PROSPECTIVE ON DEVELOPMENT OF NUCLEAR POWER AND THE ASSOCIATED FUEL CYCLE IN CHINA

***Zhongmao Gu[1], Changxin Liu[2] and Manchang Fu[2]**

1. China Institute of Atomic Energy, P.O.Box 275-8, Beijing 102413, China

2. Chinese Nuclear Society, Beijing 100822, China

zmgu@iris.ciae.ac.cn

ABSTRACT

The challenges China is facing in energy security are briefly discussed. Then, the development of nuclear power in China in the first half of 21st century is envisioned, and it is expected that Generation-3 PWR nuclear power plants (NPPs) would be the leading units of nuclear power in the coming 30～40 years. As part of the nuclear power program, the R&D work on nuclear fuel cycle is generally proposed.

Keywords: nuclear power; PWR; uranium enrichment; fuel assembly manufacturing; MOX fuel; spent fuel reprocessing.

I. CHALLENGES TO CHINA'S ENERGY SECURITY

With the drastic increase of oil and gas consumptions since mid 1990s, China is becoming more and more dependent on imports of oil and gas, and the major source of oil imports is the Middle East, the most unstable area in the world. This has aroused the people to pay attention to the energy security in China

In our opinion, China's energy security is facing to two big challenges. The first one is the contradiction between the ever increasing demands of the country's energy and the insufficient reserves of the fossil fuels. Presently, China's per capita energy consumption is only some 1 tce/a, which is about half of the world average. China's energy supply has to be increased significantly in the coming decades to meet with the requirements of the rapid development of her national economy. However, published data show that China's per capita reserves of fossil fuels are much low than the world average as shown in Table 1.

Table 1 China's per capita exploitable reserves of fossil fuels

Fuel	Per capita reserves in	Compared to the average	Compared to the U
coal	90 t	2/3	1/10
oil	2.6 t	1/13	1/5
gas	1074 m^3	1/17	1/16

The second challenge comes from the irrational energy structure, in which coal covers 60% of the primary energy and 75% of the power generation. The coal based

energy structure causes serious problems of environmental pollution and emission of green house gases(GHG). China has become one of the most polluted countries in the world. Taking the year 2000 as an example, China emitted 20 Mt of SO_2 and 3 Gt of CO_2 , both ranked the world No.2. The economic loss by environmental pollutions accounts for 3~7% of GDP in China. These problems would hinder the further development of the

country if they could not be solved properly.

Owing to the rapidly increasing demand of oil and gas, the situation that China's economy is heavily dependent on oil and gas imports seems never be reversed. Data shows that in 2004 China's oil import was over 100 Mt which covers about 30% of the total oil consumption. It is estimated that by 2020, China's oil demand will be ca 450 Mt and more than 50% will depend on import. Facing this severe situation, some people suggest to practice the multi-channel imports and to establish the national strategic reserves of oil. These measures may be effective to alleviate some problems in few decades. But, considering the fact that the oil and gas reserves in the earth will be depleted in less than 100 years, we have to adjust from now on the energy structure in China, gradually reducing the sectors of coal, oil and gas and increasing the sectors of new energy resources.

Among the alternative energy resources, hydro power resources, as the renewable and clean energy resources, are abundant in China and will be exploited with top priority in the coming years. In China, the economically exploitable hydro power resource is estimated to be some 400 GWe. At present, the installed capacity of hydro power is some 100 GWe.

The non-hydro renewable resources, such as wind, solar and biomass energies, are highly encouraged to develop (especially wind power). However, they could not replace the fossil fuels in a large scale in the foreseeable future owing to their low energy density, intermittent supply and high cost.

As a well-developed clean energy with zero discharge of GHG, nuclear energy has been received more and more attention in China and is regarded as a big supplement to the fossil fuels together with the hydro power. There is a big room for the development of nuclear energy in China.

II. NUCLEAR ENERGY WILL BE ONE OF THE MAJOR ENERGY SOURCES IN THE COMING 50 YEARS IN CHINA

With the rapid growth of national economy, it is expected that by the year 2020 China's total energy demand would be increased from the present 1.3 Gtce to 3.0 Gtce or more and the power capacity would be increased from the present 400GWe to some 960GWe (some 560GWe increase). To solve the problems of the ever increasing demand-supply contradiction, China's near term policy has to depend on coal as the major energy source while putting the top priority of improving the energy efficiency. So, more than half of the 560GWe increase will be contributed by the coal-fired power, and the installed capacity of hydro-power would be increased by more than 100GWe. Even then, there is still a big gap to be filled. This calls for the accelerated development of nuclear power as fast as possible. It is estimated that the nuclear power capacity will be increased from the present 9 GWe to 40 GWe by 2020, with the nuclear share up to some 4% of the nation's total power capacity.

After 2020, it is predicted that China's domestic supply of oil and gas will drop down and will have to be mainly dependent on import; the larger scale use of coal will be limited by the environmental burden (the highest scale of coal burning should be less than 3.4 Gtce/a); there will be no big room for further expansion of hydro-power. It will be unlikely that the other renewable energy resources (such as wind and solar energy) could replace the fossil resources in a large scale. The major way to meet the energy demand after 2020 is to further increase the share of nuclear energy so as to ensure both the energy security and environmental safety of the country.

By the mid of 21st century, the capacity of nuclear power in China should reach 120～240 GWe with its share up to 10～20% of the total power capacity. The nuclear power will then be one of the three major energy resources in China together with the cleaned coal and hydro-power. The nuclear energy will make greater contributions to China's sustainable development.

Considering the fact that the economically exploitable uranium reserves in the earth crust are limited (～4.6 Mt for the cost <130 US$/kg), sustainable development of nuclear fission energy depends on the fast breeder reactor (FR) energy system, which is based on the closed fuel cycle. China's nuclear energy development will follow the way of thermal reactor system–fast reactor system gradually. It is estimated that at least 30～40 years are needed for the commercialization of the FR energy system. Therefore, we will have to deploy all the thermal reactor power plants (mainly PWRs) before 2030 and possibly will still be mainly dependent on PWRs before 2050.

III. GEN-3 PWR NNPs WILL BE THE LEADING UNITS IN CHINA IN 30～40 YEARS

After nearly 20 years' development of nuclear power industry, 3 bases of nuclear power plants (NPPs) are formed in China, i.e., Qinshan, Daya Bay and Tianwan. By May 2005, 9 units have been put into operation with the total installed capacity of 7 GWe. After the completion of the another 2 units in Tianwan in this year, China's total nuclear power capacity will reach some 9 GWe.

In the next few years, 8 more units are to be constructed. Among them, 4 units will be the improvements of the Qinshan Phase Two (2×600MWe) and the Lingao NPP (2×1000MWe) and designed mainly with our own efforts. Another 4

units in Sanmen and Yangjiang will adopt the more advanced technologies and thus call for more international co-operations.

For the large scale development of nuclear power, China has decided to select PWR as the main reactor-type of NPPs in the coming decades.

Up to now, China has established the capability of designing and building 600MWe NPPs and has the basic capability of designing larger scale PWR NPPs through cooperation with the advanced foreign companies while mainly relying on our own efforts.

It is our understanding that China will make great efforts to quicken the pace of developing the technologies of Gen-3 PWRs in the coming decades thus narrow the gap with the world advanced level. In this regard, wide international cooperation is of vital importance.

Considering the pressing need in China to build NPPs in the coming years without stopping, we will improve the existing Gen-2 PWRs and deploy some PWR NPPs of Gen-2+ in the near-term.

By 2015, China should be capable of designing and constructing Gen-3 PWR NPPs, which will be the leading units of nuclear power before the commercialization of FR system in China.

IV. WORK ON THE CLOSED FUEL CYCLE NEEDS TO BE FURTHER STRENGTHENED

1. Front-end of the fuel cycle

It is reported that the explored uranium reserve in China is not so abundant. However, the spectacular uranium resource is said to be rather rich. We must use the advanced technologies to explore more new uranium reserves to support our

nuclear power industry. Studies on the theory of uranium ore formation and the new technologies of exploration will be emphasized.

For the uranium enrichment, we have imported from Russia two centrifuge production lines with the capacity of 500 tSWU/a for each line to replace the diffusion process. We are now improving the centrifuge technology on the bases of the centrifuge units imported from Russia and try to achieve localization in the near future and to develop the more advance supercritical centrifuge technology.

For the fuel assembly manufacturing, we imported the design and manufacturing technologies from France and Russia in 1990s. These measures have significantly improved our fuel fabrication technology. Presently, the manufacturing capability of PWR fuel assembly can meet with the requirements of the domestic nuclear power market. It is expected that by 2010 and 2020 the manufacturing capability of PWR fuel will reach 500 t/a and 1000 t/a respectively.

In order to increase the uranium utilization rate and lower the cost of the fuel cycle, R&D work is being done to develop high performance UOX fuel assemblies with the burn-up up to 60 GWd/t.

2. Back-end of the fuel cycle

Considering the relatively limited reserves of the low cost uranium resources in the earth as well as in China, we follow the closed fuel cycle as a reasonable option for sustainable development of nuclear energy.

Based on this strategy, our spent fuel reprocessing pilot plant with a capacity of 50 tHM/a is under construction which will be put into trial operation by 2007. A commercial reprocessing plant is under consideration and is expected to be

built by around 2020. The large reprocessing plant to be built in China will be designed based on the experience of pilot plant operations and the experience gained in some developed countries. International co-operation will be very important for designing and building the advanced reprocessing plant in China.

The separated Pu from reprocessing process will be probably first recycled in PWRs as is being practiced in European countries and Japan, and then recycled in FRs in the future.

The first batch fuel for China's experimental fast reactor will be HEU provided by Russia. It is planned to use MOX fuel in the proposed prototype fast reactor. The R&D work on MOX fuel fabrication has been started and is now just at its early stage in China.

It is expected that the MOX fuel pellet could be fabricated for irradiation tests by 2010 and the MOX fuel assembly could be fabricated for irradiation tests by 2015 with the aim of building a MOX fuel fabrication plant by 2020. Besides, the U-Pu-Zr alloy fuel will be also started to develop for improving the breeding coefficient of the Pu fuel in the future.

V. SUMMARY

China has an ambitious program to develop her nuclear energy in the coming decades so as to ensure the sustainable development of national economy of the country. The development of nuclear fission energy will follow the route from PWRs to FRs with the closed fuel cycle.

In the coming 30 years or so, PWR is selected as the main reactor-type of NPPs and Gen-3 PWRs will be the leading units of NPPs in China. With this goal in mind, we will quicken the pace of developing the technologies of Gen-3 PWRs with our own efforts while actively joining the international cooperation.

As a developing country, China's technologies on nuclear fuel cycle lag behind the world advanced level. In the front-end of the fuel cycle, China has established her industrial production capabilities. But the technologies need to be up-graded and the scale needs to be expanded. The back-end of the fuel cycle in China is the weak point of the whole nuclear fuel cycle owing to the insufficient investment in the past decades. We have to pay more attention to and strengthen the R&D work in the back-end of the fuel cycle and build a complete fuel cycle industry, so as to meet with the requirements of sustainable development of nuclear power in China. To achieve this goal, it is of vital importance for us to share the knowledge and experience with our foreign colleagues.