Advanced reactors in developing countries: A view from China

In many countries, energy needs are fuelling nuclear power development

by Qian Jihui

After investigating the present situation and future development trends for nuclear power all over the world, including the development strategy for nuclear power promoted by the IAEA for developing countries, a definite trend towards a new generation of nuclear power plants with improved economy, greater simplicity, and more effective use of passive safety is emerging. The incentive appears to be not only the competition for the nuclear electricity market within industrialized countries and the need to solve the problem of public acceptance of nuclear energy, but also facilitating implemention of nuclear power plants in developing countries in the next century.

Statistics show that the energy demand growth rate in developing countries is much greater than in industrialized countries. In view of limited energy resources, many developing countries have launched programmes to rely on, and introduce, nuclear power and urgently desire to carry out these programmes. In following its objective of expanding the peaceful use of nuclear technology, the IAEA has made efforts to explore ways to help developing countries deploy nuclear energy. The small- and medium-power reactors (SMPR) project, initiated in 1983, was one of these efforts.

The SMPR project included an extensive investigation, explicitly outlining the needs of developing countries introducing nuclear power technology and the large potential market for nuclear power. Major difficulties and constraints in these countries were also indicated.

The IAEA has also been striving to persuade suppliers from developed countries to make an effort to exploit this new market. However, up to the beginning of the 1980s, little interest was displayed by the nuclear industries of industrialized countries, as they were more attracted by the ongoing demands and orders in their domestic markets. For such national commercial competition, the capacity of individual reactor plants had become larger and larger. With the size increasing to 1000 megawatt-electric (MWe) and larger nuclear power plants, it became very difficult for many developing countries to contemplate building simply because of the limitation of the electricity network capacity in their countries. SMPRs were obviously required. Yet the desires of developing countries to have available SMPRs with certain prices and construction periods were not being addressed.

Admittedly, it was perhaps logical for suppliers to doubt the reality of the market in developing countries. Developing countries could hardly afford the investment for a nuclear power plant even if its capital cost was based on the same specific capital cost as large plants which is relatively low from the point of view of industrialized countries. But the fact is that if the SMPR is just simply a scaled-down version of a large one, then, according to the scaling law, it would be much more expensive and be obviously unacceptable.

With the recent decline in the nuclear power market in industrialized countries due to the lower growth rates in their domestic energy consumption, as well as the problem of public acceptance for nuclear energy, suppliers have begun to direct their attention more to developing countries. In 1985, the IAEA collected information on 23 different design concepts for SMPRs with varying levels of readiness and proveness. At that time, although the interest and support by various developed countries were encouraging, the essential problem was not solved.

Emergence of advanced reactors

Many incentives exist for developing countries to consider advanced reactors:

- Advanced reactors of highest interest to developing countries are those that are based on proven technology yet adopt new design concepts such as the passive safety principles, small modular construction, etc. and, at the same time, do not need more sophisticated or new technology. The main characteristics of these advanced reactors would be simplicity and ease of construction, operation, and maintenance.
- In utilizing new design concepts, these advanced reactors might not follow the usual scaling laws regarding specific capital costs. The specific investment cost for small and medium units might not be higher than that of larger ones. If the specific investment cost of a

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600-MWe nuclear power plant could be almost the same as that of a 1000-MWe plant, then a linear relationship of total plant capital costs versus size would exist. If such a goal could be reached, it would represent a historical turning point in the nuclear energy field and glad tidings for developing countries.

● The enhanced safety of the advanced reactors with emphasis on passive safety features may be a key point in industrialized countries to help alleviate the problem of public acceptance. Such enhanced safety is perhaps even more important for developing countries because their infrastructures are relatively poorer. It is reasonable to be concerned about the present generation of nuclear power plants which have such strict requirements for construction, operation, and maintenance. Even if this type of nuclear power plant were to be widely built and utilized in developing countries, the probability of a severe accident may increase. If an accident did happen, the continued development of nuclear energy would be jeopardized throughout the world. With nuclear power "an accident anywhere is an accident everywhere".

Developing countries are clearly looking forward to the emergence and commercialization of new types of advanced reactors as soon as possible. It is reasonable to expect that SMPRs with advanced reactors will be accepted in a large number of developing countries in the next century.

Nuclear power in China

Over the past several decades, the electric power industry in China has developed rapidly. Generating capacity increased by more than a factor of 60 during the 34 years (1952–86), corresponding to an average growth rate of 12.9% per year. Even with this growth, there has been a shortage of electricity supply of 45×10^9 to 50×10^9 kWh each year and a shortage of capacity of more than 12 gigawatt-electric (GWe). According to projections, electricity generating capacity should be increased by at least 9 GWe per year, and the total capacity should reach 230 GWe by the end of this century. Of this total capacity, more than 140 GWe will be coal-fired power plants; therefore, the coal consumption for electric power will be over 4×10^8 tons each year. Coal production is planned to be over 13×10^8 tons each year up to the year 2000, but only 3×10^8 tons per year will be available for electric power generation at that time. Even considering capacity increases in hydro-electric power, the shortage of electricity will be serious in China at the end of this century.

The necessity of nuclear power development in China was doubted by the people and the authorities until the beginning of the 1980s. Now, realism has led to the opposite opinion. The uneven distribution of hydro resources, the pollution of coal-fired power, the serious problems of transportation, the large shortage of coal production, and the impossibility of meeting the increasing energy demand in the Southeast coast industrialized areas have made Chinese energy circles and the authorities realize that nuclear power is a must in China. However, the hope of being able to rapidly develop nuclear power lies in the utilization of advanced reactors.

China's nuclear power programme requires that 6 to 7 GWe of nuclear power capacity be put into operation by the end of this century.

The decision has been made that PWRs will be the major type of nuclear power reactors deployed and, as a first step, a batch of 600-MWe PWRs is planned to be constructed using a standardized design and increasing the domestic participation step by step, so as to reduce the capital cost of plant construction. For economic reasons, the Chinese authorities expect that the transition to 1000-MWe PWRs will be made in the future. But the issue remains under discussion.

In spite of the serious accidents at Three Mile Island and Chernobyl, the Chinese authorities have openly stated that there is no change of determination in the nuclear power programme in China. In China, there is little doubt about the safety of nuclear power based on modern nuclear power technology, and not as much antinuclear sentiment as in the Western countries. When more prudent analysis is made, however, nuclear safety will place quite a heavy burden on the development of nuclear power in China. The Chinese policy-makers fully understand the importance of nuclear safety, and realize that nuclear safety is the responsibility of both the Chinese people and international society. Emphasis has been placed on accumulation of experience, on the necessity of co-operation with foreign countries and on centralized and unified management by the central Government. Basically, it has been decided that nuclear power development can not be done as boldly as with other urgently needed industries in China. This is an understandable and wise policy.

The most important factor arising from this emphasis on nuclear safety will be the overall effect on the economics of nuclear power. Because more and more complicated engineering safety features and protection systems are adopted for today's plants, the requirements for construction, operation, maintenance, and management of nuclear power plants have become more strict and elaborate. In addition, very detailed emergency planning and preparedness must be provided for the severe accident which has a very small probability of occurring. This has caused a large increase in the cost of present nuclear plants. The capital costs for coal-fired power plants made in China are rather cheap, and the capital cost for nuclear power plants seems to be rising to unacceptable levels. This is the key point which perplexes authorities in trying to decide to go forward with nuclear power more aggressively. Some economists have indicated that if the capital cost for a nuclear power plant could be controlled to under double that of an equivalent-sized coal-fired power plant (all under Chinese conditions), nuclear power would be able to be developed rapidly in China.

Advanced reactor programme in China

In 1986, the Southwest Center for Reactor Engineering Research and Design (SWRC) of China detailed a development programme on the advanced PWR and established a special research group to investigate the status and trends of the advanced technology for this reactor type and to undertake the conceptual design of a 600-MWe advanced PWR nuclear power plant for China (AC-600). The AC-600 has the following seven major requirements.

- The capital cost of the AC-600 will be about 20% lower than the 600-MWe standard PWR plant (ST-600) to be built in Qinshan, China.
- The availability factor is to be greater than 85%.
- The plant construction time is to be 4–5 years.
- The plant design lifetime is to be 60 years.
- The fuel cycle period is to be 18 months.
- The plant occupational exposure dose per person will be between 50 rem/y and 100 rem/y.
- The core-melt frequency is to be below 1.5×10^{-6} per reactor year.

In order to achieve the above mentioned targets, the advanced reactor core, the passive safety systems, and simplification are planned to be the three main emphases of research. The following major technical features will be used in the AC-600 design:

- Neutron spectral shift control will be utilized to prolong the fuel-cycle period at least by 13%, with a reduction in the core maximum excess reactivity and an improvement in the reactor safety.
- The fuel element linear power density of the core will be 12.26 kilowatts per metre, which is about 25% smaller than that of the ST-600 core.
- The core will contain gadolinium burnable poison to decrease further the core maximum excess reactivity and the critical boron concentration, with the negative temperature coefficient of the core becoming larger. This will increase the inherent safety of the reactor and simplify the systems and components.
- A 80% steel plus 20% water radial neutron reflector and larger reactor pressure vessel with a diameter of 4.3 metres will be utilized to reduce the neutron fluence on the vessel wall and to prolong the design lifetime to 60 years.
- Two canned motor reactor main coolant pumps will be attached to each steam generator channel head. It will be possible to remove 25% of the rated core power by natural circulation cooling because of the reduction in the primary loop resistance and the larger vertical distance between the steam generator and the reactor core.
- An emergency feedwater tank with a volume of 25 m^3 and an emergency air cooler with a heat transfer area of 750 m^2 are connected to the secondary side of the steam generator for each loop to form a passive emergency residual heat removal subsystem. Natural circulation cooling with 50% of the rated flow rate for the primary loop and 3.5% of the rated flow rate for the secondary loop will enable removal of the decay heat from the reactor during a station blackout.
- Two make-up water tanks with a volume of 2×40 m^3 and two accumulators with a water volume of 2×40 m^3 will be able to provide borated water to be automatically injected into the reactor without any active pumps during a loss-of-coolant accident. The AC-600 will still use an active low-pressure safety injection and recirculation system so as to conduct reliably the safety function of the emergency core-cooling system.
- A passive containment cooling system will be used to provide an effective means of long-term heat removal from the containment shell.

Implementing the above-mentioned technical measures should result in a large simplification of systems and components. For example, the number of valves is reduced by about 70%, the instrumentation by about 50%, and the pumps by about 80% for the AC-600 engineered safety systems, below the comparable systems for the ST-600. Therefore, the capital cost of the AC-600 is expected to be reduced by at least 15%.

From the preliminary analysis, the total cost of the AC-600 might be reduced by about 25% below the ST-600. The AC-600 is an evident illustration that the simplification of systems, the reduction in the number of components, and the utilization of natural laws can make the construction easier, the operation simpler, and the systems more reliable. The core-melt frequency for the AC-600 has been calculated to be about 100 times smaller than that of the ST-600, so the safety margin of the AC-600 has also been significantly increased.

The preliminary results from the AC-600 conceptual design are quite encouraging. The programme has received wide support from the authorities and will be further developed in the next 5-year State plan for nuclear power development. If the specific capital cost of the AC-600 can be reduced below or near that of the current 1000-MWe class PWR, it is very hopeful that the AC-600 could become a major reactor type to be built by China for quite a long period.

China places high hopes on the emergence of advanced reactors. If advanced reactors with passive safety principles are adopted, it may be possible to make nuclear power not only safer, but also to make systems simpler, to shorten the construction schedule, and hence, to reduce the capital cost greatly. The breakthrough of such advanced technology would have an enormous influence on nuclear power development in China. With this in mind, Chinese nuclear power experts are paying close attention to the trends in advanced reactor development in the world, especially to the AP-600 from the United States and to the modular high-temperature gas-cooled reactors. Programmes have been established and research teams have been organized under the support of the Government. China has already taken and will continue to take part in various international co-operation activities and exchanges related to these efforts.