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NUCLEAR POWER COSTS

Note by the Director General

In order to provide the General Conference with the latest data available to the Secretariat on the costs of nuclear power and on the economics of nuclear power plants the Director General is presenting the attached report which consists of two parts:

(a) Part I. Contains some information on the capital and fuel costs of nuclear power stations, additional to the cost data submitted previously to the General Conference [1]; and

(b) Part II. Presents certain considerations on the applicability of the cost data to the problem of economic selection of nuclear power plants. It is partly based on the discussions of a panel of experts convened by the Agency in April 1963 to discuss the economics of the integration of nuclear power plants in electric power systems.

[1] GC(IV)/123, GC(V)/INF/38 and GC(VI)/INF/53.

LIST OF ABBREVIATIONS

CANDU	Douglas Point nuclear power station
EDF-3	Electricité de France, reactor No. 3
KRB	Kernkraftwerk Rheinisch-Westfälisches Elektrizitätswerk-Bayernwerk, a nuclear power station at Gundremmingen, Federal Republic of Germany
kW	kilowatt
kWe	kilowatt electrical
kWh	kilowatt-hour
mill	one-thousandth of a dollar
MW	megawatt
MWd	megawatt-day
MWe	megawatt electrical
t	metric ton
U	uranium

All sums of money are expressed in United States dollars.

I. NUCLEAR POWER COSTS

1. The various elements of nuclear power costs which must be taken into account when calculating the generating costs of electricity, and the methods used in these calculations, have been described in two earlier reports [1]. The capital costs of 38 nuclear power stations in operation, under construction or definitely planned for construction, as well as some data on fuel, operation and maintenance costs were presented to the General Conference in 1962 [2]. The present paper brings the information up to date; in addition it discusses the economic aspects involved in the selection of nuclear power plants. Cost figures for new projects not included in earlier reports and significant changes in data relating to other projects are given in the Table below.

2. As a result of experience gained in building and operating nuclear stations, the margin of uncertainty in the estimates of nuclear costs is diminishing rapidly. In this connection, 17 stations of the 38 nuclear projects surveyed in last year's report have passed beyond the stage of initial criticality.

3. The economic comparison between conventional and nuclear power stations depends not only on the basic costs of the different types but also on technical and economic factors specific to each particular situation; however, the competitive position of nuclear power is improving both with regard to capital and fuel costs.

4. The reduction in capital cost is due largely to one or more of the following considerations:

(a) Construction experience;

(b) Technological advancements;

(c) Economies of scale; and

(d) Power output exceeding design rating.

5. The first three considerations are reflected, at the same time, in each consecutively built plant. The capital cost data contained in the two previous reports [3] gave clear evidence of the effects of the advancement in technology and the increase in size on the costs of the natural uranium gas-cooled reactors in France and the United Kingdom of Great Britain and Northern Ireland. As far as enriched uranium light-water reactors are concerned, an illustration of the operation of all the above-mentioned factors is afforded by the case of the Yankee reactor in the United States of America. The difference between the cost of the $248/kW Yankee station (Yankee number 1) and the $183/kW Connecticut Yankee (Yankee number 2) is mainly attributable to the larger size of the plant. It should be noted that the Yankee reactor was designed with an initial rating of 110 MWe (net), which would correspond to a capital cost of $356/kWe. The plant has actually operated with a gross output of 170 MWe or a net output of 158 to 160 MWe, which means that the capital cost is $248/kWe (net). Further power increases are also possible. It is hoped that by the end of 1963 the Yankee reactor may produce up to 185 MWe (gross). If more than 185 MWe is achieved, modifications will be necessary in the boiler feed system and in the turbine blading, since these units of the conventional plant may then limit plant capacity. As shown in the Table, a similar increase in output has been possible with the Dresden Nuclear Power Station. All of the reductions in unit capital cost are very important, since they are accompanied by a proportionate reduction in the annual fixed charges which is the major component of the generating cost for nuclear power plants.

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[1] GC(IV)/123 and GC(V)/INF/38.

[2] GC(VI)/INF/53.

[3] GC(V)/INF/38 and GC(VI)/INF/53.

6. The cost of uranium concentrate is expected not to exceed $6 per pound of U_3O_8 in the next several years. At the same time, the industrial experience acquired by the countries specializing in natural uranium gas-cooled reactors, especially by France and the United Kingdom, has led to a decrease in fabrication costs for magnox clad elements to approximately $20/kg. This gives a total cost of $35 to $40/kg of fabricated fuel.

7. With an average irradiation of 3500 MWd/t (based on extensive fuel element testing) and an efficiency of 31% (an average figure for the large gas-cooled reactors at present under construction in France and the United Kingdom) the fuel cost data indicated above would imply a total fuel cycle cost per unit of about 1.8 to 2.2 mills/kWh. In the case of the EDF-3 in France, where further details are available, the fuel cycle cost can be broken down into roughly 1.34 mills/kWh for fuel consumption and 0.46 mill/kWh for fuel inventory.

8. Fuel fabrication costs for water reactors using UO_2 fuel clad in stainless steel or zircaloy are firmly established. In the United States of America, the cost for complete fuel assemblies, excluding the value of the enriched uranium, is about $100 to $110/kg U for stainless steel clad UO_2 and about $120 to $130/kg U for zircaloy clad UO_2. These amounts show that the item of fuel fabrication may contribute between 0.6 and 1.2 mills/kWh to the fuel cycle cost. The cost of the entire fuel cycle for the large new water reactors, such as the San Onofre, Connecticut Yankee and Los Angeles reactors, is expected to be 2 to 2.5 mills/kWh, assuming current charges for fuel reprocessing and credit for plutonium at $8/g. Natural uranium as UO_2 in zircaloy cladding in CANDU-type fuel elements can be purchased at $68/kg U, including the cost of the contained uranium. With no reprocessing of spent fuel, no credit for plutonium and a fuel irradiation of 10 000 MWd/t of uranium, the cost of the entire fuel cycle, excluding inventory charge, is about 1 mill/kWh.

9. Experience gained in the fabrication and irradiation of nuclear fuel has led to offers of guarantees for fuel performance, as well as to reliable quotations for fuel cycle costs for an extended period of time. Moreover, guaranteed fuel burn-ups have been generally increased. The price of about $38/kg U for guaranteed standard magnox elements of the simplest design includes a guarantee based on 3000 MWd/t, but it is anticipated that guarantees of mechanical durability (if not of reactivity) will gradually be extended to 4000 MWd/t or above. In July 1963, the first commercial contract for the supply of fuel on a long-term basis was concluded. The United Kingdom Atomic Energy Authority agreed to supply fuel elements for a ten-year period at about $28 million to the 166 MWe gas-cooled reactor of the Japan Atomic Power Company, Tokai Mura. A Canadian fuel supplier offers to guarantee, under a ten-year contract, a fuel cycle cost, excluding inventory charge, of not more than 1 mill/kWh. In the United States, manufacturers of fuel elements have increased the guaranteed fuel lives to approximately 15 000 to 22 000 MWd/t of contained uranium for stainless steel and zircaloy clad UO_2 elements.

TABLE

Capital costs of nuclear power stations

Station	Location	Reactor type	Net electrical output (MWe)	Capital investment (millions of $)	Unit capital investment ($/net kWe)
A. Information on new plants not included in previous report					
La Crosse	La Crosse, Wisconsin, United States	Boiling water	50	18.4	368
KRB	Gundremmingen, Federal Republic of Germany	Boiling water	237	70[a]	295
Tarapur	Near Bombay, India	Boiling water	380 (2x190)	101.5	267
San Onofre	Near San Clemente, California, United States	Pressurized water	373	91.5	245
Los Angeles	Los Angeles, California, United States	Pressurized water	462	96.6	209
Connecticut Yankee	Haddam Neck, Connecticut, United States	Pressurized water	463	84.9	183
Wylfa	Wylfa, Anglesey, United Kingdom	Gas cooled	1000 (2x500)	280	280
B. Significant changes in data contained in last year's report[b]					
Yankee	Rowe, Massachusetts, United States	Pressurized water	158 (141)	39.2	248 (278)
Dresden	Morris, Illinois, United States	Boiling water	205 (184)	51.3	250 (279)

a/ Including $10 million for interest and taxes during construction over a period of 46 months.

b/ Figures contained in last year's report (GC(VI)/INF/53) are shown in parentheses if different.

II. USE OF NUCLEAR POWER COST DATA FOR ECONOMIC COMPARISONS

10. Basic capital and fuel cost data for various reactor types are sometimes summarized in the form of total generating costs. The limitations of these figures should not, however, be overlooked. For example, the economic comparison of a nuclear and a conventional thermal power station is often made on the basis of the generating costs of the two stations in their initial year of base-load operation. It should be realized, however, that this approach gives approximate results only and should not be regarded as a general method, since alternative plants are likely to be utilized in different ways in the course of their operational lives and since each station will affect the utilization of the other plants in the system differently.

11. When the problem of only one nuclear plant, the capacity of which is only a small percentage of the system into which it will be integrated, is being considered, some of these aspects may not be of immediate importance; however, as nuclear power achieves competitive status and may represent in the near future a relatively large source of electric power, the problems outlined above become significant. The Agency has undertaken to review some of them with the assistance of a panel of experts drawn from countries that have special experience in power planning and the economic aspects of integrating nuclear power stations in electric power systems will be made the subject of a separate document which will describe in detail the limitations of generating costs quoted for single stations on the basis of hypothetical operating data.

12. These limitations may be grouped into two categories:

(a) Those arising from economic and technical factors specific to nuclear power; and

(b) Those which are common to nuclear and conventional power stations.

13. The first category was especially important in the development stage of nuclear power stations. A few years ago, generating cost calculations were given with wide variations on the basis of plausible changes in assumptions on such crucial matters as total power output to be expected from a given core, burn-up, plutonium credit and processing charges. This situation is gradually disappearing as regards the industrially proven reactor types, such as natural uranium gas-cooled and enriched uranium light-water moderated reactors, and is not expected to arise in the case of heavy-water cooled and moderated stations. With regard to nuclear fuel costs, projections into the future still retain some degree of uncertainty larger than that affecting conventional fuels and differing with the reactor system under consideration. However, this should not be regarded as a disadvantage of nuclear power. In the near future many elements of the fuel cycle cost are more likely to decrease rather than to increase. Even in the case of enriched reactors, the fuel cycle of which is relatively complex, the present schedule of enriched uranium appears to show maximum rather than minimum prices although it is difficult to forecast the repurchase price of plutonium. This shows that, while the margin of uncertainty affecting basic nuclear cost data has greatly narrowed in the last few years, alternative calculations based on different assumptions for some of these cost data, which may still be expected to vary in the future, should always be made and several estimates of generating costs should be obtained.

14. The second category of reservations, an example of which is given in paragraph 10 above, stems from the fact that the utilization of all the plants operating in the system will usually be changed after the commissioning of alternative new stations so that total system costs will be different and these differences may well extend far into the future.

15. In conclusion the generating costs are useful initial approximations provided that all the basic data and parameters used in their computations are explicitly stated. In most cases, however, economic comparisons should proceed further by:

(a) Estimating a range of costs under different assumptions for each basic parameter which may be expected to vary over the life of the installation, such as the purchase price of fuel, credit for plutonium; and

(b) Carrying out a few system cost studies for even a short period of years for different patterns of plant installation all capable of meeting the requirements of an electric power system. The scope and degree of details of such analyses will depend upon the availability of data for present energy resources and upon the reliability of future load forecasts. They are, however, indispensable in all cases and especially in developing countries where a single nuclear plant often represents a significant percentage of the total installed capacity of the system for which it is envisaged.

16. The most refined methods of system cost analyses will still retain elements of uncertainty, since many assumptions on future values of parameters essential for comparison, such as nuclear and conventional fuel costs, capital costs of future stations, rate of growth of demand, system load factors and interest rates, will have to be made for a long period of time. These methods, however, have the advantage of allowing an investigation of the sensitivity of results to variations in assumed values, thus facilitating an assessment of the whole range of consequences which are involved in the selection of a particular power plant.

17. These conclusions apply to the evaluation of any category of power equipment, as indeed to any heavy capital equipment, designed to operate for a long period of time. They have also served as guidance to the Agency in its work on nuclear power costs. In this connection, the Agency has also initiated a review of the more comprehensive methods currently used by some countries for the economic evaluation of their power programmes. Moreover, it intends to follow up its power survey missions by assisting Member States, on request, in taking the different steps required for the assessment of the size and timing of nuclear power programmes.