METHODS OF ESTIMATING NUCLEAR POWER COSTS

It is obvious that the large-scale development of atomic power will depend on its economic merits, which again will be mainly determined by the cost of the power produced. There is widespread interest in obtaining cost data on established types of nuclear power stations. The International Atomic Energy Agency has been collecting technical and cost information on different types of power reactors and making it available to its Member States. A report on the current state of nuclear power costs was presented to the Agency's General Conference last year, and a revision of this report is being prepared this year.

Some of the Agency's Member States have experienced difficulties in extrapolating cost data obtained from other countries to their own situations. Apart from the fact that the factors which have a bearing on cost are often widely different from one country to another, the methods of costing are not identical in all countries. The Agency, therefore, has considered it one of its major tasks to help in establishing consistent bases for the costing of nuclear power so that the available cost information can be evaluated and used in different contexts.

An international panel of experts* appointed by the Agency's Director General, after examining costing methods in detail, has recently produced a report entitled "Introduction to Methods of Estimating Nuclear Power Generating Costs". The report is intended to help the Agency's Member States, particularly those which are less-developed in nuclear technology, in making a preliminary economic assessment before the construction of a nuclear power station. It gives a description of the different cost items involved in a nuclear power project, some suggestions as to the extrapolation of available data, and an evaluation of different methods of allocating the costs to the units of energy produced.

It is pointed out that the determination of electricity generating costs for a single station is only a first step in the evaluation of the merits of nuclear power. If the station is operated within a power system a comparison between costs to that system arising from a nuclear and a conventional power plant will be necessary. Besides, if a country contemplates a comprehensive nuclear power program, the indirect costs to the whole national economy must also be taken into account and placed against possible alternatives. These wider aspects of economic evaluation call for separate studies; the purpose of the present report is to help countries considering the possibility of nuclear power to arrive at an estimate of the cost of electricity or of process heat produced by nuclear reactors.

* *The members of the panel were from Canada, France, Hungary, India Italy, Japan, Sweden, the United Kingdom and the United States.*

Three Costs Categories

In principle, the costing of nuclear power would appear to be no different from that of conventional electricity. In both cases, the purpose is to determine a unit generating cost on the basis of the capital, fuel, and operation-and-maintenance and other costs. But the complexity of reactor types, the unique features of nuclear fuel and the limited experience in the operation of power reactors make costing more complicated for nuclear than for conventional power stations. In an introductory chapter the report reviews some of the special features of nuclear power costs in the three categories mentioned above.

The difference in capital costs is the most marked feature of all economic comparisons between nuclear and conventional power, particularly in the small size range. Most of the difference is due to the high cost of the reactor and associated equipment and provisions for safety.

For fuel also, there is a large difference in the necessary investment. The total value of the working stock of fuel for a power reactor (including the reactor charge) can amount to ten times as much as that needed for a coal-fired station. Moreover, the fuel cost per unit of power produced is much more sensitive to variations in plant size for nuclear than for conventional power. Another special feature of nuclear fuel is that at present it can be obtained only from a few countries, while conventional fuels are widely available. Furthermore, if the spent fuel from a nuclear reactor is to be put to subsequent use, the transportation and processing of this fuel would represent a significant cost item.

As regards operation-and-maintenance, it is pointed out that in view of the radiation hazards, special health and safety precautions are necessary in nuclear power plants and, at present, make for higher operation-and-maintenance costs for nuclear plants than for the conventional ones.

The cost items under these three headings are discussed in detail in the next three chapters of the report. The first of these chapters is devoted to "station construction costs", which mean the total cost of building a power station (also referred to as "capital cost" or "plant cost").

Station Construction Costs

A detailed breakdown of construction items, which permit their identification, is important for the estimation of the plant cost. A comprehensive listing of construction costs facilitates the intercomparison of various nuclear power stations.

Except for the reactor and associated facilities, the cost items for a nuclear plant are in many respects similar to those of a conventional plant. The main cost items of a nuclear plant, as listed in an appendix to the report, are (1) land and land rights, (2) site preparation and structures, (3) reactor and auxiliary equipment, (4) primary circuit heat exchangers and auxiliary equipment, (5) steam heat equipment, (6) secondary circuit and electricity generating system, (7) miscellaneous equipment, and (8) associated costs. A further breakdown of each of these items would show the costs of (a) material and equipment, (b) transport, (c) taxes, (d) labor and installation, and (e) the total installed cost.

The eight principal items of station construction costs can also be broken down into more specific cost components in order to enable precise identification and comparison. For example, in the breakdown given in the report, "reactor and auxiliary equipment" includes (a) the reactor itself, (b) reactor cooling, heating and auxiliary systems, (c) fuel handling equipment, (d) instrumentation of reactor and auxiliary equipment, (e) moderator, (f) reflector (if different from moderator), (g) moderator circuit and components, (h) other items (such as laboratory equipment), and (i) spare parts. Similarly, "associated costs" include (a) engineering, design and inspection costs (in connection with preliminary investigations, etc.), (b) indirect costs, (e.g. for general administration, etc.), (c) commissioning costs (e.g. for inspection and acceptance tests), (d) miscellaneous fees (e.g. legal fees), (e) interest during construction, and (f) contingency.

These examples would indicate the nature of the cost breakdown necessary for any useful extrapolation of cost data from one country to another; the more detailed the breakdown the greater will be the usefulness of the data.

Fuel Costs

Noting the high capital cost of nuclear power, the report points out that the promise of economic nuclear power lies essentially in improved fuel performance and a reduction in over-all fuel costs. Describing the various fuel cycles, it notes that natural uranium reactors are of considerable importance because their fuel is cheaper and more easily available. But it is also pointed out that while enriched uranium is more expensive, it permits a wide choice in the cladding and composition of the fuel material, which can result in better fuel performance and hence in an over-all reduction of the unit capital cost. A fuel cycle, therefore, must be evaluated not by itself but in the light of its over-all effect on the cost of the power produced.

The report lists the economic and technical factors determining the nuclear fuel component of the power generating costs. The first is the cost of the fabricated fuel as charged in the reactor. Secondly, there is the value of the spent fuel discharged from the reactor, i.e. the value of the fissile and fertile materials in the irradiated elements less the cost of transport and insurance of the irradiated fuel and the cost of its processing. A third factor is the fuel performance, i.e. the amount of heat obtained from a given weight of nuclear fuel before it is discharged from the reactor and reprocessed. Another factor is the fuel management (including the method of fuel procurement, the reserves of fuel required, the handling of the fuel after discharge, etc.). A fifth consideration is the specific power of a reactor, measured by the number of kilowatts of thermal power per kilogram of fuel. Yet another factor is the thermal efficiency of the plant, which determines the number of units of electric energy produced by one unit of heat. The rate of interest and plant utilization are further important factors, because of the large amounts of money immobilized in nuclear fuel. The plant life can also influence the estimation of the fuel component of the unit generating cost.

Operation - and - Maintenance and Other Costs

The report groups all costs other than those of capital and fuel in the third category. The cost of the day-to-day operation of nuclear as well as conventional plants consists of items such as labor and supervision charges, cost of supplies or consumable stores, and maintenance and miscellaneous costs. A breakdown of these costs is given in an appendix to the report.

Until further operating experience is gained, it is likely that nuclear power stations will require specialized staff especially for nuclear engineering and health and safety. This is likely to keep up the cost of operation. Supervision charges may also tend to be higher in a nuclear than in a conventional power station.

As for maintenance, the costs in respect of the conventional equipment of a nuclear power station can be assessed by reference to the costs incurred in conventional power stations. For the nuclear portion of the plant the costs are likely to be higher because of factors associated with radiation hazards; for example, it may be necessary to carry out some maintenance by remote control.

As regards special coolants and moderators, such as heavy water or organic liquids required for some types of nuclear power stations, the cost of initial charges of such materials is classified in this report as capital expenditure, but the cost of any additional supplies would be an operating expense. Some other types of special material may also be necessary in the course of operation. As regards miscellaneous costs, an important item is the cost of premiums for insurance to cover third party liability in the event of a nuclear accident. The report points out that there is no hard and fast rule for the allocation of operating charges to various categories. What is important is to ensure that no charge has been ignored in arriving at the final result.

Estimation of the Generating Cost

Once the costs of construction, fuel and operation-and-maintenance have been identified and allocated, the task is to determine the cost of the unit of energy produced. Accurate generating cost figures for a single plant would permit an economic comparison of two reactors with different cost structures in respect of capital, fuel, and operation-and-maintenance, provided they are expected to perform roughly the same services over the same period of time within the same power system.

The report, however, points out that these figures should not be used indiscriminately for comparisons between conventional and nuclear power stations. Nuclear plants will be introduced within power systems whose whole operation will be affected by them and the determination of the real cost to the system of operating a nuclear station must involve an economic analysis of the system as a whole over a period of years.

The methods of determining generating costs can be grouped in two categories: the steady state methods and the present worth method. The steady state methods, while varying in their details from country to country according to the fuel procurement system in force, have one basic common feature. They are based on equilibrium conditions under which the main costing parameters, such as average irradiation of the fuel and the plant factor, are assumed to be constant. Suitable adjustments are then made to take into account the variations which these parameters may undergo during the life of the reactor. The present worth method, on the other hand, is designed to deal systematically with any reactor type under any fuel supply system. Under this method all expenditures expected during the life of the reactor are listed and their present value determined. This value is then equated to the present value of the energy expected to be produced by the plant to yield a generating cost figure.

In the steady state methods, the cost of the kilowatt-hour (the unit of energy produced) is regarded as the sum of the costs of capital, fuel, and operation-and-maintenance and other items. The total capital cost component at the time of start-up is determined by totaling all capital cost items and adding a charge for interest during construction. An annual capital charge is obtained by taking into account the annual interest on the total investment, a depreciation charge (computed by determining the annual amounts of money which, if set aside each year, will add up at the end of the life of the plant to the total capital cost initially incurred), and taxes and property insurance where applicable. The annual capital cost component is obtained by dividing the annual capital charge by the number of kilowatt-hours produced during the year.

So far as the fuel cost component is concerned, the report describes the methods used in Canada, the United Kingdom and the United States and then points out that the allocation of the fuel cycle costs to the kilowatt-hours produced may involve the separate computation of a series of components: a fuel lease charge, a fuel depletion charge, a fabrication charge, a chemical processing charge, a shipping charge, a uranium conversion charge, a plutonium conversion charge and a plutonium credit.

As regards the component arising from operation-and-maintenance, all the cost items included under this heading can be expressed as an annual charge per kilowatt of capacity installed. The generating cost is therefore simply obtained by adding them up and dividing the total by the number of kilowatt-hours annually produced per kilowatt of capacity.

The steady state methods have the advantage of permitting rapid calculations and yielding results whose accuracy is more than sufficient when compared to the uncertainty of the present and future values of the data. They are however subject to some limitations; for example, different generating cost figures will be obtained for different years if the operational or economic parameters, such as the plant factor or fuel costs, vary during the reactor's life.

These difficulties may be resolved by resorting to what is described as the present worth method which is used in various countries for general economic evaluations. As briefly explained before, the method involves the preparation of a timetable (say, year by year) listing all capital, fuel, operation and other expenditures and credits connected with the operation of the reactor during its whole life as well as the amounts of energy it is expected to generate. A charge per kilowatt-hour is then determined, such as would make the present worth value of the total energy expected to be generated by the reactor equal to the present worth value of all expenditures at the time of start-up. The present worth method is particularly applicable when complex fuel cycles are involved, when the period of approach to equilibrium is relatively long or when future variations of relevant costing parameters can be accurately forecast.
