

CHALLENGES AND OPPORTUNITIES FOR THE DEVELOPMENT OF WORLD NUCLEAR POWER

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Before the end of 2004, the development of nuclear power shows a state of renaissance in the scope of the whole world. Russia and some countries and regions of Asia continue to construct nuclear power plants positively, and the attitude to nuclear power in the America and some European countries have changed as well, who have begun to make some relevant plans. In the next decade, the nuclear power will have a long-term, continuous and stable development. The International Atomic Energy Agency (IAEA) considers to investigate and solve problems in nuclear power development in the whole world as the most urgent task and significant assurance for its continuous development.

1. Achievements and some new situations of the world nuclear power

Nuclear power has become an important part of the energy mixture in the past forty years, and has made important contribution to meet the energy requirements. The statistical data from IAEA shows that, till 2005, there are 440 nuclear power reactors with the total capacity of about 366.913 GW(e) in the world. The total energy generated in 2003 is 2525 billion kWh, which is 16% of the whole electricity energy of the world. But last year only five units were built up and connected to the grid. Two of them are in Ukraine, and the others are in China, Japan and Russia respectively. The total capacity of the six new reactors is 4785MW.

According to the statistical data, 83% nuclear power is in the developed countries. In 17 countries nuclear power has occupy 20% of the whole electrical energy. The proportion is even higher in Lithuania, France, Slovakia, Belgium, Sweden, Ukraine, South Korea, Slovenia and Switzerland.

By the end of 2004, the total operating experience in the world is 10500 reactor-year. The majority of the current reactors operate well. The safety and economy of the reactors are continuously improved.

Recently, the prospects of the nuclear power in many countries have changed a lot., Because of the increasing energy requirements, nuclear power was generally thought as a good energy choice in the view of continuously-available energy, greenhouse gas emission control, and air condition improvement. The importance was emphasized to deploy and develop the non-fossil-fuelled power plants. In the past 10 years, some new situations turned out in the development of nuclear power due to different factors. They are:

(1) North America, which possesses most of the nuclear power, has changed its attitude to the nuclear power from reservation to positive. New policies point out that nuclear power is an important constituent in the national energy provision. Related articles from the Nuclear Energy Institution forecast that in 2020 the nuclear power will increase to 50GWe, 50% higher than current data.

(2) Russia is making a large plan of nuclear power development. She plans to increase the annual nuclear power generation by twice to 3,300,000,000 MWh. Besides, Russia announced that she would sell nuclear reactors to the countries short of energy in Asia or Africa. In view of the English nuclear industry, their government would reevaluate the function of the nuclear power, which means that the United Kingdom has paved the way to

construct new nuclear plants.

(3) For some political reasons, in some countries (for example Germany, Belgium, Holland and Sweden), the governments plan to cancel the nuclear power step by step. But the proportion of nuclear power in the whole electrical energy is so high that others types of energy haven't been found to substitute the nuclear power till now. In Sweden, poll showed that 80% population supports the continuous operation of the current nuclear plants.

(4) Some countries in East Asia and East Europe are continuing to increase their capacity of nuclear power slowly.

2. Challenges of the nuclear power development

Although the nuclear power has achieved very good success, the development of the nuclear power in the world is slow. The most important reasons are the challenges stated below:

2.1. Bad economic competitive ability

Although the operation cost of the nuclear power has drastically decreased, the investment cost which is about 1500~2000\$/KW is still much higher than other general power plants. The construction period is 5~6 years. The electricity generation cost is also higher than the natural gas power plants. It is just the bad economic competitive ability that encumbrances its development. Those reactors which can not make profit will eventually be shut down. According to the American standard, the object of electricity generation cost should be about 3cent/KWh, the infrastructure cost should drop to 1000\$/KW, and the construction period should be about 3~4 years.

In order to improve the economic competitive ability, the costs of operation and construction of nuclear power must be reduced. To set up several units in the same factory will drastically shorten the construction period and reduce the construction cost. For instance, in Japan and Korea, the construction period of those recently-debugged reactors has been shortened to 4-5 years. We should improve the operation performance, increase the load factor, reduce the times of shutting off, ameliorate the maintaining, staff training and the storage management, to improve the burn-up level, prolong the refueling period, and prolong the lifetime of reactors to 50-60 years, then we can reduce the cost.

2.2 Nuclear safety to be enhanced

IAEA emphasized that the renaissance of nuclear power depends on continuous safety records and improvement of the inherent safety. The highly emphasized importance of safety originated from the Chernobyl accident happened in 1986, which is the turning point of the public choice of nuclear power. Currently, although the PBWR is very safe, it relies too heavily on manual operation and maintenance, thus is still fragile in ensuring continuous safe operation. It can be determined that if safety of the nuclear power can not be ensured, the nuclear power will be eliminated in the future. To develop new international safety standards and clear up the fear for nuclear accidents will promote the development of nuclear power. International Nuclear Safety Advisory Group (INSAG) has brought out new safety object that the safety of future reactors must be 9 times higher than the current one, i.e., the core damage object frequency is 10⁻⁵/year. Thus we need to enhance the safety, to use the latest safety technology, to adopt inactive design and to simplify the safety system. Newly designed core fuel and structure-materials should neither melt nor react with the coolant in accidents.

In addition, there are many shortages in the international safety system. Although IAEA has done a lot on the international safety system, for example, some safety standards are established. The 9.11 Accident has shown that international safety system still has shortages, which must be solved through international cooperation.

2.3. Safe management of the spent fuel and nuclear waste needed

People pay much attention to the safety management and storage of spent fuel and nuclear waste formed in reprocessing plants. Some unsolved problems enhanced the worry of safety, such as low storage capacity of spent fuel, long-term uncertainty of policies concerning radiation waste especially the high-level radiation waste in some countries, and the unsolved deep underground disposal technology problem. All these disadvantages will affect the construction of new nuclear plants passively. Only after storage location for high-level radiation waste and spent fuel are built up, could the public believe that the waste problem has been solved. It's also helpful to improve the public trust of nuclear power. To realize the minimum of nuclear waste output step by step is also an important way to release the worry of safety in this area.

2.4. To prevent or minimize the proliferation

To prevent and avoid any possible connection between nuclear power and nuclear weapon is an international political problem. It is the core of international non-proliferation system, and the basis of the IAEA safeguards.

The newly designed reactor systems and fuel cycles should change a lot comparing with the current technology, making it has no nuclear weapon material proliferation pervasion ability. At the same time the intrinsic barriers of the new designed reactors should prevent weapons-usable nuclear materials from proliferation. With increasing number of nuclear reactors, to reduce the possibility of getting in touch with the nuclear materials that can be used in nuclear weapons and achieving technologies of producing such materials is also an important condition to enhance public trust, to turn the dropping trend of nuclear power development, and to ensure its long-term development in the future.

2.5 To develop new nuclear technology and to protect nuclear special knowledge and specialists are necessary

They are the essential methods for the nuclear power development. The International Energy Organization considers that to stabilize the status of nuclear power in the world energy structure is very important for global sustainable development. To achieve this goal, new generation of nuclear power must be developed which has strong economic competitive ability, good inherent safety, protection from proliferation, good disposal ability of nuclear waste, public-approved innovated reactors and fuel cycles. The new generation of nuclear power systems should meet the requirement not only for clean energy in developed countries, but also for energy suitable for different environment and industrial conditions in developing countries.

The International Atomic Energy Agency considers it indispensable to keep a team of qualified, well-trained technologists, for the operating, the processing of nuclear waste and the licence renewal for the existing nuclear power plants today and tomorrow. It's worthy of attention that with the world's slow development of nuclear power, and with some of old technologists' retirement, the basis of nuclear knowledge is possibly being impaired or even lost. In some countries with advanced nuclear plans, the number of graduates in this field is also decreasing. It is also passive factor for nuclear power which should be paid attention to.

3 Chances and countermeasures for world nuclear power development

3.1 The chances from the increase of the world energy and electricity requirements for the advantages of the nuclear power electricity in the environment field and its sustainability.

Increase of world energy and electricity power and the characteristics of environment protection and sustainable development bring chances for nuclear power development

Some data show that the demand for energy in the world is increasing, especially in the developing countries. The World Energy Council estimates that demand for energy will be doubled in the future 50 years. Many countries will make crucial decisions about the direction, scope and character of investments in energy production area in recent years. Because those energies that are cheap, low risk, independent, with less impact on the surroundings and beneficial to the human beings will be more and more important in the future, it's a good opportunity for the nuclear power. Some experts concluded that there will probably be a wide global acknowledgement to nuclear power in the following 20 years. The nuclear power will be in the several choices to satisfy those countries that require large quantities of energy and little waste gas that will arise greenhouse effect. It can meet the increasing demand for energy, and help the industrial countries to carry out the Kyoto Protocol passed by the United Nations Framework Convention on Climate Change about the regulation of the carbon dioxide emission. For those countries have no such requirements to be fulfilled, nuclear power can also help to improve the air quality. Nuclear power is the only way to substitute the carbon-burned energy, i.e., coal, oil, and natural gas. Furthermore, it owns versatile resources: the utilization rate of uranium is expanded 100 times in fast reactor, and the fusion energy is unexhausted.

3.2 The success of the operation of the existent nuclear plants in the world in recent years impulse the development of nuclear electricity, and more and more people now approve of using the nuclear power.

Based on some information, the nuclear power in America has a favorable transition. In the report of the energy policy issued by President Bush, it is emphasized that the United States will accelerate to authorize the license renewal for nuclear plants, and will impulse the research of nuclear technology for improving energy supply. In this new energy plan, the government will rely on the nuclear power further to meet the energy requirements. Besides, the government also indicates that to develop the nuclear power is the important part of the energy policy. They will simplify the safety authorizing process, increase investment to the research of final process of nuclear waste, prolong the law about nuclear damage liability insurance, reduce the venture capital of nuclear

power company and enhance the financial support to the nuclear power research. It is also reported that the American nuclear power industry runs very well in the last ten years. Its efficiency reaches the highest level of the history, and its capacity factor of the nuclear plants breaks the record in sequent three years, and it is the first time that its electricity- generating cost is the lowest in all kinds of energy (the average is 1.83 cent/KWh) sources. In addition, the government has permitted to renewal license of those existent nuclear power plants and to build new ones. This permission is the end of the history that no new nuclear power plants were built up for 22 years and shows that the nuclear power will serve as an important part again. At the same time the proportion supporting nuclear power in the poll increased remarkably. Some data also reveal that in the United States, the capacity will increase to 50,000,000 KW before 2020 in the industry field. The new government's policy to develop nuclear power will be helpful to the renaissance of nuclear power all over the world.

Besides, nuclear power will also be the main choice of energy in countries that have advanced nuclear technologies like Russia, France, America, Japan, and Canada, in some developing countries like India, and in some economy-style transferring countries in the East Europe. For example, In Russia, it is said that 20 nuclear units will be built up before 2020; in India and Korea, some nuclear plants are also being built up now or designed to be built in the future.

3.3 The Achievements of the development of Nuclear Power and Nuclear fuel cycle provides a good technological foundation for the Nuclear power application.

In the last ten years, new types of nuclear power technologies are explored continuously. Great progress has been made in many countries in North America, Japan and west Europe. Those new technologies have more inactive safety characteristics, which can prevent and avoid many nuclear accidents automatically. The Department of Energy invested several hundred million dollars in four types of technologies in nuclear power plants; they are ABWR, System 80⁺ and AP-600 and AP-1000. The first two kinds have already been applied in new nuclear plants and new nuclear reactors that are being built now. The last two kind, whose safety system relies on gravity and pressure differentials to safely shut down the reactor or mitigate the effects of an accident, has got design certification from the Nuclear Regulatory Commission (NRC) and will be applied to the production as soon as there are investors. The AP1000 design is for a nuclear power plant capable of producing about 1100 MW of electricity. The most ancient evolutionary units of the world k-6 and k-7 run very well all the time, their average facility availability factors are 90.2% and 84.9%, respectively. In Japan, the Japan Electric Power Co. Ltd plans to add thirteen units by the end of 2010, among them eight units are ABWR.

The Mitsubishi Heavy Industries Co. Ltd puts forward the twenty-first century plan to develop the NP-21 PWR recently. The capacity of one unit for this type is from 1500 to 1700MW, and it is combined with the active and inactive design. The 1750MW Europe Pressured Reactor (EPR), which is now developed by France and Germany corporately, also can meet the European Safety Criterion and is being built in Finland.

In Russian, the evolutionary nuclear reactors including V-392 and VVER-1000 are being developed and built up in St. Petersburg. And, in Canada, the Candu-9 is developed successfully. It has good adaptability to applied fuel. Besides natural uranium and low-level uranium, it can also use MOX fuel, PWR spent fuel and thorium fuel. Moreover, it can also burn the weapons-usable plutonium materials and separate actinoid from the nuclear waste.

3.4 Facing challenges in the new century, the most important measure is to develop the new generation (the forth generation) nuclear plant, which is indispensable for the progress of nuclear power.

According to foreign experts, the evolutionary design (the third generation of nuclear reactor) cannot solve the problems in the fields of economy, safety, waste disposal and proliferation. To solve these problems, the most essential way is to put stress on developing the new reactors (the forth generation) and new technology of fuel cycle.

Actually, nuclear industry administration of some countries have all understood the importance to reform the reactor and to study the new generation. In Canada, China, France, India, Japan, Korea, Russian, South Africa and the United States, some reformations about the fuel cycle and reactor are going on. Some countries have already investigated some simply designed, profitable small reactors such as the Carem-25 in Argentina, the KLT-40 in Russian, and the SMART in Korea, which cost little in building the factories. In the field of the fuel cycle, Japan and Russia have already studied on minimizing the volume of nuclear waste and high-temperature metallurgy technology. Korea and Canada studied on applying the Dupic-System in which plutonium is not separated from the PWR spent fuel. The Thorium-Uranium fuel cycle techniques are also studied by India and

the America; the P-T system which can prevent separating and transmuting of the actinoid is studied by France, Japan and the America; the fast reactor fuel system which is built by lead-bismuth alloy to improve the utilization rate of resources, the non-proliferation ability, and the safety, is studied by Russia.

Furthermore, based on some information, comparing the design of different kinds of revolutionary reactors with the forth generation reactor, some foreign nuclear power experts considered many kinds of reactors can be used as candidates for the new generation reactor, including the high-temperature gas-cooled reactor, liquid-metal fast breeder reactor used atrium-aluminum alloy and so on. Especially the pebble bed modular reactor (PBMR), which is explored by South Africa, is a kind of small reactor whose power is 110MW. Its heat efficiency is as high as 42-50%, the fuel is only 5-6% low-level uranium, and its burnup can reach 80000MWd/tu. PBMR can also be helpful to prevent proliferation because of another characteristic - it uses such kind of one-off fuel that we cannot separate plutonium from the disposal. Its investment cost is 1000\$/kW, and power generation cost is 1.4-1.8 cent/kWh, just the same as the coal electricity. The construction period is only 2 years. We can use ten PBMRs to form a nuclear plant of 1140MWe. Some experts considered that PBMR will be the most possible candidate style for the forth generation reactor.

In a word, what we can depend on to survive in the future competitions is to develop the new generation reactors and the new technology of fuel cycle. Only if we can solve all the problems we meet nowadays in the nuclear power field, will the nuclear power be an important part of the energy system continuously.