuclear installation



Другая термоядерная установка «Токамак-3»

Another thermonuclear machine—the Tokamak-3



Модель термоядерной установки ПР-5

A model of the PR-5 thermonuclear machine ным воспроизводством горючего. Эти работы были представлены макетом проекта реактора БН-1000 мощностью 1000 *Мвт.*

Работы в области «малой энергетики» были отражены двумя транспортабельными блочными энергетическими установками — ТЭС-3 и АРБУС. Атомная энергетическая установка на гусеничном ходу электрической мощностью 1500 *квт* работает в Советском Союзе более трех лет. Макет установки включал все 4 блока станции — реакторный, парогенераторный, турбинный и пультовый. Оживленная модель со специальной подсветкой макета реактора с водой под давлением, контуров, парогенератора и турбины позволяла понять принцип конструкции и работы установки. Модель установки АРБУС с реактором, имевшим органический замедлитель и теплоноситель электрической мощностью 750 *квт,* иллюстрировала работу по использованию органики в атомной энергетике.

Большой интерес у посетителей выставки вызвали макет и фотографии первого в мире реактора «Ромашка» для прямого преобразования атомной энергии в электрическую. Работы советских ученых и инженеров над прямым преобразованием энергии получили на конференции высокую оценку. Большой раздел выставки был посвящен исследовательским ядерным реакторам. На выставке были представлены макеты действующих и строящихся реакторов различной мощности и разного назначения — СМ-2, МР, МИР, ИР-100, ИБР, ИГР и др.

Исследовательский реактор с промежуточным спектром нейтронов СМ-2 с самым большим в мире потоком тепловых нейтронов ($3{,}0 \cdot 10^{15}$ *нейтр/см*^{2} *· сек)* длительное время работает в Советском Союзе. Макет реактора позволял видеть цикл перегрузки горючего, а также постановку и извлечение облучаемых образцов. Макеты реакторов МР и ИР-100 давали наглядное представление о работе этих установок. Макет строящегося мощного петлевого реактора МИР показывал постановку и извлечение одной из петель для испытания тепловыделяющих элементов для реакторов различных типов и конструкций.

Особый тип исследовательских реакторов представляют импульсные реакторы. На выставке демонстрировался макет импульсного графитового реактора ИГР. Данные об этом реакторе с потоком нейтронов в импульсе до 10^{18} *нейтр/см*^{2} *· сек* и мгновенной мощностью 10 млн. *квт* с температурой в центре реактора до 2500° С впервые были сообщены на конференции. Макет позволял наглядно показать порядок подъема кладки активной зоны и извлечения стержней из нее. Другой импульсный реактор на быстрых нейтронах ИБР длительное время эксплуатируется в Объединенном институте ядерных исследований в Дубне и используется для широкого круга научных исследований. Механизированный макет установки, графики и фотографии иллюстрировали работу реактора.

Хотя термоядерные исследования не были главной темой конференции, на стендах СССР, учитывая широкий размах этих работ, были представлены макеты действующих установок для термоядерных исследований «Огра», ПР-5, АС-1, «Токамак-3», «Дельта» и др., а также две действующие установки УН-3 и ЛН.

Новым этапом изучения термоядерного синтеза явились исследования на установке ПР-5 с комбинированным магнитным полем. На этой установке впервые в мире в 1963 году было достигнуто весьма длительное удержание плазмы ($\sim 0{,}06$ *сек*). Это направление получило всемирное признание.

В действующей установке УН-3, в которой впервые используется новый способ ударного нагрева плазмы, посетителям демонстрировалась плазма, нагретая до 100 миллионов градусов.

Оживленные макеты установки АС-1, «Токамак-3» и др. наглядно показывали работу советских ученых в направлении овладения неисчерпаемой энергией термоядерного синтеза. Многочисленные фотографии и графики разъясняли принципы работы и характеристики экспериментальных установок.

На выставке демонстрировались электронные приборы и установки, применяемые в ядерных исследованиях, в технике, в сельском хозяйстве и медицине. Внимание делегатов конференции привлек 16 000-канальный анализатор импульсов, который после окончания выставки был направлен в Объединенный институт ядерных исследований.

В качестве примера работ по применению изотопов в различных областях науки и техники на выставке были показаны макеты установок для радиотерапии, для облучения пищевых продуктов, а также фотографии, иллюстрирующие работы в этих направлениях.

На выставке демонстрировались также периодическая таблица элементов, включающая элемент 104, открытый в Объединенном институте ядерных исследований (Дубна) в 1964 году, и диаграмма систематики β-активных ядер, которая была предложена советскими учеными.

На выставке можно было познакомиться с научными монографиями по вопросам применения атомной энергии в мирных целях, изданными в последние годы в Советском Союзе.

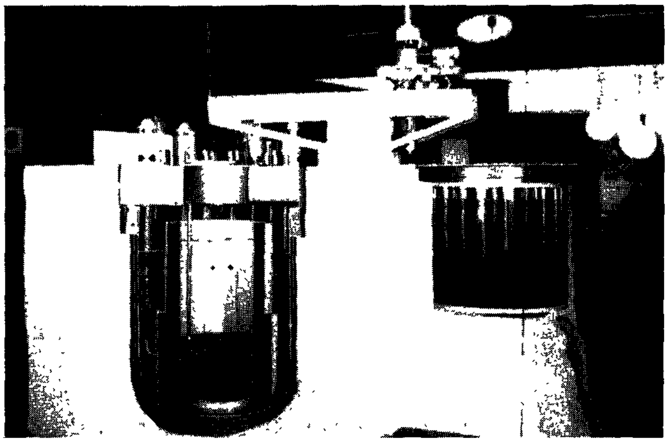
Посетителям выставки раздавалась специальная брошюра на четырех рабочих языках конференции. Она отражала основное содержание выставки и давала посетителям дополнительный иллюстрированный материал по работам советских ученых.

Один из экспонатов выставки СССР — блочная атомная энергетическая установка АРБУС

One of the Soviet exhibits—the Arbus package atomic plant

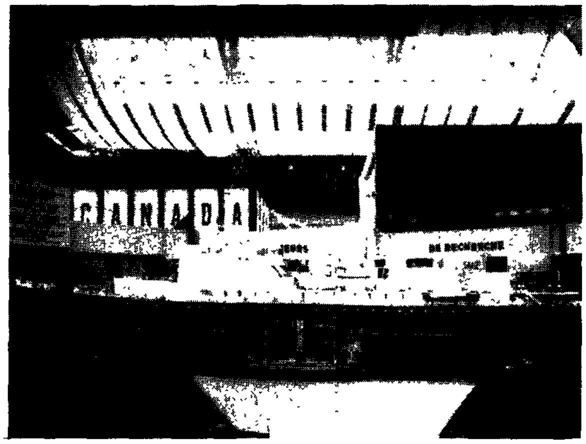
Реактор типа «Ромашка» для прямого преобразования атомной энергии в электрическую

A direct-conversion reactor of the Romoshka type



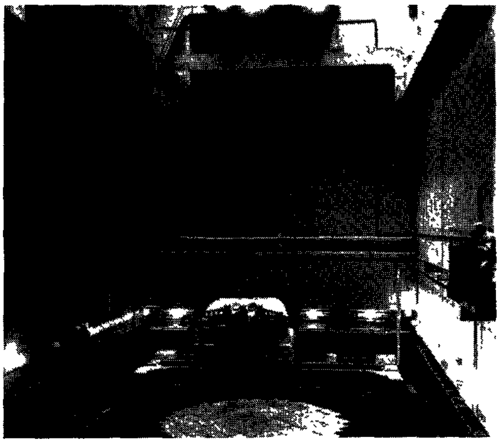
БН-1000 — один из советских реакторов на быстрых нейтронах

One of the USSR fast reactors—the BN-1000



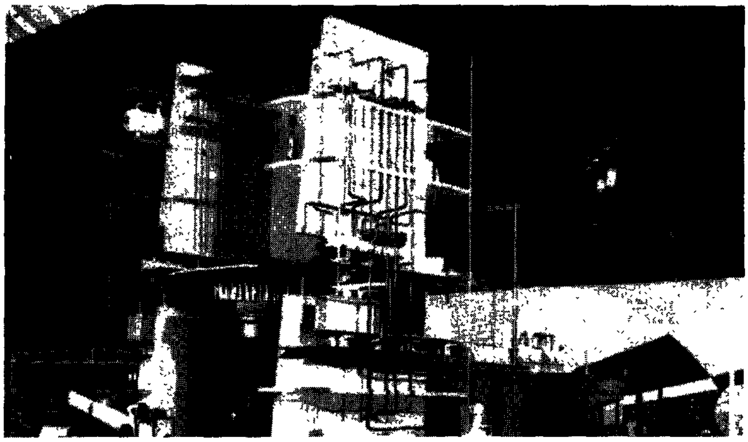
Модель атомного ледокола «Ленин» в масштабе 1 : 25

A model of the atomic-powered ice-breaker *Lenin*



Реактор Белоярской атомной электростанции имени И. В. Курчатова

Working face of the reactor at the I. V. Kurchatov atomic power station at Byeloyarsk



Модель уран-графитового реактора в Белоярске

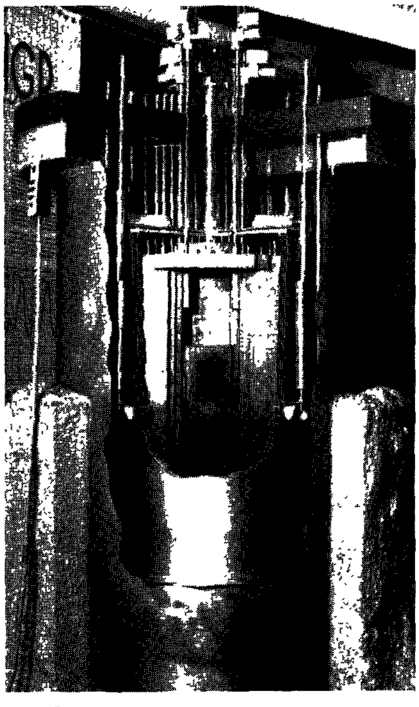
Model of the uranium-graphite reactor at Byeloyarsk

Модель исследовательского реактора ИР-100, демонстрировавшаяся на выставке СССР

An IR-100 research reactor model

Исследовательский реактор типа МИР

An MIR type of research reactor model

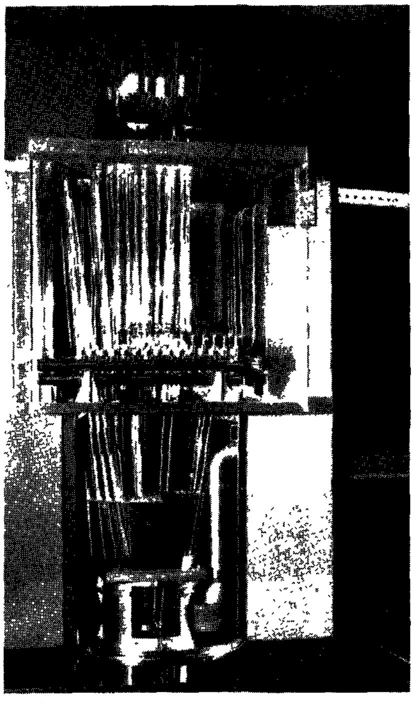


Модель исследовательского реактора ИГР

Model of an IGR research reactor

Модель исследовательского реактора СМ-2

Model of an SM-2 type research reactor



Модель исследовательского реактора МР

Model of an MR type research reactor

Translation

UNION OF SOVIET SOCIALIST REPUBLICS

The exhibit of the Union of Soviet Socialist Republics reflected the achievements of Soviet scientists and engineers in the field of the peaceful uses of atomic energy. On it were displayed, over an area of more than 1 000 m^2, working models of atomic power plants, power plants for transport prime movers and mobile power plants, and machines for thermonuclear fusion studies, together with two operating thermonuclear machines and electronic equipment used in various branches of science and technology. A large number of photographs, diagrams and drawings, illustrating the operation and characteristics of atomic power plants already in service, provided a basis for the discussion of problems of interest to specialists from many countries. The exhibits displayed illustrated and supplemented the papers submitted to the Conference by Soviet scientists. Twenty-four scientific documentary films, produced for screening at the Conference by the State Committee for the Utilization of Atomic Energy were shown in a special cinema on the USSR stand. Consultations of Soviet scientists and engineers were organized at the Exhibition, as were also meetings between them and delegates from other countries.

The exhibit comprised the following main sections: (1) atomic power plants; (2) research reactors; (3) thermonuclear fusion studies; and (4) applications of atomic energy in different scientific and technological fields.

In the centre of the exhibit was a 6 m model of the ice-breaker *Lenin*, which in 1964 completed its fifth cruise, having then steamed more than 100 000 miles under severe Arctic conditions. From the model it was possible to see the main features of the design of the vessel's 44 000-HP atomic power plant. Photographs and films were also on display, showing the ice-breaker and its crew at sea.

A model of the Byeloyarsk atomic power station named after I. V. Kurchatov was displayed, illustrating the construction and working principles of the first atomic power station in the world with nuclear superheat, the first 100-MW(th) unit of which has been delivering power since the spring of 1964. A full-scale model of the upper cover of the reactor vessel, of the graphite blocks and of the working channels gave a graphic idea of their dimensions and design. This group of models and photographs aroused great interest among the specialists attending the Conference.

A 1 : 25-scale model of the Novovoronezh atomic power station enabled the operation of the station and the interaction of its various components to be easily understood. The reactor of the first unit of this station has already gone critical and the station has been brought into service.

In the Soviet Union, the construction of fast reactors for power stations with enhanced breeding of the fuel is being developed on a broad front. This work was illustrated by a model of a projected 1 000-MW(th) reactor of the BN-1 000 type.

Work in the field of "micro" power plants was illustrated by two mobile, package power installations, the TES-3 and the Arbus. A 1 500-kW(th) atomic power plant mounted on caterpillars has been operating in the Soviet Union for more than three years. A model of the plant contained all four components: the reactor unit, the steam-raising unit, the turbine unit and the control panel. A working model with a specially-illuminated cross section of the pressure-water reactor, the working channel, the steam plant and the turbine room brought out the underlying principles of the design and operation of the plant. A model of the Arbus plant with an organic-moderated reactor and a capacity of 750 kW(th) illustrated work on the use of organic compounds in the atomic energy field.

The model and photographs of the Romashka reactor, the first in the world for direct conversion of nuclear energy into electricity aroused great interest among visitors to the Exhibition. The work being done by Soviet scientists and engineers on the direct conversion of power won high praise at the Conference.

A large part of the exhibit was devoted to research reactors. Models were shown of reactors already in operation or under construction and of different capacities and various types: the SM-2, the MR, the MIR, the IR-100, the IBR, the IGR and others.

The SM-2 research reactor with intermediate neutron spectrum and the highest thermal neutron flux in the world (3.0×10^{15} n/cm^2 s) has already been operating for a long time in the Soviet Union. A model of the reactor made it possible to follow the fuel-charging cycle, and the installation and procedure for the removal of irradiated samples. Models of the MR and IR-100 reactors gave a graphic idea of the operation of these installations. A model of the powerful MIR loop reactor, at present under construction, showed the installation as a whole and the withdrawal of one of the loops used for testing fuel elements for reactors of various types and designs.

Pulsed reactors are a special type of research reactor. A model of the IGR graphite pulsed reactor was displayed at the USSR exhibit. Data on this reactor which has a pulsed neutron flux of up to 10^{18} n/cm^2 s, an instantaneous capacity of 10^6kW and a temperature of 2 500 °C at the centre of the core, was disclosed for the first time at the Conference. The model enabled the procedure for raising the cover of the active zone and removing the core from it to be followed. A second pulsed reactor using fast neutrons, the IBR, has been in operation for some time past at the Joint Institute for Nuclear Research at Dubna, where it is used for a wide range of scientific experiments. The work of this reactor was illustrated by a working model, graphs, charts and photographs.

Although thermonuclear fusion studies were not the main theme of the Conference, the USSR, appreciating the vast extent of such work, showed on its stand models of machines, already in use for fusion studies, of the following types: Ogra, PR-5, AS-1, Tokamak-3, Delta and others; UN-3 and LN machines, also already operating, were similarly displayed.

A new stage in the study of thermonuclear fusion has been embarked upon with the introduction of the PR-5 machine with combined magnetic field. With this machine, the plasma was sustained for quite a long time ($\approx$ 0.06 second), for the first time anywhere, in 1963. This achievement received world-wide acclamation.

In the UN-3 machine, in which the new method of shock heating of the plasma is being used for the first time, visitors to the Exhibition were shown plasma heated up to 100 000 000 degrees.

Working models of the AS-1, Tokomak-3 and other machines vividly illustrated the work of Soviet scientists towards mastery of the inexhaustible source of energy represented by thermonuclear fusion. Numerous photographs and drawings explained the working principles and characteristics of these machines.

Electronic equipment and apparatus, used in nuclear experiments, as well as in technology, agriculture and medicine, were shown on the USSR exhibit. A 16 000-channel impulse analyser, intended for use at the Joint Institute for Nuclear Research after the exhibition closed, attracted the attention of participants in the Conference.

To illustrate the work being done on the use of radioisotopes in various branches of science and technology, models were shown on the Soviet stand of apparatus for radiotherapy and for irradiating foodstuffs, as well as photographs illustrating work being undertaken in these directions.

A periodic table of the elements, including element 104, discovered at the Joint Institute for Nuclear Research at Dubna in 1964, and a diagram showing the arrangement of β-active nuclides, presented by Soviet scientists, were also on display.

Scientific papers on the problems of the peaceful uses of atomic energy, published in the Soviet Union in recent years, were available on the USSR stand. Visitors were also provided with a special brochure in the four working languages of the Conference. This described the basic content of the exhibit, and gave visitors additional information about the work of Soviet scientists.

UNITED KINGDOM

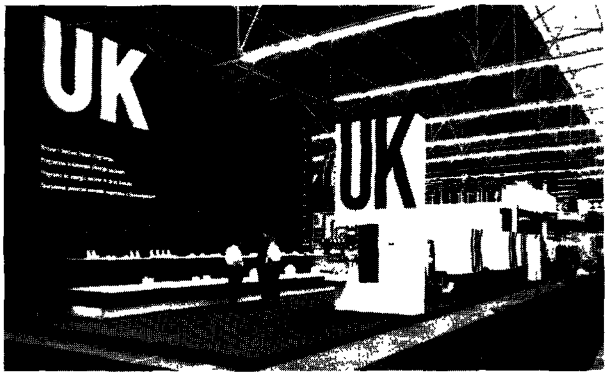
The United Kingdom exhibit covered an area of 8 000 ft^2 and presented an integrated picture of scientific and engineering developments associated with Britain's large and varied programme of nuclear power development.

The exhibits were designed to merit the attention of an audience of high scientific calibre, i.e., the delegates to the conference, and to represent the wide variety of organizations whose combined efforts have contributed to the dynamism of the British programme of research and development in the nuclear field, including the United Kingdom Atomic Energy Authority, the Central Electricity Generating Board, British industrial firms, research associations and universities.

The 150 individual exhibits were divided into five main sections: Nuclear Power Programme, Nuclear Power Reactors, Nuclear Fuels, Research, and Miscellaneous. The central feature of a "bridge" and "catwalk" eased the work of day-to-day operation and lent the stand an air of individuality without overburdening it with decorative detail. To assist enquiry and possible "follow-up" liaison between the United Kingdom and other countries, the stand included a library of unclassified reports and other publications including two produced specifically for the occasion, "Nuclear Energy Research in the United Kingdom" and "Reactors UK", the latter containing parameters, cut-away diagrams and photographs of all UK reactors in operation or under construction.

The opening feature of the Power Programme section of the exhibit was a graph, 30 ft by 60 ft, outlining the output of electricity generated in Britain's nuclear power programme. Supported by a line of models of every reactor (power, experimental or research) operating or under construction, this feature provided a graphic illustration of some statistics mentioned by the leader of the UK delegation during the conference: "We have the biggest nuclear power programme in the world—some 5 000 MW(e) of magnox reactors commissioned or under construction; and a planning programme of at least 5 000 MW(e) for commissioning during the period 1970-1975. We have already produced over 15 000 GWh of electricity from nuclear fission." Data for each power station were then given separately close-by, along with a typical example of appropriate research and development work associated with its development. The main design features were outlined for the magnox reactors in the UK power programme, namely:

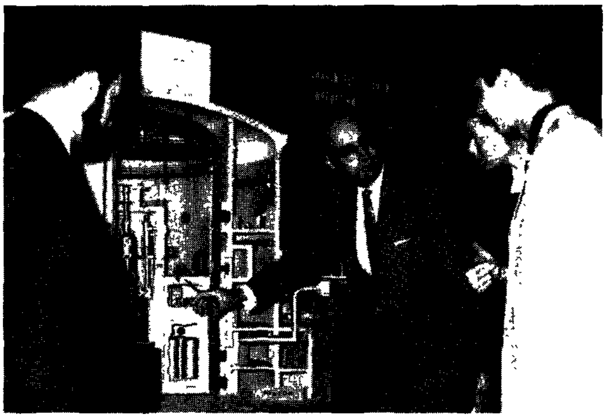
Calder Hall
Chapelcross
Berkeley
Bradwell
Hunterston
Hinkley Point
Trawsfynydd
Dungeness
Sizewell
Oldbury
Wylfa



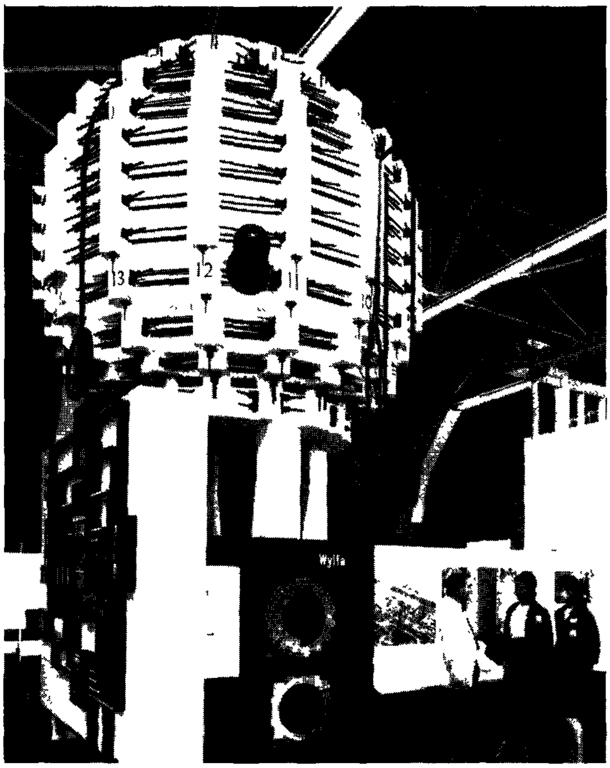
A general view of the UK stand

Models of Britain's nuclear power stations arranged in order of operating date, and research experimental reactors

A model of the UK steam generating heavy water reactor simulator



Part of the UK DRAGON exhibit



A 1 : 12 scale model of a Wylfa concrete pressure vessel

Visitors examining the working of a half-inch scale Dimple reactor model and also of the two British designed power stations built overseas, Latina (Italy) and Tokai Mura (Japan). Operational data and experience were given for the appropriate power stations Calder Hall, Chapelcross, Berkeley, Bradwell, Hunterston and Latina. A major feature of this section of the stand was a one-twelfth scale model of one of the prestressed concrete pressure vessels for the Wylfa power station in Wales; it was supported by details of background research on prestressed concrete for this project.

The Nuclear Power Reactors section on the systems built or building, and of more advanced concept than the magnox (power programme) examples, was divided under four reactor types: advanced gas-cooled reactor; fast reactors; steam generating heavy-water reactor; and high temperature gas-cooled reactor.

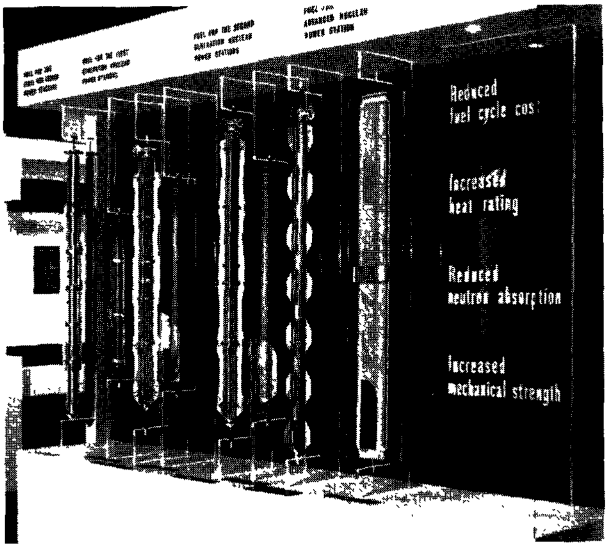
The first comprised an exhibit of an operating reactor model simulating the behaviour of the AGR; full details of reactor physics results for the AGR and similar work for sub-assemblies; and the HERO reactor in which various actual and possible core configurations have been studied. Extensive data on reactor flux, fuel and moderator temperatures and electricity generation were outlined for the AGR, which had by that time been working without trouble for eighteen months. Models showed experimental work and facilities proceeding in the AGR and also early ideas on what fully commercial and larger AGR power stations would look like.

The second typified the five fast reactors which Britain has built to date, one of which is the most powerful in the world. Operating and experimental results for the 60 MW Dounreay Fast Reactor were explained in relation both to its function as a power producer of electricity, and also as the world's most powerful fast reactor test-bed for various types of fuel. Background work was illustrated on fast reactor physics and nuclear spectra, and also on engineering research (for instance in sodium nucleate boiling) pertinent to larger commercial fast reactors currently being designed. There was a detailed model of the DFR and a sectioned fuel element on display.

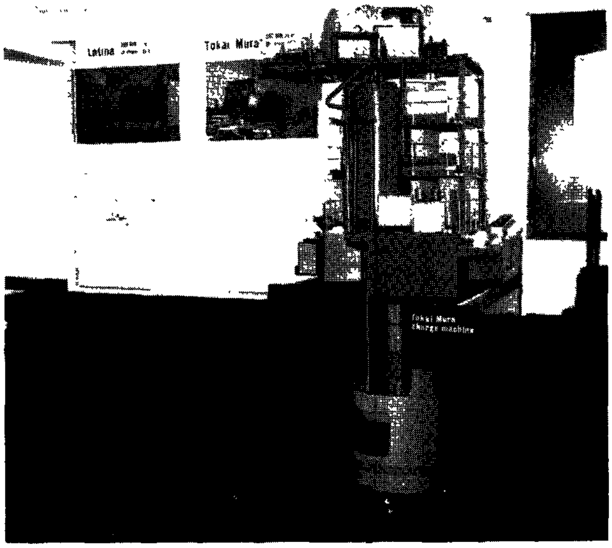
The steam generating heavy-water reactor section began with a new working model, with a four-language commentary, of the SGHWR now being built at Winfrith in Dorset, and then showed some of the corrosion development work, on zirconium and steel alloy components, which has been done in England. There was a very detailed section on the theory and experimental results obtained at Harwell and Winfrith on two phase heat-transfer of particular significance to water moderated power reactors —including a working Freon rig demonstration of the various modes of heat transfer and boiling, simulating water behaviour in a reactor. Several types of large steel/zirconium joints were displayed and also a complete zirconium superheater tube with superior internal finish. Reactor physics of water reactor systems were illustrated by results and also a half-scale working model of the DIMPLE reactor at Winfrith. This demonstrated a novel fast dump system and also a new, simple fuel assembly, allowing easy accurate changes to be made in fuel lattice arrays.

The fourth section outlined the DRAGON reactor and was submitted by the European Nuclear Energy Agency. The DRAGON reactor, which went critical just before the conference, is sited at Winfrith in Dorset, and is a high temperature gas-cooled reactor designed, built and operated as a co-operative European project. Exhibits in this section outlined the various international organizations involved in manufacturing the DRAGON fuel elements, and in irradiation testing engineering components in various reactor loops throughout Europe. Other features were a gas circulator after 1 400 hours use, supported on gas bearings, and a model of the main entry valve for the reactor.

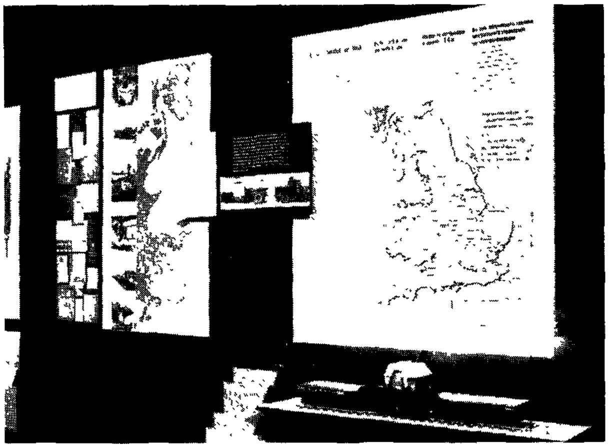
A major section of the UK stand was that devoted to nuclear fuels, and was opened by a large colour diagram of fuel cycles for natural uranium, enriched uranium and plutonium reactor fuels. Detailed reasearch and development was discussed for magnox, oxide and plutonium fuels as well as fuel reprocessing plant. Considerable details were given on the performance of the magnox fuel, used for all Britain's gas-cooled civil nuclear power stations. Magnox fuel is natural uranium metal with special alloying additions and specific heat treatment to determine grain-size, etc., enclosed in a magnesium alloy can. Detailed results were given by both the UKAEA and the CEGB on this fuel behaviour in power reactors, for example, the effects of gas forces, aerodynamic stability, the use of araldite models to simulate these effects and the progressive development of fuels with higher ratings. During the course of the conference it was announced that the guarantee for this fuel was raised 30% from 3 000 MWd/t to 4 000 MWd/t. Radiographs were shown and discussed of magnox fuel after use up to 6 000 MWd/t. Results were given showing that magnox is non-permeable to plutonium on the creep deformation of the magnesium alloy can, and on the behaviour of this fuel under fault conditions. A display of magnox fuel elements for the British gas-cooled power stations, Calder Hall, Berkeley, Bradwell, Dungeness, Oldbury, Sizewell and the TNPG flat bar design, showed progressive improvements in conception, manufacture, aerodynamic stability, and heat transfer properties. Enriched oxide pellet and fuel element production and development were shown with special reference to AGR fuel assemblies using stainless steel canning, and also for SGHWR fuel using zirconium alloy cans. Research work was outlined on ultra modern techniques here, such as electron beam welding of wires to cans, and of electromagnetically deformed can surfaces. Plutonium fuel is subject to intensive



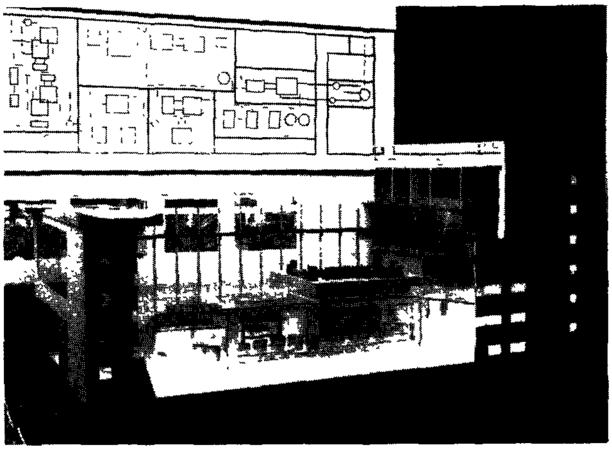
A panel showing various types of magnox fuel elements



An exhibit showing the two British-designed nuclear power stations built in Italy and Japan



Panels illustrating the domestic and international transportation of British reactor fuel after irradiation



Another section of the exhibit showing a cutaway model of the new Chemical Separation Plant at Windscale

research in the UK, both from the viewpoint of reactor physics properties in thermal and fast reactors. Detailed results were given for this field of work and also with regard to the manufacturing techniques developed in British production facilities. A detailed model of the new Windscale fuel reprocessing plant, which had just commenced operating and is Europe's largest, was displayed.

A special section of the stand was devoted to the transportation of radio-active materials, with particular reference to containers for nuclear fuel. Details were given of research into new types of container, to IAEA standards, which are fireproof and withstand 30 ft drop tests on to metal beams, using wood as an integral part of the structure. Actual containers were shown, and also a model of the road-rail containers used for moving irradiated magnox fuel from Britain's nuclear power stations to the Windscale fuel reprocessing plant, and information on international shipments of enriched spent MTR fuel from the PLUTO type reactors at Hifar (Australia) and Risø (Denmark) to the Dounreay reprocessing plant.

A wide range of results in basic research, from Harwell and elsewhere, pertinent to nuclear power reactors and their fuels was on show. Some of the topics were: measurement and calculation of basic nuclear data and spectra; the behaviour of aerosols in pipes with special reference to very fine plutonium aerosols; accurate dosimetry of reactor radiation; new precision reactor control instrumentation; the FINGAL work on fixation of active waste liquors in glass; and a working display of the Monte Carlo analogue computer technique for estimating neutron populations in power reactor gas ducts. A considerable amount of data was presented on irradiation effects in pressure vessel steels and pressure vessel lifetime. Research results of irradiation on beryllium oxide, ceramic and cermet fuels, stainless steels and materials were presented along with production methods for cermet fuels. A binary cross-correlation analyser was working on the stand and two new types of prevision pressure transducer were outlined. A new solid-liquid contactor—from a university—was demonstrated; this is suitable for resin extraction treatment of radio-active liquors. A display on graphite technology showed dislocation movements, as seen by electron microscopes, and other irradiation damage effects; work on dimensional stability; the formation of carbon suboxide resins on fuel etc.; improved, less porous graphites; and the graphite/carbon dioxide reaction, with a working model using ultra-violet simulation. Finally there was a display of various reactor rigs made for precision use over a temperature range from liquid hydrogen to 2 000 °C.

In the Miscellaneous section of the stand a twenty-seat four-language cinema showed ten new colour films on various aspects of nuclear power, fusion research and radioisotope uses. There was also a display of Britain's commercial and research plants using cobalt-60 for gamma ray sterilization of medical and pharmaceutical products.

UNITED STATES OF AMERICA

The United States stand occupied an area of 1 710 m^2, and was visited by more than 22 000 participants, scientists, technicians, and general public. Devised as a background for, and graphically supplementing, the US Papers Program presented by the US delegation to the Conference, the US stand provided a person-to-person exhibit wherein the newest developments in the US nuclear energy field were freely explained and discussed by the visitors with over 30 US scientific and technical attendants. To assist the free interchange of ideas and information, 44 specially selected and trained guide-interpreters were available who between them spoke no less than 14 languages. A large central lounge area and several small lounge areas, interspersed throughout the stand, plus a lecture hall and conference area, provided opportunity for roundtable discussion.

Two multi-language theaters, each with a capacity of 20 seats and some standing, showed 24 films with sound in English, French, Russian and Spanish as selected by the viewer. A Technical Information Center featuring a reference library, a technical book exhibit, a nuclear safety information point and a publication distribution counter, gave everyone an opportunity to study in print the developments in US nuclear technology since the 1958 Conference.

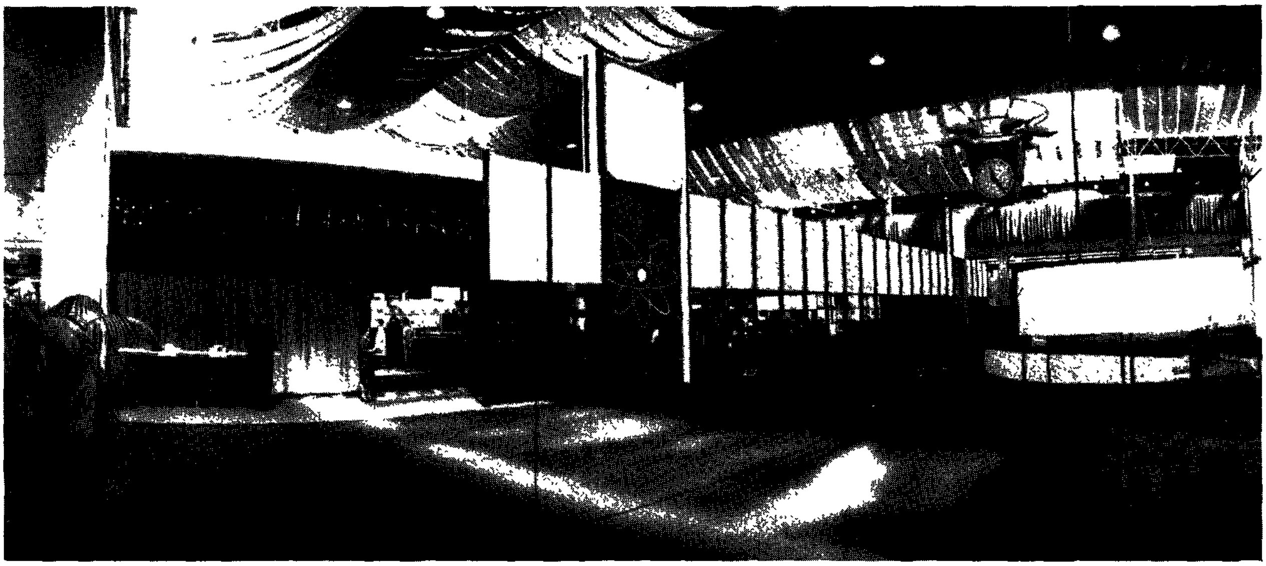
On the afternoon of 30 August, the UN Secretary-General and his official party were welcomed to the US Exhibit by the Chairman of the US delegation, and the exhibit was officially opened by a filmed greeting from President Johnson, who, referring to nuclear power, sounded the keynote for the US delegation's contribution to the Conference in these words: "... Today we begin to know its hope as a power-house of peace. . . ."

As the visitor entered the US Exhibit, he was met by a guide-interpreter, presented with a descriptive brochure, and offered interpretation assistance if desired. The Exhibit was divided into areas paralleling those of the Papers Program, i.e., Reactor Technology; Reactor Fuels; Non-Destructive Testing; Nuclear Power and Remote Areas; Instrumentation and Controls; Various Nuclear Applications; Co-operation and Safety. In addition, the technical film theaters, the technical information center, the delegates' lounge, the lecture room and the conference room were provided for the convenience of visitors.

The Reactor Technology area contained exhibits, equipment, transparencies and technical charts on boiling water reactors (Oyster Creek); nuclear superheat reactors (BONUS—Boiling Nuclear Superheat); pressurized water (Yankee and Malibu), spectral shift control reactors, high temperature gas cooled reactors (Peach Bottom), fast breeder reactors (showing development from Clementina to Enrico Fermi), sodium graphite reactors (Hallam), and maritime reactors (N.S. *Savannah*, 630A (nuclear steam generator), unified modular plant and consolidated nuclear steam generator). An important part of this area was a graphic display of comparative costs of nuclear power plants versus conventionally-fueled power plants contained in the Economics of Nuclear Power Production area.

The Reactor Fuels exhibit was of great interest. Explained by models, illuminated transparencies and actual equipment was the high temperature gas coolant reactor fuel fabrication, featuring a 12 ft fuel element. Also included were the SOL-GEL bulk oxide process and the SOL-GEL microsphere-forming process, as well as the vibratory compaction of bulk oxide; the experimental breeder reactor fuel processing facility, showing each step in the recovery of fertile and fissionable material by pyrometallurgical methods; and the fission product recovery system and radio-active waste spray calcination processes for storing radio-active waste products which give the latest US techniques on fuel processing.

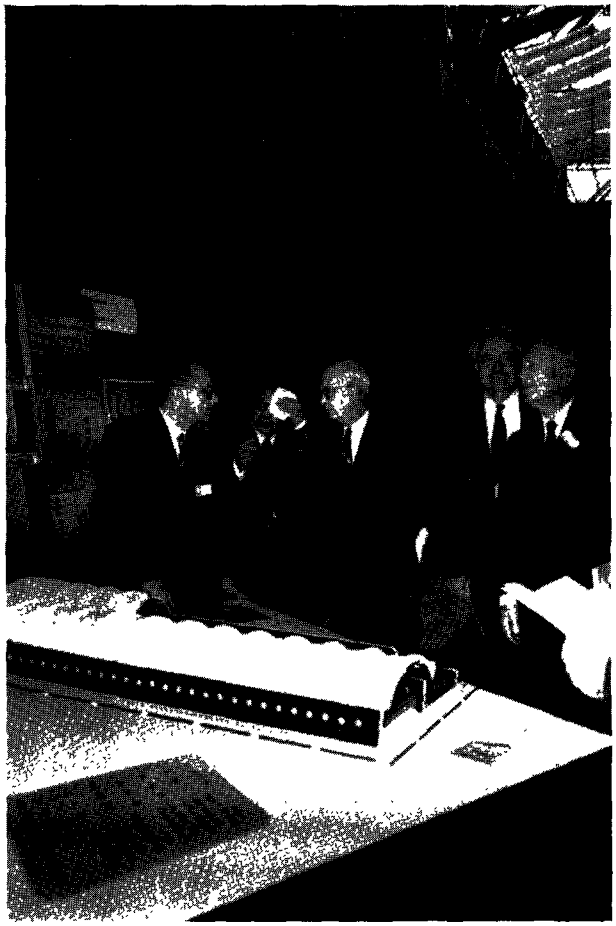
The Non-Destructive Testing area provided the pulsed eddy current device for inspection of fuel element jacket tubing, the eddy current U-tube inspection system for discovery of defects and corroded areas in tubing, the ultrasonic thin-wall tube tester to insure the integrity of nuclear sheath tubing with wall thickness of 0.015 in; the beta material tester which reports thickness and uniformity of bore coating in tubes of 2.5 mm, the phase system eddy current instrument that made accurate measurements of thickness of stainless steel as great as 0.5 in, the fuel homogeneity scanner used to determine thickness, density, and/or homogeneity of specific alloys, the eddy current spacing device which measured the coolant-channel spacing



The entrance to the US stand

Over-all view of the US exhibit

A recorded message from the President of the United States of America



Above: visitors examining a desalination process

At left: explaining the fuel element assembly of the US BONUS (boiling nuclear superheat) reactor

Multilingual film theatres on the US stand

US SNAP-10-A *nuclear space reactor*

Exhibits featuring the nuclear weather ship

The Technical Information Center at the US exhibit between fuel plates in a range of a few mils to several hundred mils, a metal identification meter using eddy current techniques to identify metals and alloys, an exhibit on neutron radiographic techniques in non-destructive testing, a microradiography exhibit showing techniques for X-ray evaluation of tiny specimens (or of selected small regions in larger specimens), and the insertion X-ray generator which displayed the method of insertion X-ray inspection of welds in tubing.

Nuclear Power for Remote Areas featured a working SNAP 7F nuclear generator and an actual weather boat, which, powered by the generator, transmitted and recorded samplings of temperature and atmospheric data in the exhibit hall. Other uses of SNAP generators were also shown. A mechanical demonstration model of the SNAP IOA, the first nuclear reactor planned for use in space, and a mock-up of the Advanced Dynamic Conversion System, proved of great interest to the scientists.

The Instrumentation and Controls area featured some of the latest US developments and included the hi-ball control road mechanism whereby stainless steel balls containing 2% natural boron were used as control rods resulting in an increase of the average power density of a water coolant reactor by 40%, a magnetic jack control rod drive employing a solenoid activator to produce linear motion within the sealed control units, with the working reactivity computer continuously analysing signals from the ion chamber to compute the shut-down reactivity of a reactor core. Of particular interest was the unified digital instrumentation which measured liquid level, temperature and pressure without physical contact with the medium being monitored. The ultrasonic level sensor by means of a magnetostrictive transducer gave direct read-out as a voltage. The wide range neutron flux sensor recorded neutron ranges of 10^4 to 10^9 nv as a counter and 10^8 to 5×10^{13} nv as a chamber. The detector measured only 4 in long × .355 in in diameter. The reliability shut-down for HTGR combines the outputs from the high temperature gas reactor scram channels, and caused the reactor to scram when unsafe conditions existed.

Other nuclear applications were the extensive Plowshare (use of nuclear explosion for peaceful purposes) exhibit; the neutron activation analyses exhibit and its widening use in all fields of science; the bio-degradable detergents exhibit, showing the reaction between petroleum hydrocarbons and sulfur dioxide under radiation to produce a detergent degraded by bacteria in a conventional sewage disposal plant—one solution to a universal problem. The de-salination of sea water exhibit, with a model flow diagram and other data, described a nuclear power-producing, desalting and chemical extraction plant capable of producing approximately 50 million gallons of fresh water a day from sea water. The Nova wood exhibit showed the result of impregnating soft woods with a liquid monomer and gamma irradiation, thus producing a harder wood, with test samples of the treated and untreated wood available to interested scientists.

The Co-operation area reviewed the many ways in which the US and other members of the IAEA and the United Nations co-operate in the promotion and development of nuclear energy for peaceful uses. The Safety area, featuring a different sort of "magic hands", explained why the nuclear energy industry in the United States continues to remain among the leaders in industrial safety.

The US Exhibit was devoted to the pursuit of its planned purpose—namely, to foster the scientist-to-scientist exchange and discussion of the newest nuclear developments in the United States.

Annex 1

LIST OF OFFICERS, DELEGATIONS AND CONFERENCE SECRETARIAT

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Vice-Presidents:

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Dr. W. B. Lewis (Canada)
Professor Francis Perrin (France)
Dr. Homi J. Bhabha (India)
Sir William Penney (UK)
Dr. I. I. Rabi (USA)

National delegations

AFGHANISTAN

Dr. Abdul Ghaffar Kakar, Chairman, Afghan Atomic Energy Commission

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M. Mohammed Benamar, Deuxième secrétaire

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Contraalmirante Ingeniero (R.E.) Oscar Armando Quihillalt

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Dr. Pedro N. Stipanicic
Ing. Celso C. Papadopulos

Expertos:
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Ing. Bela Csik
Ing. Eduardo V. Nasjleti

Asesores:
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Ing. Angel Lachica
Dr. Carlos T. Friz
Ing. F. A. Van Braam Houchgeest
Ing. Jorge A. Bertoni
Lic. Guillermo Ricabarra

Secretario:
Señor Héctor A. Fernández Mendy, Jefe, Asuntos Internacionales, Comisión Nacional de Energía Atómica

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H.E. Mr. B. C. Hill, Ambassador, Permanent Representative of Australia to the European Office of the United Nations
Mr. K. F. Alder, Director, Research Establishment, Australian Atomic Energy Commission
Dr. R. K. Warner, Deputy Chief, Special Projects Division, Australian Atomic Energy Commission

Advisers:
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Mr. D. J. Stevens, Director, Commonwealth X-Ray and Radium Laboratory
Dr. A. W. Wylie, Senior Principal Research Officer, Division of Mineral Chemistry, Commonwealth Scientific and Industrial Research Organisation
Prof. C. Watson-Munro, O.B.E., Professor of Plasma Physics, University of Sydney
Mr. W. H. Connolly, C.B.E., Chairman and General Manager, State Electricity Commission of Victoria
Mr. F. R. Hooper, Departmental Engineer, State Electricity Commission of Victoria
Mr. F. Sykes, Vice-Chairman, Electricity Commission of New South Wales
Mr. K. H. Milne, Manager (Engineering), Electricity Trust of South Australia
Mr. A. McCulloch, Chief Engineer, Southern Electricity Authority of Queensland

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Deputy Head of delegation:

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Dipl. Ing. Rudolf RENNER, Director, Federal Ministry for Trade and Reconstruction
Prof. Dr. Adalbert ORLICEK, Director, Federal Ministry for Transport and Electricity Supply

Secretary of delegation:

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Dr. Alfred BOESE, Director in the Federal Ministry for Social Administration
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Mr. Harald HICK, Austrian Study Company for Atomic Energy
Dipl. Ing. Armin RUMPOLD, Austrian Study Company for Atomic Energy

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M. A. WILLOT, Deuxième Secrétaire d'ambassade

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Chef de délégation :

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Prof. Elysiario TÁVORA Filho, Directeur de département, Commission brésilienne de l'énergie nucléaire
Prof. Tharcisio Damy DE SOUZA SANTOS, Directeur de département, Institut de l'énergie nucléaire
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M. Fernando Buarque FRANCO-NETTO, Premier secrétaire d'ambassade ; Représentant-résident auprès de l'Agence internationale de l'énergie atomique
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Conseillers :

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Dr. Clauer Trench DE FREITAS, Institut de l'énergie nucléaire
M. Luíz Antonio Jardim GAGLIARDI, Secrétaire d'ambassade
Dr. Witold Piotr Stefan LEPECKI, Institut de recherches sur la radio-activité

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Ing. Nicolas PETROV, Représentant permanent a.i. de la République populaire de la Bulgarie auprès de l'Office européen des Nations Unies

BYELORUSSIAN SOVIET SOCIALIST REPUBLIC

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UNION OF SOVIET SOCIALIST REPUBLICS

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Atomic leader

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PEACEFUL USES OF ATOMIC ENERGY

Proceedings of the Third International Conference held at Geneva, 31 August-9 September 1964

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