The Potential Role of Nuclear Power in Developing Countries

by G. Woite

In response to recommendations by the 1971 Geneva Conference and in compliance with a resolution by the IAEA General Conference to intensify efforts to assist developing countries in planning their nuclear power programmes, the Agency has performed a number of general as well as country-specific studies in co-operation with Member States. To be able to evaluate the order of magnitude of the economic potential of nuclear power in developing countries, the Agency carried out a Market Survey in fourteen selected countries. This survey was completed in 1973 and has been summarized in IAEA Bulletin,Volume 15, Number 5.[1]

After the quadrupling of oil prices in late 1973 it became obvious that nuclear power will have vital importance for covering an increasing portion of the electric energy demand of many developing countries in the coming decades, both for economic and diversification reasons and to secure an energy supply.

In order to extend the scope of the Market Survey and to incorporate the effects of changes in fossil and nuclear energy economics, it was updated in 1974 and extended to all countries eligible to receive technical assistance under the United Nations Development Programme.[2]

Parallel to this necessarily theoretical ap approach, a number of in-depth studies were performed to assist the nuclear power planning activities of Member States[3, 4]. The methodology and results of these studies are summarized below.

GENERAL METHODOLOGY AND ECONOMIC PARAMETERS

Theoretically, the ideal methodology to estimate the potential role of nuclear power in meeting the electric energy requirements of the countries in question would be to compare all benefits and costs arising from alternative development patterns. The electricity generation expansion plan yielding maximum total net benefits for the national economy would have to be regarded as the optimum expansion pattern.

Since this ideal approach would be practically impossible to achieve because of time, manpower, and data limitations, costs rather than net benefits were defined as the yardstick of comparison. This means that forecasts of the electric energy demand were evaluated independently from the choice of supply strategy, and that it was assumed that all alternative power expansion programmes at a well-defined minimum system reliability level would offer the same total benefits to the consumers. The least cost expansion programme would consequently yield maximum net benefits. Indirect effects such as, for instance, different employment levels arising from alternative power programmes and their consequent effects on future savings and investments were neglected.

In the case of multi-purpose hydro projects, the correct approach would be to take into account only the share of costs assignable to power production for economic comparison to their competitors. A corresponding cost breakdown of the projects exists, however, only in rare cases. Existing hydro power expansion plans were therefore considered as firm for most of the countries, i.e. it was assumed that these hydro power plants would be constructed, even in the eventuality that other electricity generation alternatives would be economically preferable. Where hydro power development plans were not available, it was assumed that 40% – 60% of the total hydro potential of the country would be in operation by the year 2000.

To evaluate the present worth of total costs of the electricity generation system over an adequate planning period, the operation of all existing and future power plants of a country was simulated by the computer programme WASP(6) for the Nuclear Power Planning Studies.

For the extended Market Survey a less time-consuming approach was chosen. Planned hydroelectric power plants, conventional plants using indigenous fuels, and other peaking plants such as gas turbines were deducted from total yearly required capacity additions. For the remainder, an expansion strategy yielding minimum costs was chosen by comparing the present worth of capital investment and lifetime operating costs of nuclear and oil-fired plants as the main competitors on the basis of expected average lifetime capacity factors. Economic parameters which are crucial for both the general and country-specific analyses are discussed below.

FOSSIL FUEL PRICES

As a result of the action taken in the last quarter of 1973 by the OPEC countries, the tax paid costs typical for crude oil (before company profits) in the main producing area of the world, the Persian Gulf, has risen to a minimum level of US $7 per barrel.* Since then, participation agreements imposed by the producing countries have led to a price of more than US $10 per barrel in the Gulf. With regard to the longer term future (1980 and beyond) it would seem realistic, however, to assume that the US $7 per barrel level escalated for inflation is more likely to prevail than the present inflated average of US $10 for two reasons:

(a) Oil demand has not had time to readjust to the discontinuous price increase;
(b) The cost of oil which might be obtained from shale, tar sands or coal is estimated to be of the order of US $7 per barrel.

Consequently, the latter figure has been taken as the reference oil price.

Generally, the prices of other fossil fuels were traditionally derived from their production and distribution costs. The sharp rise of oil prices in late 1973, however, has led to an increasing awareness of the regional limitation of energy resources and their value as a raw material. While it was not possible to handle this problem in depth for the extended

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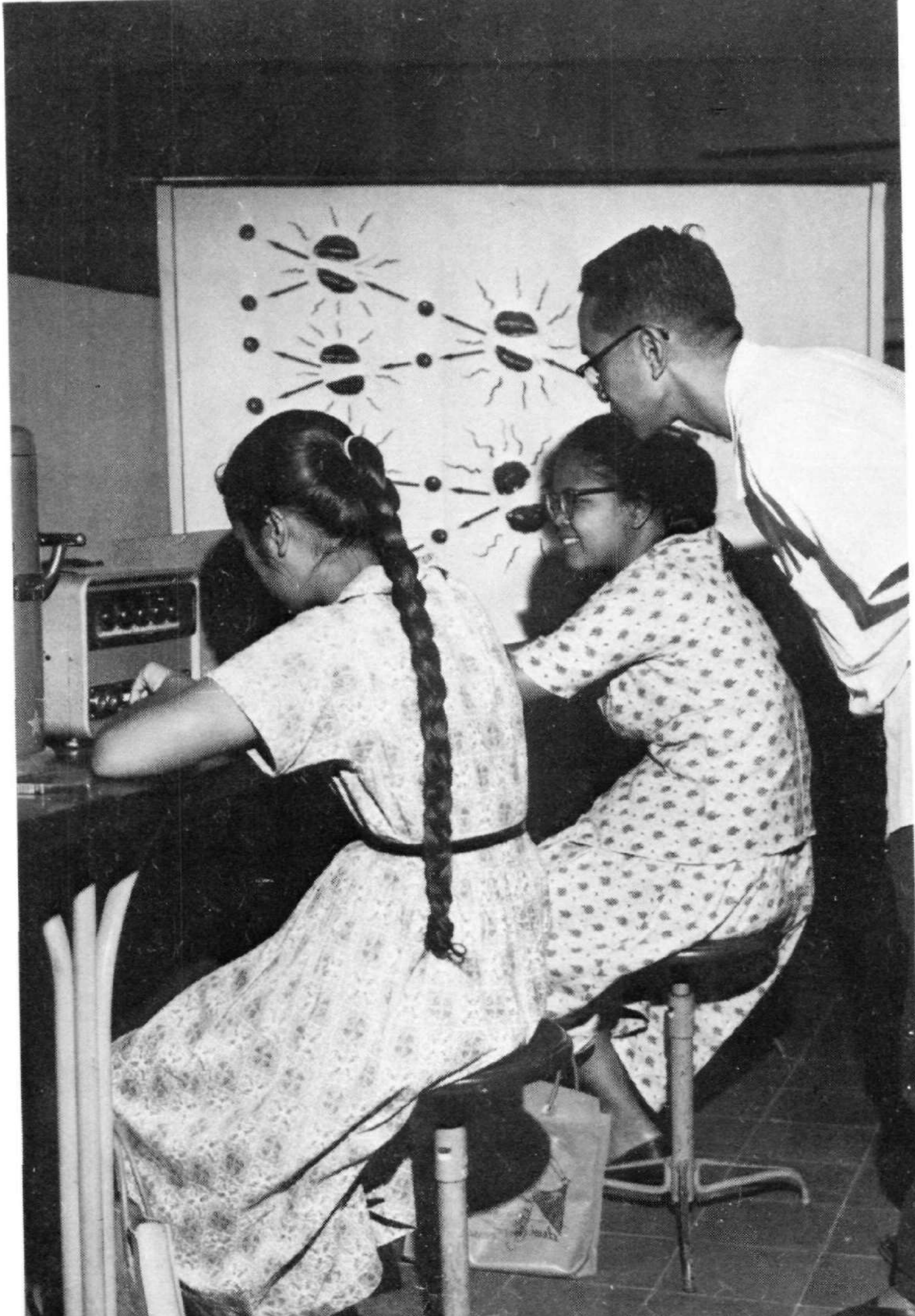
* All prices and costs are in January 1974 US $

Indonesian students study atomic physics at the Gadjah Mada University in Jogjakarta, in preparation for an expanding nuclear programme in their country. ▶



Market Survey, this was done for the country-specific studies where applicable to assign values to fossil energy resources which are expected to reflect the country's long-term supply and demand situation.

COSTS

Utilities in the United States and elsewhere are currently contracting around \$20 per lb U_3O_8* (unescalated) for uranium which will be delivered in the mid to late 1980's. During this same period, the cost of a unit of separative work is likely to be of the order of at least \$50/kg SWU according to experts in the field. The remaining components of the nuclear fuel cycle (fabrication, recovery, etc.) were increased by 10% from Market Survey values to allow for escalation since January 1973.

Capital costs of fossil-fired and nuclear power plants were derived from recent cost experience in industrialized countries. This was done by using an updated version of the ORCOST computer programme(7), reflecting potential cost savings or cost adders caused by local wage rates and prices of local construction materials, foreign supervision, engineering and management services etc. The capital costs so derived refer to two-unit stations at ideal sites. It was assumed that potential cost adders for site difficulties would apply to both nuclear and conventional plants.

ESCALATION AND PRESENT WORTH RATE

Escalating expeditures can be discounted to a present worth reference date (usually the start of the planning period) by

$$C = \Sigma C_i \frac{(1+e)^{t_i}}{(1+r_n)^{t_i}}$$

C = present worth of all costs

C_i = cost item in constant currency

e = escalation rate (per unit)

r_n = nominal discount rate (per unit)

t_i = time interval (years) from present worth reference date to date of expediture for cost item C_i

By definition of a real discount rate r,

$$r = \frac{1+r_n}{1+e} - 1$$

the above formula can be written

$$C = \Sigma C_i (1+r)^{-t_i}$$

The capital investment and operating costs of electricity generating systems were evaluated according to the latter formula, treating escalation implicitly. A real discount rate of 8%/a appeared to be reasonably high to reflect both the capital scarcity generally prevailing in developing countries and the large profitability of other investment projects competing for limited financial resources.

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* in January 1974 US \$

◀ View of the GKT (Gemeinschaftskernkraftwerk Tullnerfeld) nuclear power station near Zwentendorf, Austria. The GKT nuclear power station is a 700 MW(e) BWR. It is being built by KWU, Fed. Rep. Germany and Siemens/Austria, and is scheduled for operation in 1976.

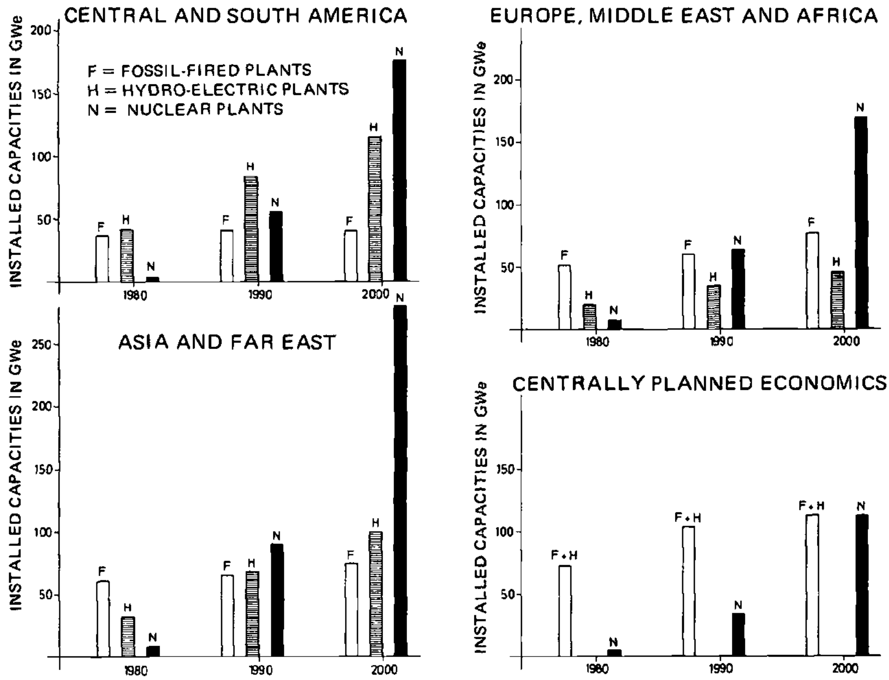

Fig. 1. Conventional and nuclear capacities

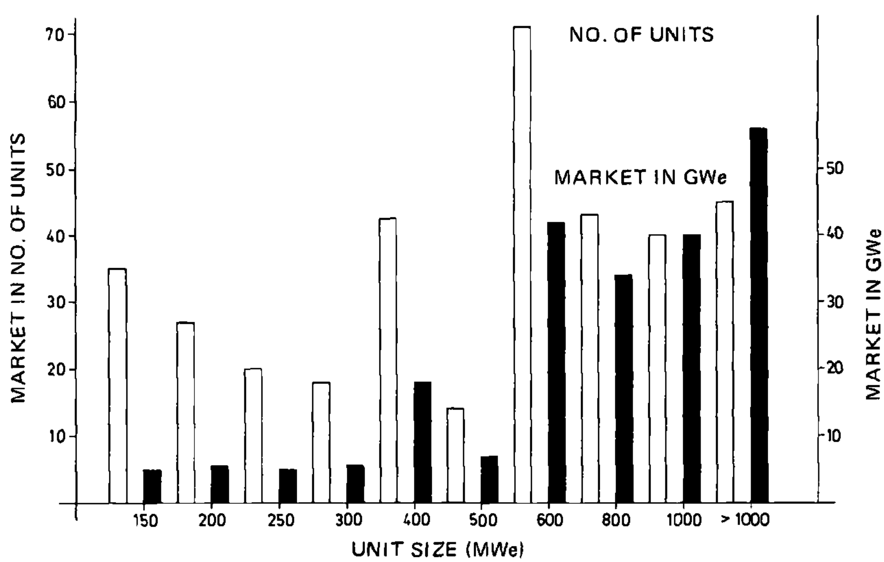

Fig. 2. Market for nuclear plants by unit size

As has been indicated in the course of the Agency's programme to promote the design of small and medium size reactors of a proven type in the 100 – 500 MWe range, concerted action by several potential buyers interested in six to ten essentially identical units could help to make more designs available, and would also be likely to reduce the capital costs.

Representatives of Member States who may be interested in a possible concerted approach by purchasers will be able to discuss this during the General Conference. Room 202 of the Hofburg Conference Centre will be available for the afternoon of Wednesday, September 22, from 14.30 p.m. for this purpose. More information is available from the Secretariat for those interested in participating in this meeting.

EXTENDED MARKET SURVEY RESULTS

In **Fig. 1** the results of the 1974 Market Survey are summarized by regions, indicating the estimated economic potentials of fossil-fired, hydroelectric, and nuclear power plants in the years 1980, 1990, and 2000.

For the total of all developing countries, the economic nuclear potential is expected to be approximately 25 GW(e)* in 1980, 240 GW(e) in 1990, and 740 GW(e) in the year 2000. These nuclear capacities would represent 7% of the total installed capacity in 1980, 35% in 1990, and 57% at the end of the century.

In **Fig. 2** the distribution of the estimated market by unit size is indicated. It refers to nuclear capacity additions in the years 1981 to 1990. This time span was chosen as planning period, whereas the nuclear potential after 1990 should be understood as indication of an order of magnitude. It can be seen that 80% of the estimated market refers to unit sizes of 600 MW(e) and above. The remaining 20% still represent a potential market of 45 GW(e), or 150 units of sizes below 600 MW(e).

It should be kept in mind that these results indicate a potential role of nuclear power based solely on economic factors as summarized above. They do not take into account practical problems of financing, manpower training, local manufacturing capability, public acceptance, etc. which are expected to limit nuclear installations considerably. Furthermore, although some manufacturers are starting to offer units below 600 MW(e), this section of the nuclear market has not been established so far. In the meantime, some countries with small electric grids might find it advantageous to purchase a 600 MW9e) unit and to accept a higher loss-of-load probability of the electric system in case of an unexpected outage, or to run it at reduced output until the expanded electric system can reliably accept a unit of this size.

Other practical limitations to the theoretical nuclear potential might result from national policy, from fostering the exploitation of indigenous energy resources, or from the fact that the introduction of a bigger unit size will generally require substantial investment in the transmission system. The combined effect of these limitations will certainly reduce the theoretical economic nuclear potential in practice, especially for unit sizes below 600 MW(e).

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* 1 GW(e) = 1000 MW(e)

NUCLEAR POWER PLANNING STUDIES

The essential first step of a Nuclear Power Planning Study is an extensive analysis of the country's national economy, energy consumption, and energy resources. Based on this analysis, forecasts of population, GNP, total and electrical energy consumption are evaluated for a planning period of 20-30 years and compared with forecasts of governmental or other institutions.

The indigenous energy potential is then compared to the cumulated total energy demand of one or more selected forecasts. The energy amount to be imported or available for export is obtained in this way, and appropriate long-term pricing of indigenous energy resources can be assessed on this basis.

Together with capital cost estimates of electricity generating plants and estimates of long-term world market prices of oil, uranium, and nuclear fuel cycle costs, this provides the basis of an economic optimisation of electricity generating system expansion. In late 1974 and early 1975 the Agency performed Nuclear Power Planning Studies for Pakistan, Bangladesh, and Indonesia in co-operation with experts in these countries.

PAKISTAN

In terms of fossil fuel reserves, Pakistan is in a difficult situation. The total combined reserves of coal, oil, and natural gas are equivalent to about 800 million TEC*, i.e. less than 12 TEC/cap. This is less than 1% of the world average. Of the theoretical hydro potential of some 20 GW(e), the economically exploitable hydro resources are about 8 GW(e). They are concentrated mainly in the north of the country.

The present total annual energy consumption of Pakistan is 14×10^6 TEC (1974) or 0.2 TEC/cap, which is quite low when compared to the world average of 1.9 TEC/cap. According to current projections, it is expected to grow to about 1 TEC/cap, or 130×10^6 TEC in the year 2000. Pakistan's combined indigenous coal, oil, and gas resources of 800×10^6 TEC appear to be quite inadequate in the light of this energy demand. In view of this lack of indigenous fuels and the very high price of imported oil, the most economic sources of future electricity production would be hydro and nuclear power.

Since the local contribution to the construction of hydro power stations can be much greater than for any other power stations, and in view of other benefits of hydro dams, maximum possible consideration was given to the further development of Pakistan's hydro potential. In addition to 12 X 175 MW(e) Tarbela units assumed to be ready by 1981 (this would mean earlier completion than foreseen in present planning), Kalabagh with 1125 MW(e) was considered to be completed by 1985. Further hydro stations were added to the electrical system in 1990 and thereafter, bringing the total installed hydro capacity to about 7.3 GW(e) in the year 2000. This would mean that 90% of the economically exploitable hydro reserves would contribute to electric power generation by the turn of the century.

* TEC = tons of coal equivalent

The economically preferable capacity expansion schedule resulting from the optimization studies can be summarized as follows (see **Fig. 3**): In addition to planned hydro power extensions, three 250 MW(e) coal-fired units were to be added in 1980-81. They represent the largest size acceptable at that time for frequency stability reasons. From 1982 onwards the study indicated that all additions should be nuclear except for the fixed hydro and gas turbine capacities specified in advance.

These nuclear additions are indicated to total 4.8 GW(e) [8 X 600 MW(e)] in 1982 – 1990 and 11 GW(e) in 1990 – 2000. The financing required to cover the installation of these nuclear power plants including their first cores would amount to US $2.9 X 10^9 1/ in 1982 – 1990 and US $6.3 X 10^9 in 1991 – 2000. The crucial problem will to be find additional financing sources for an investment of this order of magnitude.

BANGLADESH

The annual per capita income of Bangladesh has been estimated to be only US $77 (in 1972–73). Severe floods caused by the Brahmaputra River which separates the eastern and western parts of the country, low agricultural productivity, lack of transportation and other technical infrastructure, and a fast-growing population are some of its major handicaps. Both the total (commercial) energy consumption of only 0.033 TEC/cap and the electric energy consumption of 20 kWh/cap. annually (1970) are on very low levels.

The country's fossil energy resources of 1.4 X 10^9 TEC consist of coal deposits in the western zone and of natural gas found in the eastern part of the country. Coal has not been produced so far, and no decision on future production has been taken. Coal production would require sophisticated and costly mining techniques, including freezing. Gas has traditionally been low priced on the basis of its production and distribution costs. In view of the inadequacy of the reserves versus the anticipated demand of the coming decades, however, and considering the value of gas as a feedstock (e.g. for the production of fertilizer which is urgently needed), a price of 4 US $/Gcal was considered as a minimum in the long run. This would be equivalent to less than half the current oil price, or two-thirds of the estimated long-term oil price. Gas-fired plants would be the main competitors of nuclear plants at this price level.

In view of the great uncertainty of Bangladesh's future electricity demand, two alternative load forecasts were considered for the study. The lower one was developed using the Aoki method(1), the higher one represents an extrapolation of a local planning group forecast.

The computed optimum schedules of capacity additions are illustrated in **Fig. 4**. It can be seen that for the low load forecast the first [200 MW(e)] nuclear capacity addition is selected for 1984, with the next [400 MW(e)] nuclear unit to follow in 1990.

A nuclear portion of 40% of the total installed capacity in 1995 is indicated to be economically preferable under the assumptions of this study. For the high load forecast, the first nuclear unit is already selected for 1982, the nuclear portion amounting to 47% of the total installed capacity in 1995.

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* *in January 1974 US $*

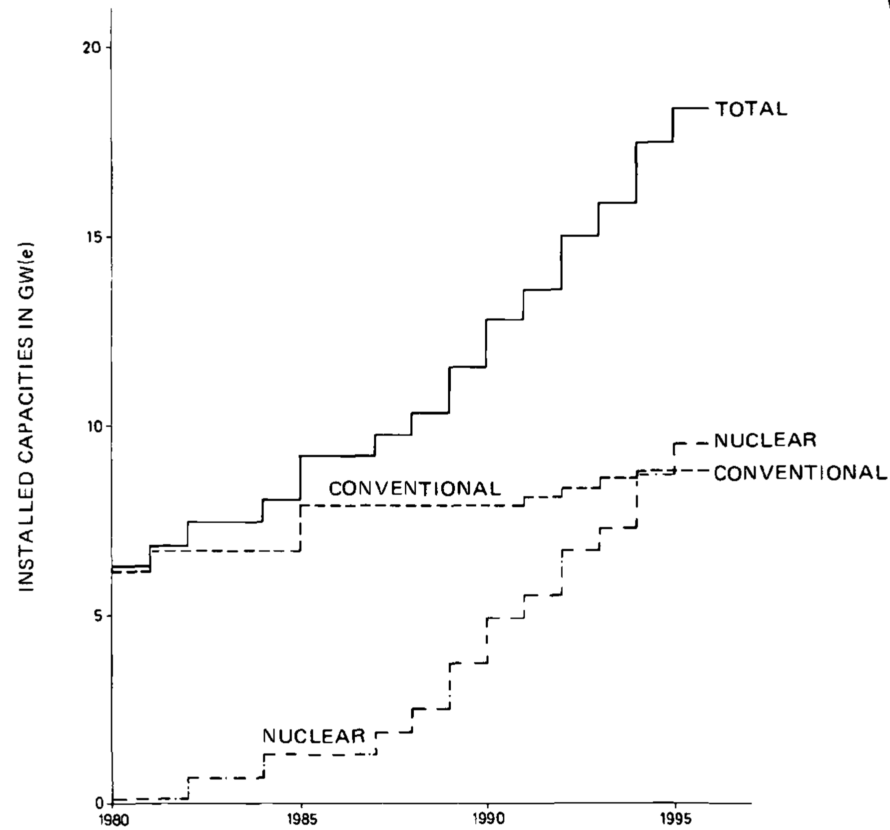

Fig.3. Optimum electricity system expansion schedule for Pakistan.

The feasibility of these expansion patterns depends on a number of conditions. In addition to some practical limitations summarized above, the installation of a grid connection between the eastern and western parts of the country would be necessary to allow for the unit sizes indicated. This interconnector is expected to require a substantial investment as it would have to cross the Brahmaputra River. Financing is a severe problem in view of the many investments which are imperative for early stages of development.

INDONESIA

Indonesia consists of aproximately 3000 islands and islets, of which Java is the most important one with respect to its population, economy, and energy consumption. The Nuclear Power Planning Study focussed on this island where 80% of the electrical demand is concentrated. Unlike in Pakistan and Bangladesh, considerable deposits of coal and oil have been found in Indonesia. Out of its annual oil production of 70×10^6 t/a (1973), Indonesia exports more than 60×10^6 t/a (1973). The coal production has been steadily

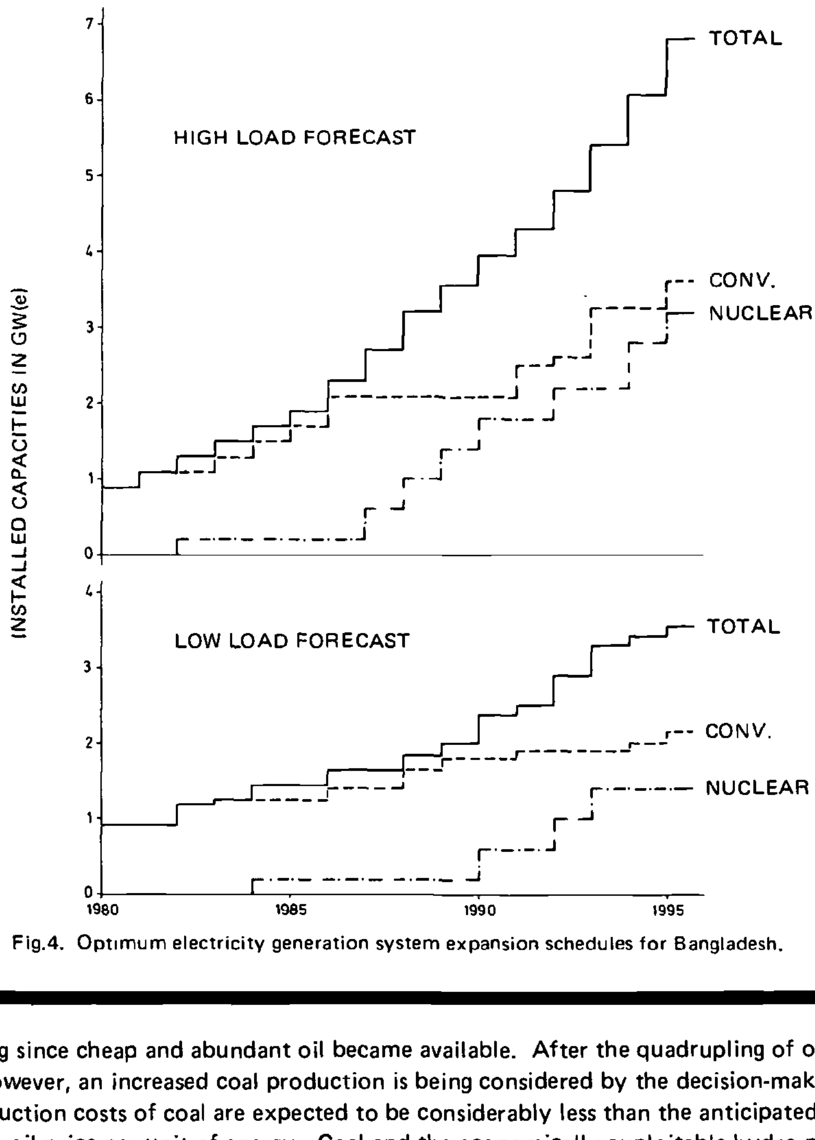

Fig.4. Optimum electricity generation system expansion schedules for Bangladesh.

decreasing since cheap and abundant oil became available. After the quadrupling of oil prices, however, an increased coal production is being considered by the decision-makers. The production costs of coal are expected to be considerably less than the anticipated long-term oil price per unit of energy. Coal and the economically exploitable hydro power reserves of Java [2.5 GW(e)] will be the main competitors of nuclear energy.

In spite of an accelerated growth in electricity production (19% annual growth rate in 1973) the present electricity supply situation is a long way from reflecting the real needs of the Javanese population and industry. In West Java, the potential peak demand has been estimated to be three times as high as the installed capacity. In this situation of suppressed demand many enterprises and dwelling complexes generate their own electricity rather than acquiring it from PLN, the state-owned electric utility. It is obvious that a steep increase in electric capacity to close the production gap is imperative. Current planning assumes growth rates of 30%/a or even more until 1982, declining to more moderate growth thereafter.

Based on this planning and on the electricity generation system which will be in existence by 1977, an optimization study for the years 1978 – 1997 was carried through for Java, giving maximum possible consideration to hydro power projects and allowing the computer to select the number, size, type, and timing of additional units required to meet the growing demand. Although the results of the study have not yet been officially released, it can be said that a first nuclear unit of approximately 600 MW(e) would be economically justified before 1985.

FURTHER IAEA ACTIVITIES

The Agency aims to offer its Member States comprehensive and impartial guidance at various stages of nuclear power planning and implementation. The general need for nuclear power has been assessed by the Market Survey. Upon request of a Member State, the scope and timing of its nuclear power programme can be evaluated in more detail by a Nuclear Power Planning Study. Such a study will usually be performed at the Agency headquarters, with one or two engineers from the country concerned being given on-the-job training. In this context, the planning methodology and tools (e.g. computer programmes WASP, ORCOST, etc.) will be made available to the Member State. Following an increasing commitment to nuclear power, the Agency will continue to assist Member States to perform feasibility studies for certain nuclear power plants at definite sites.

To provide further advice and guidance, the IAEA has published a Guidebook, "Steps to Nuclear Power"(5) which summarizes the necessary steps before implementation of the first nuclear power plant in a country. Other publications, such as a Guidebook for Economic Bid Evaluation and a Guidebook for Contracting for Nuclear Fuel Supply, are in preparation. In addition to these aids in nuclear power planning, comprehensive training courses of about 15 weeks on nuclear power project planning and implementation for staff in management positions, are being prepared. The first one will start in September 1975, in Karlsruhe, Fed. Rep. of Germany. Similar courses will be held at Argonne, USA, and Saclay, France, from the beginning of 1976. They will be supplemented by other seminars for executive level staff and regional courses for project engineers.

The Agency will also continue to advise Member States in other essential, selected fields, such as the establishment of a legal framework, safety assessment, and site selection.

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