On the Sustainability of WCR Development in China

Shen Wenquan

State Nuclear Power Technology Corporation, Beijing, China

Abstract. By analyzing the status of China's energy supply, an excellent perspective of water cooled reactor (WCR) development in China has been stated. the good opportunities are coupled with austere challenges. Taking the 21 century's nuclear power sustainable development requirements into account, two countermeasures of strategic consideration have been put forward. Thus China's WCR development can not only catch up with the world advanced level in proper time, but also possess the enough stamina of sustainability.

1. INTRODUCTION

As far as 2000, the electricity production capacity in China has ranked to No.2 of the world. In the new century, the electric industry has entered a rapid developing stage. From 2004, the annular installed capacity increase has kept in almost constant rate of 100GW nationwide, arrived at 800GW in 2008. China has become the veritable electricity production and consumption country in the world. However, the electricity consumption per person is only the half of the world's average. That is to say, in order to become a medium developed country in the middle of this century, China still has a long way to go. Meanwhile regarding the environment safety aspect, due to the fossil fuel-based energy structure, China has been the largest country of SO_2 and CO_2 emissions in the world.
Considering the challenges of national security, energy safety, and environment safety etc, and taking into account that oil and gas resources will be more dependent on international market, the coal-fired generation will put more and more pressure on the environment, and the reasonable usable hydro power will be less and less, as the most practicable large-scale alternative energy source, WCR nuclear power plant has an excellent perspective in the Chinese energy development program of this century. Of cause, the good opportunities are coupled with austere challenges [1] .

2. OPPORTUNITIES

2.1. Inconsistent status of China's energy

2.1.1. Contradiction between energy demand and its supply

Because of the rapid development of China's national economy, the speed up of industrialization and urbanization, as well as the upgrade of people's life standard, the continuous energy demand increase is the must. For the goals of well-off society by 2020 and medium developed country by 2050, there still exist considerable gap between energy demand and its supply.

In addition, China's discovered coal reserves is 115 billion tons, which seems quite enormous, accounting for 12% of the world's, however, China has a population of 1.3 billion, personal capita reserves is equivalent to half of the world's, a tenth of the United States', one-seventh of the CIS, and even much less the personal capita oil and natural gas reserves (11% and 4% respectively)[2]. It would not be imaginable to set the goal of per capita installed capacity in China as high as those in developed countries, otherwise the most of world fossil fuel resources would be consumed by China.

2.1.2. Imbalanced distribution of energy resource and its consumption

In China the geographical distribution of energy resource is imbalanced, such as nearly 80% of coal reserves distribution in the North, more than 70% of water resource in the Southwest, and the energy resource of eight provinces of South China together with Shangdong, Hebei provinces only occupy 13% of our whole country, however, their population percent is 63%, and energy consumption percent is 65%. For example, half of the national rail freight volume and one third of the water freight volume are used for transporting coal, yet it is unable to meet the energy demand for those regions [2], resulting in not only the heavy burden to the transportation systems, but also the considerable increase in coal price.

2.1.3. Irrational energy structure and its environment impact

At present, in the electricity supply, coal accounts for 74%, hydropower accounts for 24%, and nuclear power accounts for only 1.6% [2]. Large-scale coal firing not only causes the serious environmental pollution, but also results greenhouse gases problem. For example, the acid rain coverage has already been very large. In 2005, among the monitored 696 cities in the country, the acid rain appeared in 357 cities (i.e. 53.1% occupation), and among the 111 cities in those special controlled zones, it appeared in 103 cities (i.e. 92.8% occupation), including 25 cities (22.5% occupation) meeting with more than 80% frequency of acid rain, and 27 cities (24.3% occupation) subjected to rain water with PH value less than 4.5[3]. In general, the pollution level seems getting higher yet.

2.2. Significant roles of WCR NPPs in China[4]

2.2.1. Significance to energy security

Energy security is related to the national security, economic development and social stability, and is closely related to people’s life. To deal with above mentioned 3 inconsistencies, China must pay more attention to energy saving, and take positive measures to open up new growth point in the energy supply.

Priority should be given to support the development of energy-saving technology innovation, improve the efficiency of energy use. In this regard, there is still a big gap between the developed countries and China (The per capita GDP energy consumption in China is 8 and 3 times higher than that in Japan and in US, respectively). It means a considerable potential needs to be tapped. There is an old Chinese proverb-“opening the stream source, while cutting down the flow”. According to the reality of China’s per capita energy resource deficiency, saving energy consumption should be committed, while developing and deploying new increasing point of energy sources, such as nuclear energy and non-water renewable energy.

Moreover, nuclear energy could loose the heavy burden to the national transportation systems, because of considerable less fuel transportation requirements, compared with those for fossil power plants. WCR technology is mature in the world and in China as well. At present, it is the most practicable choice, which can replace the conventional energy on a large scale, and speeding up its development has been an ongoing pathway in China to cope with the aspiration demands for energy supply and environment protection.

2.2.2 Significance to environment safety

As mentioned above, China has become the No.1 country of CO_2/SO_2 emissions in the world. China has set the policy to accelerate the development of nuclear power as the most realistic and effective way out to reduce CO_2/SO_2 emission. If there will be operating WCR NPP of 40GW in 2020 (It is foreseeable to have an upward adjustment of the goal. How much upward is now under discussing within governmental organizations), the reduced amount of CO_2 emission would be 3×10^8 ton each year in China. Considering the much large scale NPP development after 2020, as a responsible large country, China will surely made the great contribution to the world conspired emission reduction goal in proper time.

Of course, considering the history and status of China’s energy structure, before 2020 China’s coal based energy supply will be unable to extricate itself from the pattern, but to develop nuclear power is a viable option. The State Council principally approved a clear medium and long-term nuclear power development plan – in 2020 China’s nuclear power installed capacity should reach 40 GWe (about 4% of the national total installed capacity) in addition of 18GWe under construction. Through these years effort, it has been shown that the trend to have upward adjustment of 40GWe goal is foreseeable, and after couple of years China will have the domestic capability to start constructing 6 units of GW-size WCR/NPP each year. WCR power plant development in China has shown its excellent way ahead within foreseeable 30-40 years, and its significant role to realize Chinese top leader’s commitment to CO_2 emission reduction during last month’s UN Summit Meeting.

3. CHALLENGES

Although WCR nuclear plant is conducive to resolve the issue of China’s energy sustainable development, it also has its own challenges, especially for the status of large scale deployment.

3.1. To improve safety and economics

It is well known the large scale deployment of NPP could improve the economics because of the scaling factor; meanwhile, it needs to pay more attention to the overall risk reduction from nationwide and worldwide sight. The historic facts remind us that the Three-mile Island and Chernobyl accidents resulted in significant impacts on the development of nuclear power in the world. Several decades’ stagnation was encountered in some nuclear power developed countries. Of cause, worldwide R&D efforts, so called 3rd generation technology development, have never been stagnated. The safety performance improvement is focused on the sever accidents risk reduction, and the economics improvement relied on either system simplification or unit capacity increase. Distinctly, the passive system application could obviously improve the safety performance coupled with the system simplification and consequently the economical competitiveness.

Considering the demand of installing 40GWe nuclear power capacity in China before 2020, and the available domestic capabilities, the reasonably scale construction of evolutionary 2nd generation nuclear power plant is still ongoing in China. Based on the international bidding, China has caught the favorable chance to import advanced 3rd generation AP1000 technology from abroad, and will build up the domestic innovation capability through its digestion. It is expected to complete the first AP1000 plant around 2013, and meanwhile to realize its batch and standardized construction immediately.

3.2. To gain the domestic capability of design and manufacture

Obviously, for the safe and economical reasons China’s large scale development of WCR/NPP must rely on our own capability of design and manufacture. The available 2nd generation PWR technology foundation is easy to be upgraded to 3rd generation PWR, based on the digestion of imported AP1000 technology. A special national R&D key project has been approved partly for this purpose. All designated design institutes and manufacturers are acting as the transferred technologies users to carry out the task for localization through 4 units’ self-reliance support AP1000 projects, and to have enough financial support for gaining their capabilities of self-relied design and manufacture. Then the following standardized AP1000 batch construction could be relied mainly on our own.

Taking examples of materials’ supply, the worldwide available large forging, Zirconium and Inconel 690 tubes supply capabilities are not enough to fully support China’s speeding up NPP development requirements. The Chinese production entities for large forging, Zirconium and Inconel 690 tubes supply will finish construction within a few years. Moreover, the large pieces of NPP modules’ manufacture and construction are unique for AP1000 without any previous examples, and we have to build up relevant capabilities by ourselves.

3.3. To push forward the plant life management (PLiM)

China's NPPs have multi-type WCR units, such as PWR, WWER, CANDU, and will have AP1000 and EPR. It's an unremitting and arduous task to maintain their safe operation. China has paid more attention to the R&D on ageing and life management.

Qinshan Phase 1 is the first NPP in China. It is at the middle age of its 30 years' design life, and the ageing management and life extension R&D activities have been carried out for many years. The main emphases are put on the reactor pressure vessel aging issues, including structure integrity under PTS, ex-vessel neutron dosimeter application and irradiation embrittlement evaluation, and fatigue aging analysis. Another focus point is assessment and aging management of I&C cables, especially 1E grade cables are safety important for operating NPP, including the tiny-destructive testing or non-destructive method to test the cable aging phenomena. These activities would surely gain some preliminary experiences, which are not enough for so many operating NPPs requirements. Of cause we hope to promote the international exchange and cooperation in this area. That's why we quite welcome the IAEA hosting the PLiM Symposium last spring in Shanghai, China.

Anyhow, most of NPPs in China is still quite young, and much more WCR NPPs are under construction within coming 30-40 years with their design life as long as 60 years and possible life extension of a few decades through the effort of PLiM. It is quite sure that WCR will be the domain type of NPPs and last its viability for the whole 21 century, as well as the early stage of next century in China.

3.4. To improve utilization rate of nuclear fuel

The fissile uranium which can be used in the reserves of the earth's resources is limited. If we simply develop once-through fuel cycle WCR nuclear power plants, the uranium resources utilization rate is less than 1%. According to the forecast of the nuclear developing scale, the discovered uranium resource (of cause new discovery is expected) can be maintained to use for nearly 100 years. The sustainable way for solving this problem is to develop WCR with fuel recycle capability or with fast spectrum reactor core. The 3rd generation NPPs could use MOX fuel with full core loading, which will increase uranium utilization rate and partly ease up the uranium resource supply before the fast spectrum reactor and relevant fuel cycle technologies get maturated and commercialized in China.

Regarding the 4th generation nuclear technologies, most reactor types adopt fast spectrum core. Then, discovered Uranium resources will be able to support one thousand years nuclear energy development, even if its uranium utilization rate reaches 10% (it is much higher by theoretical estimation). For the long-term development, fusion reactor nuclear plant could have unlimited fuel resource and can finally solve the challenge of sustainable application of nuclear energy.

3.5. To prove up more uranium resource

The potential uranium resource in China is comparative ample. The natural uranium supply would not become a unconquered restrict factor, but to compare with the long term demand of nuclear energy development the amount of discovered uranium resource remaining still retains large differences. In order to ensure the enough uranium resource supply for the speeding up nuclear energy development, the parallel utilization of inland and overseas uranium resources has to be considered.

Regarding the inland activities, the research on uranium geological proving up technology and mine formation theory should be emphasized, and the support to the geology prospect for uranium resource should be promoted, so as to improve the capability to prove up more uranium mines. [1]

In summary of chapter 1 and 2, in order to meet the demand of country's economy and society development, the realization of China's energy sustainability needs to enhance adjusting and optimizing the national energy mix, by means of seeking new increasing point of energy resource. Thus, WCR nuclear power must be the most reasonable practicable pathway, and doubtless posses the irreplaceable strategic position in this century. Meanwhile, considering its own sustainability challenges, the proper arrangement of medium and long term's development program is of more strategic significance.

4. STRATEGIC ARRANGEMENT

The map of NPP sites distribution shows the most NPP located in coastal areas, including 4 units of AP1000 plants arranged in Sanmen and Haiyang sites, and the inland LPPs are firstly programmed along the Yangzhi river in Jiangxi, Hunan and Hubei provinces. With passed more than 20 years' nuclear power development in China, the preliminary nuclear energy industry foundation has been built up. It's the time to speed up the development of nuclear energy.

Fig. 1. The map of NPP sites in China

4.1. Speeding up 3rd generation technology deployment and its self –reliance [5]

Generally, the 3rd generation PWR will become the main stream NPPs for the coming 30-40 years in China, with their designed life time as long as 60 years. To fulfill this task, our SNPTC was established on May 22, 2007, and is a state-owned corporation with 3 government authorized responsibilities.

4.1.1. To sign the contract of introducing AP1000 technology from U.S. on behalf of the state owned share

The Contract was signed on July 24, 2007, and put into effective on Sept. 24, 2007 after both sides government approval.

4.1.2. To organize the construction of first batch of 4 units AP1000 NPPs, as the self-reliance supporting projects

The picture shows the overviews of Sanmen and Haiyang sites. The construction schedule of Haiyang is half year behind that of Sanmen. Sanmen Unit 1 completed first concrete pouring on March 31, 2009, and Haiyang Unit 1 had that on Sept. 26, 2009, both in schedule.

Fig. 2. Modal views of Sanmen and Haiyang sites

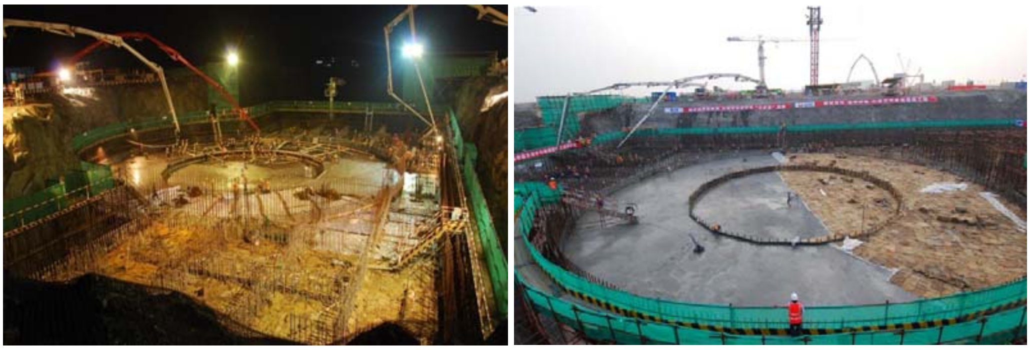

Fig. 3. The FCD in schedule on Sanmen and Haiyang sites

Also, the good practice has been shown during the largest module of fuel building assembling and lifting on Sanmen site, as seen in the pictures.

Fig. 4. Module construction on Sanmen unit 1 site

4.1.3. To act as the implementation organization of National Key Project on large advanced PWR R&D for AP1000 technology digestion, assimilation, and its innovation

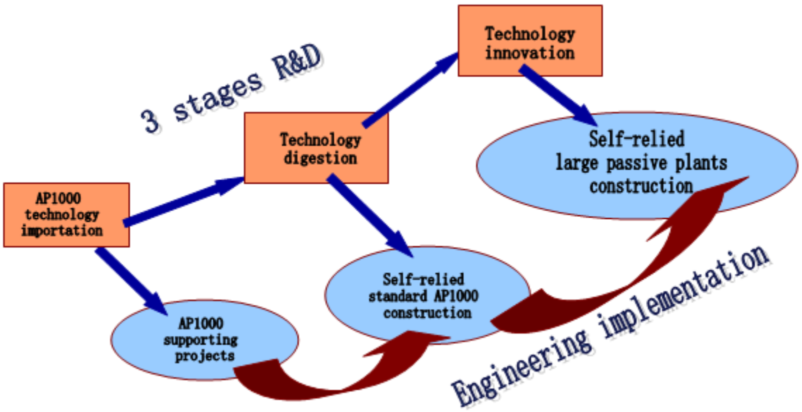

Fig. 5. The three stages of National Key Project on large APWR

Three stages R&D, including AP1000 technology introduction, digest, and innovation, while coupled with engineering project implementation of first 4 units AP1000 supporting projects, self-relied standard AP1000 construction and finally to reach the goal of self-relied large passive PWR, with same safety performance level of AP1000, but better economic competitiveness.

And, after the implementation of National Key Project on large advanced PWR R&D, 4 goals will be achieved before 2020:

***Digestion goal**: To construct more AP1000 units, including inland NPPs, with design self-reliance and manufacture localization, based on 4 supporting projects in Sanmen and Haiyang sites.
***Innovation goal:** To develop self-relied large passive PWR with safety performance similar to AP1000, and better economics.
***Engineering goal:** To have capability of localized AP1000 in batch construction, and to complete the self-relide large passive CAP1400 demonstration.
***Platform goal:** To form the self-relied innovation technical platform with abilities of R&D, including test facilities, component manufacture, and code & standard systems.

4.2. Initiating inland NPP construction at the earliest

At the beginning stage, the reasons why China's NPP started in coastal areas were that there existed the higher economical development speed, the better electric grid withstanding large NPP capacity, and the longer distance from coal mining regions. Nowadays, the story has changed quite a lot. Compared with coastal areas, the inland areas are facing stronger challenges regarding economical development, environment protection, coal transportation, and electric grid structure problems. Some southern-middle inland provinces are also lack of coal, which is even more difficult and expensive to transport to inland by railroad than to coastal areas by ocean shipping. Therefore, to develop inland NPPs could not only ensure the energy demand for the regional economical and social development, but also reduce the regional strength of acid rain, the pressure to environment protection, and the heavy burden to railway for coal transportation.

For the time being, the constructing NPPs are still mainly at coastal areas, but China has large territory with richer nuclear power site resources at inland areas. Considering the long construction period and much larger NPP future development requirement, to develop first batch inland NPPs at feasible sites could provide strong assurance for realizing the target of national mid-long term nuclear power program, and build up the technical foundation for constructing more inland NPPs in the future. The economical and social benefits of developing inland NPPs are obvious. Chinese Government has clarified that inland NPPs will start soon with the only option of AP1000, because of its higher safety performance and compact plant layout, the standard design of which has been in progress. The first inland AP1000 plant could hopefully in construction by the end of 2010.

In fact, the world most NPPs are built at inland areas. For example, in France and U.S. the 65.1% and 75.7% of installed capacities are located inner land respectively. The relevant technologies are also available in China. China has been building and operating lots of inland nuclear reactors, and has successfully exported 300MWe PWR plants to Chashma, Pakistan (Phase1 has been operating for many years, and Phase 2 is under construction). They are both located at inland.

According to the preliminary survey, the potential inland NPP sites are quite lot. Many prophase works, such as earthquake, geology, hydrology, transportation, and meteorology data acquisition and analysis studies have been carried out. Some of them have passed site preliminary feasibility review, and shown the readiness to build large NPPs. Many of local governments and public actively support the development of NPP, push forward the prophase activities, and express their aspiration to initiate local NPP at its earliest possibility.

4.3. Paying attentions to 4th generation WCR—SCWR

SCWR is the sole water cooled reactor technology which was passed experts evaluation by "the Generation 4 Nuclear Power International Forum" (GIF), and may become the successor of large-scale advanced PWR in the future. Compared with the current designed water cooled reactor, it is simple, highly efficient and economical. SCWR running pressure overtakes the critical pressure of water (22.1MPa), therefore the coolant temperature can surpass critical temperature (374℃), arrive at the expected higher value, and attain higher efficiency of 44%, which is larger than current PWR power plant efficiency of 33%. On the other hand, under the super critical pressure, the whole plant can adopt one primary circulating system, coolant directly flows from the reactor core to turbine, the recirculating system, separator, dryer of BWR and the pressurizer, steam generator of PWR are needless, the systems are simplified and the volume of reactor containment is decreased to reduce the nuclear power plant cost. SCWR is built on the basis of the two mature technologies, i.e. PWR nuclear power plant and super critical conventional power plant. Its main technical challenges include the reactor core design and relevant materials.

The large-scale SCWR, as the successor of PWR, is hopeful to be the future option of nuclear electricity generation. China has taken part in this international coordination research plan of SCWR which is organized by IAEA and started from 2006, and has been the new member of Generation 4 International Forum (GIF) from 2007, not only to participate the activities in the frame of VHTR and SFR System Steering Committee (SSC), but also to be the observer in SCWR SSC. A National Key Research Program on SCWR supported by Government organization has launched in 2007. Some basic research projects on reactor physics, thermo-hydraulics, and materials have been ongoing, and a few innovative reactor design concepts are proposed and have got reputably evaluation.

4.4. Following the trend of non-electrical applications

The small and medium reactors (SMR) are characteristics in its own safety and economy especially have well adaptability in non-electric application, lower one-time investment, and more component in-machine shop manufacturing. They are easy to realize modularization and to be built in outlying area. Based on the modular design, manufacturing and installment technology, the site selection and unit-capacity of nuclear power plant can be more flexible. Moreover, the possible higher burn up and longer life reactor core could possibly be exported abroad with nonproliferation performance.
The SM-WCRs for heating, seawater desalination, commercial ship, and isotope production are under R&D, in order to broaden the potential non-electrical applications in China.

In general, for WCR sustainable development two countermeasures have been taken by Chinese Government.

The first is to introduce generation III PWR technologies for the current large-scale commercial applications, since GIII PWR technologies have considerable risk reduction comparing to generation II technologies with comparable economical competitiveness. The more capacity scale, the more

attention has to be taken to the single unit risk reduction. And, the possibility of full core loading with MOX fuel is another advantage of GIII PWR for improving fuel resource utilization rate.
The second is to take part in GIF activities, including SFR, VHTR, and SCWR, in order to follow up the world technology advancement and make joint effort in some common interested R&D projects, so as not only to catch up with the world advanced level in proper time, but also to have the great stamina for the long term sustainability of nuclear power in China[6].

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