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CONTENTS

THE ROLE OF NUCLEAR ENERGY IN NATIONAL ENERGY PLANNING

1. National energy planning involves the following two essential steps: determination of future energy requirements; and identification of energy sources which can meet these requirements in an optimum way.

2. The energy plan then sets out the priorities for development with due regard to the social and economic factors entering into play in the implementation.

3. The electricity sector occupies a paramount position in the energy plan. This sector is the most capital-intensive, the most demanding on energy resources and generally the most susceptible to forward plannng; electricity is furthermore an essential constituent in any scenario for achieving economic progress. This justifies giving the electricity sector some priority when deciding on the allocation of resources in the national energy plan.

4. Electricity production in bulk relies essentially on four sources of primary energy, namely fossil and fissile fuels, and hydropower and geothermal energy. New sources such as solar, wind and biomass energy are playing no more than a fringe role for the present. Of the four principal sources, hydropower and geothermal energy are site- and resource-dependent; they must be used at the very spot where they arise and they are available only to a predetermined and limited extent at a specific site for covering a demand within their reach. Fossil fuels permit more flexibility because they can be transported over long distances and the waste products readily disposed of, provided the necessary means can be established under economically acceptable conditions.

5. Fissile fuels permit total flexibility in the relationship between source, point of use and point of disposal because the bulk handling requirements are minimal. This means that, from the energy-planning point of view, nuclear energy can be used wherever its introduction can be economically justified and technically feasible. Nuclear energy thus assumes an important position as a balancing factor in the energy supply to areas where there is a scarcity of alternative energy forms because they are not locally available in adequate quantities and at an acceptable cost, and because their transportation from elsewhere to the point of use, in the quantities required, would be too difficult or expensive.

6. This view of nuclear energy as a balancing factor, on grounds of economic merit and technical convenience, in an energy supply system relying on a mix of energy resources, may be unconventional but it appears to be justifiable in present circumstances. In most situations, there are viable alternatives to nuclear energy, and it therefore remains to be examined what particular features can make nuclear energy the preferred choice and what particular role can be assigned to it in a national energy plan, bearing in mind recent experience in the introduction of nuclear generation into electricity supply systems.

A. <u>The size factor</u>

7. The first nuclear power plants built in the late 1950s were of relatively modest unit rating, with a maximum in the range of about 100 MW. It was soon realized that the rating could be increased at low incremental cost. The power systems into which the nuclear plants were introduced were able to absorb substantially larger unit sizes because, at that time, electricity

demand was rising rapidly in the major industrial countries, the war years had left much outdated generating capacity and considerable operational flexibility of the power systems had begun to be built up through strong transmission links between generating centres. Nuclear unit ratings therefore increased as rapidly as the designers could cope with them. Greater standardization of components was introduced to facilitate the design and construction of the plants and lower still further their specific costs per kilowatt installed. This led to a situation where units of less than about 600 MW of electrical output were no longer attractive for the developer and indeed unit sizes of less than 900 MW became only marginally attractive. The current size ceiling, in the range of about 1,300 MW, is prescribed by the design and operational limitations of the conventional side of the nuclear power plant, essentially the turbine, and not by the nuclear elements as such.

8. Abandoning smaller unit sizes below 600 MW has moved nuclear plant out of range of those utilities which, because of their network capacity or their load pattern, cannot absorb large unit capacities into their system. The cost structure of nuclear generation, which is somewhat akin to hydropower, involves a high capital investment component per kilowatt of output and low running costs; the cost of nuclear energy is therefore lowest if the plant is operated at a high load factor. This means that the utility installing the nuclear unit must have a base load at least equal to the unit capacity. It must also have sufficient standby capacity to cover outage of the nuclear unit. These conditions place a restriction on the maximum unit size that a utility can accept and cause difficulty if utilities with an interconnected network capacity of less than 5,000-6,000 MW contemplate the installation of nuclear power plant under present conditions.

9. This capacity limitation can be overcome if neighbouring power systems are available with which sufficiently powerful interconnections can be established. The limitation applies of course to the time period in which the nuclear plant comes into operation so that, as long as the anticipated increment in base load demand is sufficiently great over the lead time of the nuclear development, nuclear generation can be planned for at a time when the network capacity is well below the minimum size mentioned. But this implies also that, throughout the development and construction period of the nuclear station, other power plants and corresponding network reinforcements are being built in step with the rise in demand to raise the system capacity to its minimum nuclear limit.

10. Studies by several agencies have shown that there is a market for nuclear power plant of less than 600 MW, principally in relatively fast-developing power systems which, because of their structure or isolated location, are unlikely to offer scope for introducing nuclear units of 600 MW or more. Interest has therefore focused on smaller units, developed not so much from outdated designs of the early period of nuclear generation but from new designs derived from nuclear propulsion programmes or adaptations of large-reactor concepts.

11. A number of such designs are now commercially offered, ranging from little over 100 MW to about 500 MW and embracing all the proven concepts. Specific costs do however tend to become very high at the lower end of this range, partly because some of the peripheral costs of the reactor island, of the shielding and redundancy systems for example, do not decrease <u>pro rata</u> with the scaling-down of reactor size, and partly because the development costs of new small-reactor designs are spread over only a few units. The economic disadvantage of small reactors introduced into a developing power network for the first time is accentuated further by the considerable investment needed for establishing a nuclear infrastructure of inspection

and regulating bodies and an adequate cadre of trained personnel. Many countries have nuclear research establishments but their work is generally far removed from the power sector and they can therefore offer no more than minimal support for nuclear power development, even though they can sometimes provide personnel with basic knowledge of nuclear processes and thereby help in forming a national nucleus for the necessary infrastructure. It remains to be seen whether the threshold problems and high initial investment requirements of small-scale nuclear power plant can be overcome in smaller power systems where the now conventional sizes of nuclear units cannot be accepted. These matters are of particular concern to some of the more industrialized developing countries where, from the point of view of energy supply, nuclear power generation may have an important role to play. Although present prospects may not be encouraging, much attention is given to small-scale nuclear power development and acceptable solutions may well be found.

B. Environmental issues

12. The public at large has become increasingly accustomed to and dependent on the ready availability of electricity and takes it for granted that utilities responsible for its supply will have the means to ensure this. There was no public concern for many years with the way utilities were provided with these means. Tolerance levels towards the building of power plants of all types and of transmission networks were high; utilities were free to select sites and routes purely on grounds of economy and the convenience of the supplier. But the impact of industrialization, of which electricity supply is one aspect, gradually began to change public attitudes. Growing concern developed with the disturbance of the environment and with the consequences arising from concentrated industrial activity. Tolerance levels were lowered dramatically, especially in areas where industrialization and public dependence on it had become the basis for economic life. The electricity supply planner was faced with a new situation in which virtually every project needed for ensuring an adequate and economic supply of electricity and inevitably having some environmental impact was challenged. Planning procedures had to be radically revised not only to cope with increasingly stringent environmental requirements but also with the growing public concern with whatever disturbance of the status quo - real or imagined - might be caused by the proposed project. The concept of environmental acceptability was extended to embrace not only the physical impact of the proposed development but also the public attitudes to it.

13. The initial euphoria over nuclear energy as a new resource of great promise gradually gave way to growing public unease. Fear of the unseen and unknown hazards of nuclear radiation, subconscious linkage with military uses and popular fiction all contributed to create an adverse image of fissile processes with the public. Utilization of fossil fuels on the other hand, the hazards of mining and of transporting them to the point of use and the impact of their waste products appear to attract only passing comment; the attendant risks are accepted. Nuclear power is thus identified as a potential source of danger and subjected to increasingly stringent regulatory requirements and a proliferation of safety measures, often applied retrospectively during the design and construction of the plant. The need to ensure environmental compatibility in the widest sense, the delays in the implementation and completion of nuclear power plant programmes arising from it and the attendant escalation of construction costs have led to the virtual abandoning of nuclear programmes in some countries and to a prolonged cycle of investigations and public enquiry in others. Strictly technical issues have become matters of emotive debate and logical energy planning has become clouded by subjective

judgement. The question thus arises to what extent the nuclear option is still available to the energy planner and whether it can still be taken into account as a potential energy resource when establishing a national energy plan.

14. The answer to this question is as intangible as the question itself; much depends on the local circumstances and the socio-political environment within which the nuclear power concept is to be developed. Past experience has shown that constructive education of the public in the management of the nuclear power option and the benefits it can bring can have a major impact on public acceptability and can greatly ease the pre-investment processes and thereby contribute materially towards a reduction of lead times and overall costs. Public information campaigns should not be limited to the nuclear issue alone. An ample, secure and economic supply of electricity tends to be taken for granted in developed countries, but its benefits are sometimes not fully appreciated in developing countries. The information campaign should therefore start with the marketing of electricity in the broadest sense; it should then present openly and fairly the options available for providing a supply, the steps taken for selecting the options which are most appropriate to the particular circumstances and the way in which safe and effective implementation and operation of the chosen facilities is to be ensured. Matters of public concern should be dealt with frankly. Public accountability needs to be maintained throughout the life of a project on those issues which have, or could have, an impact on the public, but this must be done within a framework in which the project can properly function and in which the decision-making process - be it longer-term or day-to-day - is not impeded by interference from outside. Formulation of such a framework is perhaps the most crucial issue of nuclear power development at the present time. Nuclear energy cannot become a realistic component in the energy plan unless the problems of its acceptability are first solved.

C. Energy requirements

15. The determination of requirements is the basis of any energy planning exercise. The approach adopted will depend greatly on the economic and socio-political conditions under which the energy demand will develop and on the time frame over which it is to be assessed. The time frame will depend in turn on the lead time required for developing the corresponding supply facilities and on their life span; there must be reasonable assurance that whatever facility is being planned will be able to meet the planning criteria for an adequately long period ahead. The uncertainties arising with planning for the longer term will have to be explored through sensitivity analyses, with the objective of establishing a basis on which firm decisions can be taken.

16. Determination of the role of nuclear energy in this plan requires sectoral segregation of the different energy components making up the demand pattern and examination of requirements separately for each sector. The interrelation of sectoral requirements must also be taken into account if a composite plan is to be established. Great care is needed to distinguish between primary energy demand and the demand for secondary energy and to ensure that conversion losses are adequately allowed for. Losses will inflate energy requirements and will arise with the production of electricity from whatever source. It has become customary to classify electricity produced by processes other than combustion under primary energy and only electricity generated from fossil fuels (oil, gas and coal) under secondary energy. Nuclear, hydrothermal and geothermal sources thus produce primary electricity,

a fact which is important for the statistical segregation of energy demand into primary and secondary components, although not for the analysis of demand as such.

17. Current trends appear to show that electricity demand rises more rapidly than energy demand as a whole, which may indicate a sectoral shift from the direct use of fossil fuels as well as more efficient production and distribution of electricity. Consequently, the need for additional power plants may be greater than the need for other energy handling and processing facilities, refineries for example. On the other hand, economic recession and energy conservation have led to substantial regression in the rate of growth of electricity demand and there is currently as much surplus power plant as there is surplus refinery capacity. Electricity demand has little inherent inertia and responds quickly to changes in economic climate, weather, habits and even moods; lead times of demand fluctuation - short- or longer-term - are minimal. If this is contrasted with the substantial lead times required for providing power generating and distributing facilities, the dilemma of the planner becomes clear.

18. The planner's situation is eased to some extent by the fact that growth of demand and aging of electricity supply systems go hand in hand. The need to provide additional facilities for meeting increments of demand is reinforced by the need to replace existing facilities approaching the end of their economically useful life. The increments of capacity which can be planned for may thus be considerably larger than the increments of demand alone would allow.

19. Power plant replacement will reduce the uncertainties of planning and ensure that only a proportion of the additional capacity needed will be subject to the vagaries of future demand. This issue is particularly important for nuclear plant where, as already explained, capacity additions need to be large and lead times, from conception to commercial operation, long, which makes load forecasting for the period of commercial operation hazardous.

20. Once a power plant is to be added to an existing system, for whatever reason, the primary energy demand for it forms a constituent of the energy plan. The proposal to install this plant should therefore be reviewed not only from the point of view of sectoral suitability but also in the context of the global energy plan and the criteria according to which this plan is to be developed. The choice of sources for electricity production will influence the primary energy requirements by energy form and also globally, and it is important therefore to ensure an adequate recycling of information once a particular demand projection has been established and ways of meeting this demand determined. This means in practice that the estimation of losses incurred in the conversion to electricity and in its distribution will form an integral part of the demand analysis.

21. An additional and economically attractive market for nuclear energy may be offered by the replacement of fossil fuels in process and space heating. Heat may be provided either from specifically dedicated plants or from cogeneration and heat recuperation in association with nuclear power production. Obstacles to the more widespread use of nuclear heating are principally the following:

(a) The large sizes of the currently economic nuclear units which make it difficult to find adequate heat loads. The commercial development of smaller units might overcome this problem;

(b) The relatively large separation distances between nuclear plant sites and industrial and population centres generally required by regulatory authorities. Improvements in heat transmission technology can offer better supply conditions to remote heat loads and have already done so in several cases.

22. The introduction of a nuclear heating component into the national energy plan will depend as much on ambient conditions as on technical and economic factors and will probably remain of marginal importance in most countries.

D. Energy sources

23. The objective of energy planning is to meet the anticipated demand in an optimum way by using whatever mix of sources can be available to achieve this optimum. The term "optimum" covers in this connection the safety and reliability of the energy supply and its environmental and social acceptability, as well as its economic merit as such and its favourable impact on the national economy as a whole. A favourable impact is created by satisfying the energy demand with least strain on the national economy.

24. The energy demand, which finally determines the sources brought into play for meeting it, is not necessarily restricted to clearly defined sectors, and this may bring some uncertainty into the selection of the sources that need to be employed. For example, electricity cannot be used for transportation purposes in any substantial way unless there is a major investment in electric traction, but it can be used for space heating as an alternative to other forms of heating, with a very small investment at the user end. The planning process must bridge such uncertainties of utilization, and the sources of supply selected must allow adequate flexibility for this. The electricity supply is particularly sensitive to uncertainties of utilization because of its monolithic supply structure. Electricity must be used in the particular form and at the very instant in which it is available to the consumer, leaving the supplier no choice but to supply the electricity or not to supply it at that instant and to accept whatever economic or social consequences this decision may entail.

25. An essential step in energy planning is therefore the sectoral segregation of demand because the primary sources selected for meeting it are not necessarily interchangeable. Electricity is a specific energy form requiring dedicated installations with predetermined conversion processes for its production. The primary sources from which electricity is converted, not electricity as such, will form part of the global energy supply plan. Optimization of primary sources is distinct from the optimization of conversion, although both are interlinked through the conversion processes. As already mentioned, the losses incurred in the conversion of electricity form part of the total demand which the primary sources have to meet. The distinction between primary and secondary electricity explained earlier affects only the classification of primary energy forms selected for electricity production; the availability and merit of alternative primary energy forms is assessed in the supply optimization process.

26. The optimum supply scenario is determined by a number of interrelated factors such as the following:

(a) An increment of demand which is adequate to justify the additional capacity, the increment being determined by the sum of load growth over the lead time of the proposed plant and the amount of obsolescence of existing power plant capacity;

(b) Available power plant sites and an adequate system size in relation to the proposed additional unit capacity;

(c) The composition of the existing power supply system including generation and transmission;

(d) Availability and costs of alternative sources which can meet the same increment of demand;

(e) Investment requirements and financing aspects;

(f) The state-of-the-art and local familiarity with it;

(g) Public acceptance of the proposed solution.

27. Factors such as these are now commonly evaluated in computer programmes which also permit testing of the sensitivity of the results to uncertainties of choice; the uncertainties will become magnified as the lead time for the proposed development expands. Planning becomes ultimately a matter of judgement in which the importance of intangible factors must be carefully weighed; computer programmes can only provide basic inputs for decision-making.

28. The corner-stones of the energy supply plan will be formed by indigenous resources, in the first place the renewables - hydrothermal and geothermal resources - which have no commercial value unless they are exploited locally for electricity and heat production. Second in order of priority come fossil fuels of low commercial value (lignite and peat) which must also be used locally, and finally the conventional commercial energy forms - coal, oil and gas, indigenous or imported. What then is the position of nuclear energy in this plan?

29. Nuclear energy is a highly refined energy form requiring a well-developed infrastructure for its application. Complex handling, processing and storage facilities for fuel preparation and waste disposal are needed, so that even in cases where the fissile raw material is indigenous the local availability of processed fuel and the capability for handling the fuel cycle may have to be questioned. Nuclear energy therefore competes in the first instance with the most advanced and commercially most valuable or most expensive energy sources, primarily with imported coal, oil or gas. A straight-forward economic break-even point between a nuclear and fossil-fuelled generating plant is not difficult to establish with the aid of computerized analytical techniques. It is more difficult to take account of the intangible factors which enter into consideration in the nuclear case, such as regulatory requirements, lead periods, environmental impact and public acceptance, on the negative side, and reduced dependence on any single energy form and on energy imports, on the positive side. The cautious planner will assign some contingent costs to all these matters to weight the nuclear case correspondingly and to establish, within whatever margins of uncertainty appear appropriate, the true value of the nuclear option.

E. The composite plan

30. The national energy plan must extend to a period well beyond the lead time for the design and construction of the facilities to be provided under the plan. The plan must be sufficiently flexible to accept the uncertainties which long-term projections entail. The role of nuclear energy within the plan should in theory be no more difficult to determine than the role of any alternative energy form. Nuclear technology is now mature and its economic

merit is readily established in normally predictable circumstances. Uncertainties are however greatly increased in the nuclear case by intangible and generally unquantifiable factors and they impinge on both the technology and the economics. They give rise to situations in which logical forward planning involving nuclear programmes becomes extremely difficult. The planner will therefore have to develop alternative scenarios which can readily be adapted to changing circumstances, allowing for projects with shorter lead times to be prepared and available in case a proposed nuclear scheme cannot be implemented or suffers undue delay.

31. The shortest lead times are generally achieved in the construction of oil- and gas-fired power plants. Recourse to such plants may then be necessary in cases where a nuclear programme runs into difficulty and where other solutions - extensions of existing power stations, electricity imports or demand curtailment - are not available. The alternative to the nuclear case will probably comprise an equivalent capacity addition of other plant and a rearrangement of the operational order of merit of the existing generating plants to make up any shortfall in energy output, bearing in mind that the nuclear plant would have operated at the highest possible load factor, whereas the replacement plant will probably use lower load factors for optimum operational economy. The difference in cost between the nuclear and the alternative solution providing the same output overall will indicate the price to be paid for the intangibles which prevented completion of the nuclear programme.

32. This difference can be computed, within the estimating error which forward planning necessarily entails, when an energy plan proposing alternative solutions is first established. The incremental cost of the alternative solution, expressed over the lifetime of the respective scheme and duly weighted where appropriate by shadow pricing and by the cost of supply curtailment, is an important figure to present to the decision-makers because its economic consequences will ultimately affect the national economy as a whole. A direct link can thus be established in the national energy plan between public acceptance of nuclear energy and the total cost of the energy supply to the public.