NUCLEAR POWER COSTS

A report prepared by the IAEA Secretariat and presented to the seventh session of the Agency's General Conference says that information on nuclear power costs is now rapidly moving from the domain of uncertain estimates to that of tested factual data. As more and more nuclear power stations are being built and put into operation, more information on the actual costs incurred is becoming available.

This is the fourth report on nuclear power costs to be submitted to the IAEA General Conference. The report last year gave cost information on 38 nuclear power projects, 17 of which have already gone into operation. Certain significant changes in the data given last year are included in the present report; besides, information is given on seven new plants. (See table on page 4.)

The report is divided into two parts, the first on recent developments and current trends in nuclear power costs and the second on the use of the cost data for economic comparisons. Both stress the fact that the margin of uncertainty in the basic data has lately been drastically reduced. At the same time, it is pointed out, some degree of uncertainty is inherent in the assumptions made in arriving at over-all generating cost figures, especially when - as is usually the case - a nuclear plant is part of an integrated power system.

Current Cost Trends

The relative position of nuclear power, the report states, is improving noticeably with regard to both capital and fuel costs. As regards capital costs, this is largely due to one or more of the following factors:

(a) reduction in capital costs as the second or third plant of a given type are built, taking advantage of (i) experience gained and (ii) improvement in technology;

(b) reduction in unit investment cost with increase in plant size, the larger plants being more economical than small ones; and

(c) increase in reactor power output beyond design rating.

Since two plants of the same size and same design are seldom built consecutively, it is difficult to separate the effect of experience from that of improved technology. The technology advances before a second plant is built and it is not easy to decide how much of the reduction in cost is due to repetition of the same design. Besides, of two plants of the same design the second is almost always larger than the first, and as a result the effect of the increase in size is not easily separable from the effects of repetition and technological advance.

The combined effect, however, is clear in the progressive reduction in the costs of the gas-cooled natural uranium reactors in Britain and France. As regards light water cooled enriched uranium reactors, a striking illustration of the effects of all the above-mentioned factors is provided by the Yankee plant in the USA. The plant, which is based on a pressurized water enriched uranium reactor, was originally designed to have a net output of 110 MWe, which would have meant a capital cost of $356 per kilowatt of installed electrical capacity. But it has actually operated with a net output of about 160 MWe, bringing down the capital cost to $248 per kilowatt. The second plant of this design, the Connecticut Yankee or Yankee No. 2, will have a net output of 463 MWe and the capital cost is estimated at $183 per kilowatt, the increase in size being mainly responsible for the reduction in unit cost.

The fuel cost picture has also brightened considerably. For the immediate future, the price of uranium concentrate (U_3O_8) can be taken to be 6-8 dollars per pound. Fabrication costs have also fallen; for the Magnox fuel elements used in Britain and France, the cost of fabrication is now about 20 dollars per kilogram. The total cost of fabricated fuel thus works out to $35 - 40/kg. With an average irradiation of 3500 megawatt-days per ton and an efficiency of 31 per cent, this would imply a total fuel cycle cost of 1.8 - 2.2 mills per kilowatt-hour.

Fuel fabrication costs are quite firmly established for water-cooled reactors using uranium dioxide fuel clad in stainless steel or zircaloy. In the USA the costs are between 0.6 and 1.2/kWh. The cost of complete fuel assemblies, excluding the value of the leased enriched uranium, is $100-110 per kilogram of uranium for stainless steel-clad uranium dioxide, and $120-130 when the cladding material is zircaloy. The cost of the entire fuel cycle for the large new water reactors such as San Onofre, Connecticut Yankee and Los Angeles is expected, on conservative estimates, to be 2 - 2.5 mills/kWh, assuming current charges for fuel reprocessing and credit for plutonium at 8 dollars per gram.

Natural uranium fuel in dioxide form and with zircaloy cladding, such as is used in the heavy water moderated and cooled plant in Canada (CANDU), can be purchased at $68 per kilogram of uranium, including the value of the contained uranium. With no reprocessing of spent fuel, no credit for plutonium and a fuel irradiation of 10 000 megawatt-days per ton, this means that the cost of the entire fuel cycle, except inventory charge, is about 1.0 mill/kWh.

The experience gained in fuel fabrication and irradiation has made it possible for suppliers to offer guarantees for fuel performance. As a result, it is now possible to quote dependable fuel cost figures for long periods.

Use of Cost Data for Economic Comparisons

For purposes of economic comparisons, certain limitations of the data on nuclear power generating costs must be borne in mind. For one thing, generating costs are always obtained under a set of assumptions, some of which are based on solid experience, others on reasonable extrapolations. For another, a large nuclear power station can hardly be expected to operate in isolation; usually it supplies energy to an interconnected system. The individual generating cost of a power station is therefore only a guide to the total system costs over a period of time. Finally, when economic comparisons are to be made between different alternatives for meeting the requirements of a power system, much more than individual generating costs will have to be taken into account.

The Agency, with the assistance of a panel of experts, has begun a review of this complex problem of the economics of integration of nuclear power stations in electric power systems. The review has already shown that generating costs quoted for single stations suffer from two kinds of limitations:

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

(b) limitations on the use of a generating cost figure computed for any single power station in assessing the actual cost incurred in meeting power system requirements and in comparing different alternatives.

With improvements in technology and greater experience, the limitations of the first kind are gradually disappearing, especially for proven reactor types. Nevertheless, for economic comparisons, it would be desirable to have, in place of a single figure, alternative calculations with different assumptions regarding those data which may be expected to vary in the future.

The limitations of the second type are not specific to nuclear power costs. They may not be serious when a new station is intended to contribute only a small proportion of the power supply of the system, and in such a case a comparison between the merits of a nuclear and a conventional plant for a predominantly thermal system may usefully be made on the basis of individual generating cost figures. But the method may be inadequate for the economic comparison of extensive conventional and nuclear programmes, each involving a series of stations, or even for the comparison of two single stations intended for a system characterized by some unusual features, such as the presence of large amounts of very obsolete capacity, extremely rapid rate of growth, or anticipated large variations in the system load factor.

These considerations, however, should not detract from the value of nuclear power generating cost figures. What they show is the need for two supplementary kinds of activity to help comparisons of the economic merits of different alternatives for supplying power to a system.

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					
La Crosse	La Crosse, Wisc., USA	Boiling Water	50	18.4	368
KRB	Gundremmingen, Germany	Boiling Water	237	70*	295
Tarapur	near Bombay, India	Boiling Water	380 (2x190)	101.5	267
San Onofre	near San Clemente, Calif., USA	Pressurized Water	373	91.5	245
Los Angeles	Los Angeles, Calif., USA	Pressurized Water	462	96.6	209
Connecticut Yankee	Haddam Neck, Connecticut, USA	Pressurized Water	463	84.9	183
Wylfa	Wylfa, Anglesey, UK	Gas Cooled	1000 (2x500)	280	280
B. Significant Changes in Data Reported Last Year **					
Yankee	Rowe, Mass., USA	Pressurized Water	158 (141)	39.2	248 (278)
Dresden	Morris, Ill., USA	Boiling Water	205 (184)	51.3	250 (279)

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

** Figures previously reported, if different, are shown in parentheses.

In the first place, in addition to computing a single generating cost figure for a particular station on the basis of the most reasonable assumptions, estimates should be made of a range of costs under different assumptions for each basic parameter which may be expected to vary substantially over the life of the installation. Secondly, a few studies should be carried out on the costs to be incurred by the power system concerned (and not merely the isolated costs of individual stations) for different types of plant installation all capable of meeting the requirements of the system. These are particularly important in the developing countries where a single nuclear power plant often represents a significant proportion of the total installed capacity of the system for which it is envisaged.

OPERATING EXPERIENCE WITH POWER REACTORS

The principal reactor types now in use for power generation have generally had a satisfactory record of performance and such problems as have occasionally arisen in nuclear power stations have been mostly with conventional components of the plants. This was one of the broad findings that emerged from an international conference on Operating Experience with Power Reactors, held by IAEA in Vienna from 4 to 8 June 1963.

Attended by about 250 scientists and engineers from 27 countries and five international organizations, the conference was one of the largest scientific meetings organized by the Agency and the first on the subject to be held under international auspices.

From a panel discussion held at the end of the conference, it could be seen that representatives of the major nuclear power-producing countries now share a growing optimism about both the technological and economic outlook for nuclear power. Leading experts from France, the USSR, the United Kingdom and the USA, who took part in the discussion, envisaged the advent of economically competitive nuclear power by the end of the present decade. This could be achieved with reactor types whose technical soundness had already been established - possibly with some further improvements in design, manufacture of more reactors of the same design and construction of large-sized plants. It was also foreseen that the excellent operating record of the established reactor types might justify less overdesign than at present and this would lead to a substantial reduction in capital costs.

Although economic prospects were touched upon during the panel discussion, the conference as such dealt mainly with the technical aspects of reactor operating experience. It was divided into eight sessions: the first was devoted to general reviews of experience with nuclear power plants in the context of national programmes; the next four discussed experience with specific plants; the sixth dealt with specific plant components; problems of staffing were taken up at the seventh session; and the last session was on fuel cycles and fuel handling. Reports on the experience with about 20 individual plants were given at the conference. As Mr. Pierre Balligand, the Agency's Deputy Director General in charge of Technical Operations, pointed out at the opening session, these plants represented about half of the total installed capacity of nuclear power in the world today.

Light Water Reactors

Power reactors cooled by light water have two main varieties: the boiling water and pressurized water types, both fuelled by enriched uranium. Most of the nuclear power plants in the United States utilize light water reactors, and they are in use in several other countries as well, including the USSR.

In a review of operating experience with boiling water power reactors, R. J. Ascheri (USA) pointed out that by the end of last year over 2200 million gross kilowatt-hours had been generated by three boiling water reactor plants - the Dresden and the Vallecitos plants in the USA and the Kahl station in the Federal Republic of Germany. Early this year, two more boiling water plants were commissioned in the USA: the Big Rock Point and the Humboldt Bay plants. "The overall performance of the boiling water reactors in these nuclear power plants under standard electrical utility operating conditions," said Mr. Ascheri, "has been uniformly excellent. Their safety, reliability, ease of mainte-