Nuclear Engineering Research for Development of Nuclear Power in Pakistan

By
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INTRODUCTION

It has been decided to build two nuclear power plants in Pakistan, one at Karachi in West Pakistan and the other at Rooppur in East Pakistan, as the first phase in the programme for development of nuclear power in the country. The Karachi Nuclear Power Plant, presently under construction, will have a capacity of 137 MW (gross) and is of natural uranium and heavy water type. The capacity of the Rooppur Nuclear Power Plant will be about 140 MW (gross) and its construction is scheduled to start as soon as the necessary financing is arranged. The Rooppur reactor is also likely to be of heavy water and natural uranium type. Even though the types of the nuclear power plants at Karachi and Rooppur appear to be the same, there is a difference between them in terms of the techniques employed for the transport of heat generated as a result of nuclear fission. In the Karachi Plant, pressurised heavy water is passed through pressure tubes of fuel elements, whereas in the proposed Rooppur Plant, it is likely to be boiling heavy water flowing through natural circulation.

It is believed that because of limited indigenous fuel resources, nuclear power has a bright future in Pakistan. As such, it is necessary to examine and see what engineering research could and should be conducted in Pakistan with the limited resources available to develop the nuclear power technology in the country as a support for the promising nuclear power programme.

PECULIAR NEEDS OF PAKISTAN

For a long time to come the position of Pakistan in the field of nuclear power technology will perhaps remain such as only imported nuclear power plants will be built in the country, just as we are doing with conventional power plants now-a-days. Pakistan will, therefore, be a place where the primary activities will be in terms of utilising the results of research and development

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done in other countries rather than doing the research to develop some original concepts here. But it will not be proper to expect that development work done in other countries will solve all the problems which are peculiar and of special interest to Pakistan. Because of the nature of complications involved and the fact that nuclear power technology has a great potential, for example, its connection to the development of fusion power, more engineering research and development should be done in Pakistan than has been done in the cases of conventional power. In fact in conventional power generation, nothing or very little has been done to develop better plants and resources for which we have to rely on foreign supplies at present. For example, it has long been known that peat available in East Pakistan is a source of power. But it has not yet been possible to develop a technique to burn it in boiler for power generation and we continue to import coal and oil. This is because a base for engineering research is lacking in Pakistan. The result is that we suffer economically.

The purpose of conducting nuclear engineering research in the field of nuclear power will be mainly the following :—

(*i*) to achieve economy and reliability in the systems that we purchase from abroad or develop ourselves, and

(*ii*) to provide greater degree of safety.

PROBLEMS OF PARTICULAR INTEREST TO PAKISTAN

In fact the scope for conducting nuclear engineering research in Pakistan seems to be limitless. But it will not be prudent to talk of unlimited number of problems at this stage when our resources which could be available for conducting such research are very limited. Below are mentioned some of the areas, rather than specific problems, in which engineering research should be conducted in Pakistan as essential requisite for the size of nuclear power programme envisaged for the country. These are not problems for developing new concepts of reactor or to revolutionise the technology in any particular line, but to develop some of the most important techniques which will be essential for the operation and maintenance of nuclear power plants in the country economically and reliably within the limits of safety requirements. Necessary resources exist in the country for conducting such research. As the problem areas indicate they are more or less confined to the nuclear features of the power plant. It, however, does not mean that there are no areas for conventional engineering research in nuclear power plants. It has been presumed that those problems will be tackled by organisations concerned with conventional power generation. In selecting these problem areas, it has also

been presumed that for a long time to come Pakistan will be primarily interested in building nuclear power plants using natural uranium with heavy water or slightly enriched uranium with light water, as moderater and coolant. All the problems enumerated below could be linked to the two concepts of reactor mentioned above. There are, however, other concepts of reactors, such as gas cooled graphite moderated, spectral shift, breeders, etc. whose technologies are different. All of them except the gas cooled ones involve comparatively advanced forms of technology. Therefore, the problems for those concepts of reactors will be more complicated than those mentioned below and as such are not proposed to be pursued in Pakistan at this stage. If at a later stage Pakistan decides to introduce any of those concepts of reactor the scope of these problems will have to be expanded.

Plant location

Theoretically, it is possible to instal a nuclear power plant anywhere. But practically, the cost involved and the hazards associated with the location have to be considered first. To protect the surrounding population—man, animal and plant—it becomes necessary to introduce features in the plant what are known as engineered safeguards which may increase the cost of the plant beyond limits. To provide the necessary safeguards, if the plant becomes uneconomical and hence non-competitive compared to conventional power plants, the purpose of having the nuclear plant is spoilt. Therefore, it becomes necessary to know the solution of the problems regarding the nuclear characteristics of the plant, its structural features and how they will affect the surrounding areas during normal operation as well as under the conditions of an incident or an accident. In certain parts of Pakistan where the density of population is very high and because of the fact that a nuclear power plant has to be located very near a load centre which means a city, such problems have to be examined very thoroughly to understand their implications. It is necessary to know how the nuclear plant structures will behave if it is built in the type of soil available in Pakistan and how the radioactive materials might leak through the structures into the underground and to the water streams. It should be recognised that the water from rivers and streams in Pakistan are consumed by people practically for all purposes. Above the ground level it is necessary to know how the radiation resulting from the normal operation of the plant and the release of fission products through the stack during normal operation as well as accidents disperse and settle in the surrounding areas with the prevailing wind. A nuclear power plant is not required for conducting such research. There are several ways by which information about these problems could be established. If proper precautions

are not taken in the selection of a site, a critical situation will be faced somewhere some day.

Plant Containment

Judgement on the type of containment for a nuclear power plant at a given site has crucial effect on project feasibility and plant operability. Usually, reactor containment is provided for the core melt-down accident. While there are divergent opinions about the credibility of situation where the reactor core might melt-down, it seems apparent that full or partial melt-down is and will be assumed in the foreseeable future for the determination of containment and other plant safety features. Since there are no absolute standards for comparison, there is no precise method for calculating containment for a reactor at a given site. The designer, however, tries to give every consideration to the possible accidents, the operation and effectiveness of safety features, the site environmental conditions and the population near the plant site. Research problems which could be undertaken in this field will be to help the designers to determine as to how much radiation will leak through the containment depending on the pressures and how it will affect the edge of the site and the surrounding area. The extent of the local dose of radiation will depend on the plant containment selected and the type of incident/accident occurring. There are again no prescribed standards or methods for determining the engineered safeguards required for a particular containment for any specific location. They mostly depend on the information available about precedents, experiments and analysis. But in Pakistan there are no precedents. Therefore, the necessity to determine the information on the basis of experiments becomes obvious.

Engineered Safeguards

Engineered safeguards introduced in any plant fall into the following three categories :

(*i*) Accident preventive
(*ii*) Accident limiting
(*iii*) Accident-consequence limiting

These are achieved by introducing such concepts in the design and providing such equipment, facilities and procedures as are required for normal operation as well as all other conditions. The equipment and facilities provided as engineered safeguards for the first category of normal accident prevention are reactor instrumentation, control rod system, sampling and monitoring systems, failed fuel detection systems, fuel handling systems, emergency power and mechanical protective devices. The second category of engineered safeguards are equipment for core spray and poison injection systems. But the operators

of the plant will be more concerned with the systems provided as safeguards for accident-consequence limiting. They could not do much about the systems which are already incorporated in the plant under first two categories. Actually from the public safety viewpoint containment is the most important safeguard. Other system, which can serve to reduce the leakage of radioactive materials from containment are also consequence limiters, and these include vapour spray systems, post-incident cooling systems, filters and foams. Even though the systems which are incorporated in the plant could be tested from time to time, their actual performance can seldom be duplicated. This means that incorporation of the most practical devices is necessary. This requires further development of the spray system. There is no safe device evolved yet which can remove or fix the gases released from the fission products after an accident. At present the main concern is about iodine as the source of principal hazard after an accident. The removal effectiveness of iodine by the present systems is only 95%. More work is necessary to achieve higher performance. Solid daughter fission products are removed in the particulate filters ; gases could be adsorved by either refrigerated or cryogenic absorption beds with long holdup times. More work for developing these systems on practical lines to achieve higher efficiency is required. Foams and scrubbing systems are also useful accident consequence limiters. Foams, due to their bigger surface area per unit weight, are excellent for gas fixation. Scrubbing systems are particularly suited to the vapour-suppression type of containment. While both types of safeguards are promising, further work is required to determine their effectiveness.

Improved Fuel Cycle

There are several factors which will influence fuel cycle performance of a nuclear power plant in Pakistan :

(*i*) For a long time to come the fuel for the nuclear power plants in Pakistan will be imported. If fabrication of fuel elements is done locally, then the raw materials in the form of yellow cake will be imported until Pakistan discovers and, if so, processes its own uranium ore. But fuel elements made from local uranium could be used only for natural uranium plants, because there will be no enrichment facility here in the foreseeable future. For enriched uranium plants, fuel will be imported from abroad, if Pakistan decides to build in future nuclear power plants using enriched uranium. This means that a steady flow of fresh fuel to Pakistan, its irradiation and then its return from Pakistan to the reprocessing plants in other countries, will have to be

maintained keeping several other factors in view such as time for fabrication of fuel, turnaround time in Pakistan, etc. The effect of all these stages of a fuel cycle on its economics has to be studied very thoroughly to establish the fuel cost per unit of power generated.

(*ii*) In the reactor, the performance of the fuel has to be examined in the light of the conditions prevailing in Pakistan, such as low plant factor and unreliable condition of the power grid which usually trips down frequently. It is easy to formulate a plan for the most economic utilization of the fuel when the plant achieves a steady operating condition as a base load station in a grid, but it becomes difficult to achieve good performance in fuel when the load factor is low and the grid reliability is poor. Moreover, the low load condition introduces certain other problems in the form of xenon build-up in the plant which renders the restarting of the plant very difficult after it once trips. The plant has to wait for nearly forty hours to enable the poisons to decay sufficiently so that restarting is possible.

(*iii*) The performance of the fuel has to be watched by the operators of the plant practically in its day to day operation. Even though the manufacturers of the fuel guarantee its burn-up, it is upto the operators to see that it is achieved, and in almost all cases the guaranteed value could be exceeded if the operators are imaginative. The manufacturers of fuel do not accept the condition that its performance could be guaranteed under any kind of operation of the plant. It has been observed that slight surface roughening in fuel elements increases its heat transfer considerably without any penalty on enrichment. On-load refueling, besides improving station availability, enables plant operation with lower reactivity, which eliminates the need for margins against possible variation in load and power net work limitation. Other problems which should be studied during the irradiation of the fuel elements in reactor are dimentional changes, strains due to differential growth or shrinkage as a result of flux and temperature gradient and chemical attack by the coolant on the fuel. During the operation of the plant the fuel elements may develop bowing effect due to thermal stress. The flow of coolant through the core will in that case be restricted and this may result in partial damage to the core and consequent release of fission products.

Power Flattening

Power flattening refers to neutron flux distribution in the core during the operation of the plant, and is in proportion to the nuclear fission taking place in the fuel elements and as such to the release of heat from the core. It depends on the flow pattern of the coolant through the core. In boiling water reactors upto a certain power level natural circulation in the flow of coolant is adopted. This makes the flux shape to develop a peak generally in the centre of the core. This means that most burnup takes place in the centre. In pressurised water reactors, the coolant is subjected to forced circulation, and thus can be distributed through the core uniformly. This enables the burnup to be uniform in the core of the pressurised reactors. For the purpose of achieving better burnup and to ease the problems of operation of the reactor the ideal situation is the one where the flux distribution is completely flat. It is not however possible to achieve this practically. Therefore, it is necessary to achieve power flattening by incorporating measures both during the design as well as by evolving a series of procedures during the operation of the plant. During the operation, the following programmes could be pursued for achieving flux flattening in the core :

(*i*) Fuel loading pattern and control load programme.

(*ii*) Additional gross power peaking reduction through auxiliary control devices.

Both these techniques which depend on the judiciousness of the operators of the plant could help considerably in maintaining uniform flux shape in the reactor and thus achieve better burnup in the fuel.

Measurement of Fuel Burnup

There is no method evolved yet which can determine the burnup achieved in a fuel element in a reactor. In a place like Pakistan far away from the fuel reprocessing centres, it is necessary to know at every stage what burnup has been achieved in the fuel elements. This is very essential for determining whether guaranteed burn-up has been achieved or not and also for determining the most economical plant operating procedures. There are five methods at present employed for determining the burn-up in the fuel elements. They are as follows :—

(*i*) Depletion of uranium-235 as determined by mass spectrometry.

(*ii*) Production of cobalt 60 in cobalt monitors.

(*iii*) Production of Cesium 137 in fission.

(*iv*) Production of plutonium by neutron capture in uranium-238.

(*v*) Calorimetry.

It should be mentioned that none of these methods gives a very accurate result of the burn-up and many of them require rather complicated equipment to conduct the tests.

Reliability of Safety Systems

The most reliable system is the one where a safeguard incorporated in the design has been integrated with the operating philosophy of the plant. Specifically, the selection and training of personnel, the establishment of sound operating standards and procedures, the implementation of a thorough pre-operational testing programme and the adherence to a well-planned maintenance schedule, all in continuation with a series of engineered safeguards should constitute a high degree of reliability. Improvement in reliability will continue to come through experience—the selection of methods and devices that prove superior and the rejection of the less satisfactory ones—but additional developments could quicken the pace of improvement in reliability. Reliability obtained in the operation of nuclear equipment has been found substantially better than that of similar conventional equipment. Greater reliability will come from research programme both for :

(*i*) design and development of reliable components, and

(*ii*) developing methods of measuring and predicting reliability.

In Pakistan research in this line could be conducted in the following specific areas :

(*a*) A high rate of failure results from malproduction and faulty installations. The faults are revealed during shakedown operations.

(*b*) Constant failures occur in certain components of the plant during normal operation, but whose reasons are not properly determined.

(*c*) Failure which occur due to wearout in the various components of the plant.

Development of Special Equipment

Even though all components used in nuclear power plants are being developed in advanced countries from where we will buy them for a long time to come, it is necessary for us to undertake the development of certain components without spending any big amount. These components when developed fully will help us to operate our plants in a more efficient manner. It will be, therefore, in our interest to undertake the development work of such items. Some of these components could be as follows :

(*i*) *Jet Pumps.* These pumps are used in boiling water reactors for the purpose of maintaining proper circulation in coolant,

Problems in connection with the development of jet pumps to be undertaken are as follows :—

(*a*) Exploring the capabilities of and defining the limits of single jet pump performance.

(*b*) Investigating means of improving performance and acquiring first hand knowledge of jet pump fundamentals.

(*c*) Evaluating system performance.

(*d*) Continuing the development into advanced concepts of boiling reactors.

(*ii*) *Fission products removal mechanism.* Various fission products removal mechanisms are available. There are usefully optimistic notes associated with them. Iodine is released from all reactors as one of the fission products and is regarded as most hazardous of all. The fact is that methyle iodide resists filtration under high humidity condition, (above 75%). In Pakistan, specially in East Pakistan humidity most of the times remains above 75% and as such more amount of research will be required to evolve a filtering system which will filter out the iodide from the products efficiently.

Heat Transfer and Fluid Dynamics

Research in heat transfer and fluid dynamics to understand the working characteristics in the core of the reactor are going on in all advanced countries of the world. But so far none has been able to understand the problems in a satisfactory manner and evolve any theory. Empirical correlations have been evolved to predict performance. These have worked rather satisfactorily in most cases so far. But while using empirical relations, the manufacturers of reactors often try to be liberal in order to be economic and test some of their own techniques or do an experiment with a new idea. This may lead to a serious mishap, *i.e.*, damage the core. One of such empirical correlations with which the core designer becomes seriously involved is the D.N.B. ratio. It stands for Departure from Nucleate Boiling in light or heavy water cooled reactors. It denotes the limits of thermal and hydro-dynamic performance of the core. The lower the value chosen, the lower the size of the core and hence the size of the pressure vessel. Usually the manufacturers prefer to use the lower value without having the necessary experimental backup data. The D.N.B. ratio involves a number of factors of heat transfer, burnout, fluid friction, pressure drops, etc. in the flow channels of fuels. It is necessary that similar problems should be tackled in Pakistan as well to be able firstly to understand the complications and secondly to improve the technology of any reactor that is offered to Pakistan.

Fuel Fabrication

The technique for fabrication of fuel elements using natural uranium and also slightly enriched uranium is well known and can be done in Pakistan without much of difficulty. But the methods for testing the fuel elements after they are manufactured have not yet been properly developed. The methods and procedures used by various manufacturers vary from place to place. It is believed that with the introduction of natural uranium nuclear power plants, facilities will be built for fabrication of fuel elements in Pakistan. It will, therefore, be necessary to design methods of our own for testing fuel elements which will be manufactured locally. The reactor will also continue to produce plutonium which could be best utilized as fuel in the reactor again. The plutonium could be mixed with natural uranium and thus enriched uranium fuel elements could be made. If plutonium is used as enriching material, the fuel cycle cost will go down considerably even in thermal reactors. It will not be economical to send the irradiated fuel elements or the extracted plutonium to fuel fabricators outside the country to get new fuel elements made of them. It will be necessary for us to develop our own facility. There are at present two methods for the production of plutonium and uranium fuel. These are pelletising and vibration methods. But these methods have their associated problems. It is not known at present which process will turn to be superior ultimately. Evidence suggests that vibrational compaction may be cheaper, whereas pelletised fuel has better in-reactor properties.

Standardisation

As more and more nuclear power plants are built in the country, it is necessary to have some standards in them—in their manufacture, testing and operation. Unless this is done we are likely to end-up by having equipment of several standards in our country. This will create problems for us and prove costly for maintenance. There should be a uniformity in the standards we adopt. Furthermore, the standards prescribed in certain countries are very conservative and hence costly. On the other hand we could not be very liberal either, which may be hazardous. It will thus be necessary for us to introduce a system of standards of our own to achieve the most economic plants within the limits of safety requirements.

Waste disposal

We will face a problem of disposing of the radioactive wastes, both liquid and solid, which will accumulate from the nuclear facilities that are being built and will be built in future in Pakistan. Fool-proof and safe methods have to be evolved for disposing of these materials. At present there are two

methods adopted in other countries for disposal of the highly radioactive wastes. One is to dispose them in underground and the other in deep sea. Disposal of highly radioactive materials in underground anywhere in Pakistan will require a thorough study of the sub-surface, underground rock formation, flow pattern, and the geological condition before any location can be selected. Similarly for disposal in sea, it will be necessary to study the marine life existing there, under water stream, tidal formations, etc. before a decision could be made to dispose the radioactive materials in sea. After the main principles of disposal are decided, it will be another job to develop equipment to transport and dispose of these dangerous wastes.

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