A Review in ITER Project and the Safety Problem of Inland Nuclear Power Plants in China

JUAN HUO, MINGJIE ZHANG and XIAOWEI SUN

ABSTRACT

Under the new situation of China's economic development, the construction of inland nuclear power is of great significance to improve the energy structure, ensure the energy supply and promote the virtuous cycle of economic development and environmental protection. This paper introduces the current situation of nuclear power development at home and abroad and the latest development trend in the field of nuclear power: International Thermonuclear Experimental Reactor (ITER) project. Analysis the structural safety, radiological impact and waste treatment three safety problems of the construction of inland nuclear power in China, and summarizes the current situation and development trend of the technology. Finally, some suggestions are put forward for the construction of future inland nuclear power plants in China.

KEYWORDS
Inland nuclear power; ITER project; structural safety; waste treatment.

INTRODUCTION

As an efficient, stable and clean low-carbon energy source, nuclear energy plays an important role in today and future world. As of January 2016, the global nuclear power installed capacity of 383 million kilowatt. According to IAEA predicted that in 2030 this number will increase to 740 million kilowatt, 2050 increase to 1.137 billion kilowatt [1]. Nuclear safety has always been an important problem to be solved in the course of nuclear power development, three major nuclear accidents occurred in nuclear power, exposed the deficiencies of the existing nuclear power plant in staff management, structural safety design, waste discharge and radioactive treatment.

This paper will introduce the scientific objectives, design parameters and research results of ITER project, and expound the positive impact of the ITER project on future nuclear power development. At the same time, this paper analyzes the safety problems of the construction of inland nuclear power plants in the future and the current situation and development trend of the relevant technologies are reviewed. Finally, the paper puts forward several aspects that should be paid attention to in the construction of inland nuclear power plants in China.

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CURRENT SITUATION AND TREND OF NUCLEAR ENERGY DEVELOPMENT IN THE WORLD

Current situation and trend of foreign nuclear power development

The current international divide nuclear power unit into four generations [2]. The first generation of nuclear power plants now there are only two in operation. The second generation built during the 1960s and 1970 is the main body of the world's currently running nuclear power plants, with a total installed capacity of 383 million kilowatt. The third generation of nuclear power plants adopt the new security technology in design and developed a higher security goals [3], the overall security has been greatly improved. The main characteristic of AP1000 is the Passive Safety System, the melting probability of core is reduced by 1 to 2 orders of magnitude [4], and the EPR adopts 4-channel security system and double-layer containment [3]. The Generation IV International Forum (GIF) was set up in July 2000, the goal is to meet the basic requirements of future nuclear energy sustainability, high security and reliability, more economic and counter nuclear proliferation [5]. The generation IV nuclear power system mainly includes: gas-cooled fast reactor, lead cooled breeder reactor, molten salt reactors, sodium-cooled fast reactor, ultrahigh temperature gas cooled reactor, supercritical light water-cooled reactor six kinds of reactor type in total [6]. The current generation of nuclear power accounts for about 11% of the world's total power generation, which is expected to be double by 2050.

Current situation and trend of nuclear power development in China

China's nuclear power development began in the 1980s and now has been formed including Qinshan, Dayawan, Lingao, Tianwan multiple nuclear power bases. In 2006, China formulate the current nuclear power development route for the introduction, digestion, absorption and innovation. According to this policy, China has actively introduced the third generation of nuclear technology AP1000 from the United States. At the same time, independent research and development of the third generation of nuclear power technology ACPR1000 and CAP1400. At present, the nuclear power units in China are mainly the second generation and the improved PWR unit, and the distribution area is mainly concentrated in the eastern coastal region. China shall accelerate the construction process of coastal and inland nuclear power plants and optimizing the layout of nuclear power.

By the end of 2016, China's commercial operation of the nuclear power unit a total of 35, installed capacity of 33.632 million kilowatt, the total annual nuclear power generation of 210.519 billion kilowatt-hour, accounting for 3.56% of the national electricity generation, significantly below the global average of 11%. According to China's long-term nuclear power development program, by 2020, the total capacity of nuclear power installed to 58 million kilowatts, under construction of 30 million kilowatt.
Controllable Nuclear Fusion

Fusion energy is more abundant than fission energy resources, more safe and efficient production capacity, small operating radiation and other advantages, have a more development potential than fission in the future. The raw materials of fusion are hydrogen isotopes (hydrogen, deuterium, and tritium) and helium-3. It is estimated that there are about 23.4 trillion tons of deuterium in the Earth's oceans. If humans can control the occurrence of nuclear fusion, these reserves can meet the energy demand for billions of years in the future.

The critical problem with nuclear fusion is that it is difficult to bind the light nuclei in extremely high temperatures, and then fusion occurs. At present, there are two methods to realize controllable nuclear fusion: magnetic confinement and inertial confinement. Now the magnetic confinement nuclear fusion represented by tokamak device is recognized the only device with the ability to manufacture experimental nuclear fusion reactors [7]. In the research of inertial confinement fusion, the high-power laser technique [8] and particle beam technology [9] provide a way to solve the problem of "ignition" of controllable nuclear fusion. In addition, the ultra-high microwave heating method is also one of the ways to solve the ignition problem [7].

ITER project

The ITER project was originally launched by the United States, Soviet, European and Japanese Quartet in 1988, after which China, South Korea and India have joined the plan. The project is devoted to solving future human social energy problems. On the basis of making full use of the achievements of the 40-year world fusion study, plan to build a fusion reactor at the Cadarache center in southern France in 2019, comprehensively verifying the feasibility of fusion in science and engineering technology, while carrying out a series of high-parameter plasma experiments in scientific exploration for future large-scale commercial operation. The basic design parameters of the ITER device are shown in Table 1[10].

The scientific objectives and engineering objectives of the ITER project are listed in [11], the scientific objectives are:

TABLE 1. BASIC PARAMETERS OF ITER DEVICE.

<table>
<thead>
<tr>
<th>Projects</th>
<th>Numerical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total fusion power/MW</td>
<td>50</td>
</tr>
<tr>
<td>Q (fusion power/heating power)</td>
<td>10</td>
</tr>
<tr>
<td>14MeV neutron average wall load/(MW/m²)</td>
<td>0.57</td>
</tr>
<tr>
<td>Repeat continuous burning time/s</td>
<td>&gt;500</td>
</tr>
<tr>
<td>Mass radius/m</td>
<td>6.2</td>
</tr>
<tr>
<td>Small radius of plasma/m</td>
<td>2.0</td>
</tr>
<tr>
<td>Plasma current/MA</td>
<td>15(17)</td>
</tr>
<tr>
<td>Small cross-section ratio</td>
<td>1.7</td>
</tr>
<tr>
<td>Plasma center magnetic intensity/T</td>
<td>5.3</td>
</tr>
<tr>
<td>Plasma volume/m³</td>
<td>837</td>
</tr>
<tr>
<td>Plasma surface area/m²</td>
<td>678</td>
</tr>
</tbody>
</table>
The combustion plasma of fusion power 500MW, Q greater than 10, pulse time 500s is obtained by induction drive;

The steady state operation of plasma is studied by using the non-induction drive to produce a plasma with fusion power greater than 350MW, Q greater than 5, and burning time of 3000s.

Engineering technical objectives:
To test and realize the integration of various fusion technologies, and further research and development of the future can be directly used in the commercial heap of the relevant technology;
Test the performance of each part in the fusion environment;
Test the concept of TBM.

An important part of the entire ITER device is the design of the cladding. TheITER cladding is divided into two kinds: shielding cladding layer and experimental cladding layer, shielding cladding is mainly used for radiation protection of the device, and the main function of the Test blanket module (TBM) is to verify the generation, extraction and energy acquisition technology of tritium in fusion reactor, and to design tools, programs, data and so on to verify and test the fusion reactor material's comprehensive performance. Reference [12] expounds that one of the most important engineering experimental objectives of ITER is to verify the technology of tritium multiplication and self-sustaining of fusion fuel. For this purpose, 6 TBMs are planned to be installed in three equatorial ports [13], these three ports act on different stages of ITER operation (H-H, D-D, D-T), successively experiments on electromagnetic, thermodynamic, tritium multiplication and overall performance [14].

According to the agreement, the cost of the ITER project and all the equipment shall be paid and constructed by the all countries, and all the intellectual property rights of the ITER project will be shared. The program participates in all parties, Europe, Japan and Russia to participate in the earliest, has accumulated more solid experience and results in the field of fusion research. The large-scale tokamak devices including European JET, Asdex-u, Japan's JT-60 and the superconducting tokamak T-7 and T-15 in Russia provide the foundation for the development of the physical research and engineering technology for ITER [15]. Participating in the ITER construction and operation, the United States, China, South Korea and India are intended to learn and accumulate the developing technology and management experience of the large nuclear fusion reactor, as well as training talents to build their own fusion DEMO reactor in the future.

The construction of the experimental reactor is an important step in realizing the commercial road of fusion energy, this goal is hard to achieve because of the high technical difficulty and construction cost. It is worth noting that the governments which involved in ITER have recognized the necessity of international cooperation in the study of fusion energy, and that only the concerted efforts of all parties can make the ITER project move forward quickly.

INLAND NUCLEAR POWER CONSTRUCTION FACING SAFETY PROBLEMS ANALYSIS

The safety risk of nuclear power plant is mainly from the leakage of nuclear fuel circulation system, the nuclear radiation of the reactor and the disposal of waste. In particular, it can be summed up as follows [16]:

666
The probability of accidental accident is very low; however, the occurrence of an accident would have unpredictable effects.

The lack of a comprehensive, universally recognized nuclear waste disposal plan, which is particularly common in developing countries.

Concerns that civilian nuclear power may lead to or promote the proliferation of nuclear weapons.

**Structural safety of nuclear power plants**

It is considered that the nuclear power plant in the design of all kinds of extreme natural disasters and major emergencies, the overall implementation of defense principles in depth, in the building facilities and contingency plans to form a different level of overlay protection, to achieve the overall safety of nuclear power plant strong guarantee to prevent the occurrence of accidents [17]. Reference [18] believe that the next generation of nuclear power plants will be in a fail-safe state due to the large number of Passive Safety Systems, within 72 hours after the accident, the natural circulation can maintain the core cooling and maintain the integrity of the containment, thereby significantly reducing the core melting probability. References [19] give the specific numerical value of the current nuclear power plant safety target: The United States Federal Nuclear Regulatory Commission (NRC) limited light water reactor core damage rate of 10^-4 (heap • years)-1 and 0.1 auxiliary target [20]. For the next generation of core damage and the occurrence of large radioactive leakage probability is lower than 10^-5 (heap • years)-1 and 10^-6 (heap • year)-1. Overall, the safety of nuclear power plants is guaranteed.

**Radiological impact of nuclear power plants on the environment**

There are three evaluation methods of the radiological impact of inland nuclear power plants on the residents. First, the probability analysis of the risks caused by the radiation to the public health in the background of the overall social risk. The second is the comparison of the acceptable safe radiation doses. The third is the evidence-based epidemiological analysis of the health of the residents around the inland nuclear power plant. The NRC believes that acceptable levels of public radiation risk are: The per capita risk of acute death caused by a nuclear accident in the vicinity of the nuclear power plant should not exceed 0.1% of the sum of the United States public's risk of immediate death from other accidents [21]. Reference [22] compares the daily radiation doses received by the public daily life and the maximum public personal dose measured value of the American ESP site, and concludes that nuclear power is safe for human beings under normal conditions. According to the environment report of China's inland nuclear power plant, Zhao Chengkun through the model to calculate the radiological impact of low radioactive waste water to the surrounding residents, the four million of kilowatts units in the normal operation of the surrounding residents per capita years may accept the largest radiation dose is a few or a dozen μSv level, far lower than our country's Ministry of Health measured the annual per capita 684μsv radiation dose [23]. According to the domestic and international nuclear safety testing institutions in the nuclear power plant around the residents suffering from a long-term follow-up of the cancer situation, the relationship between radiation and pathology is still not clear, there is no credible evidence to prove that the residents around the nuclear power plant cancer risk is affected by radiation [24]. The impact of nuclear radiation on people's health is a
long-term research subject, and further research is needed to obtain more conclusive and credible evidence to help increase public confidence in nuclear safety.

**Nuclear power plants waste treatment**

1) Waste liquid treatment: The waste liquid from the inland nuclear power plant mainly comes from the cooling tower waste water, the chemical waste water, the decontamination liquid, the ground hydrophobic and the service draining. According to the difference of chemical composition and radioactivity concentration of these waste liquid, it is necessary to classify and collect the treatment. At present, the treatment measures widely used at home and abroad are the first to store the radioactive waste liquid, then use the cement curing method to treat. In recent years, the improvement methods of the traditional method [25], membrane separation technology [26], adsorption process [27] and other new methods have good performance and development potential. The three kinds of inorganic ion exchange materials mentioned in [25] overcame the disadvantage of the poor treatment effect of the traditional organic resin material on the high salt content, and could form the combined complementarity in the treatment effect. Reference [28] found that the reverse osmosis technology in the treatment of radioactive waste liquid certain specific nuclides effect is obvious, but it is necessary to do further research on the overall purification effect of complex composition of radioactive waste water. The studies about the effect of biological technology on the treatment of radioactive waste liquid, and found that some fungi can absorb more than 99% of radioactive materials such as uranium elements [29-30].

After 1000 times dilution of liquid effluent from circulating cooling water in the coastal PWR nuclear power plant, the radioactive concentration in the waste water of the drainage outlet is controlled in 1~2Bq/L (except tritium). The new revised “Nuclear Power Plant Radioactive Liquid Effluent Emission Requirements” puts forward a higher request to the nuclear power plant radioactive waste water treatment [31].

2) Exhaust emissions: The components of radioactive waste gas from nuclear power plant include: inert gas, activated gases, iodine, solid particles and tritium, mainly from the process of the nuclear power plant operation of the process of exhaust and ventilation exhaust [32]. In the purification treatment methods, the main pressure storage decay, activated carbon retention of decay, wet absorption and solvent washing and so on [33]. Reference [34] analyzes the relationship between the adsorption effect of activated carbon and the temperature and humidity of the gas through the study of the delaying process of activated carbon. It is considered that the Passive Safety System used in the third-generation nuclear power plant simplifies the equipment of the waste gas treatment system, so that the safety is greatly improved [35]. It should be noted that inland nuclear power plant is different from the coastal station site is, the inland area static wind time is long, therefore may appear the atmospheric local radioactivity concentration to be high situation.

3) Solid waste treatment: The solid waste that needs to be treated mainly includes: water filter core, ventilating heating and air conditioner (HVAC) filter core, waste activated carbon, dry solid waste, miscellaneous waste and waste resin [36]. In accordance with the strength of radioactivity, solid waste can be divided into high release solid waste, medium and low solid waste and very low non-metallic waste. There are three kinds of waste treatment methods: the high-level activated waste needs to be decomposed into block-mounted shielding, finally send into the deep disposal
facility; medium and low discharge solid waste according to the degree of biodegradable and controllability, corresponding to the off-line decontamination, smelting and container packaging treatment, very low discharge of waste packaging sends to the extremely low landfill landfills landfill. Reference [37] optimizes the treatment process of AP1000 radioactive waste resin, adds a pretreatment procedure, and optimizes the results of exponentially several times. Studies about the treatment methods of solid waste in Qinshan, nuclear power plant from two aspects of technical method and management principle, puts forward that a complete scientific solid waste classification and management system should be established in the future [38].

CONCLUSION

Under the new situation of China's economic development, the contradiction between economic development and environmental protection intensifies, and it is necessary and urgent to carry out the construction of inland nuclear power plant. The future construction of inland nuclear power plants in China should pay attention to the following aspects:

Based on the actual situation of our country, we should make full use of the mature nuclear power construction technology and operation experience at home and abroad, set up a complete contingency plan and strengthen the nuclear safety culture of nuclear power workers.

To promote the study of the effects of nuclear radiation on human health, to enhance public awareness of the safety of the people and to remove the fear of nuclear power.

The establishment of a complete nuclear waste treatment and management system, and constantly tracking foreign advanced nuclear waste treatment technology, the overall safety of nuclear power plants continue to improve.

The implementation of the ITER project has made the future of mankind hopeful, and people are expected to use clean and inexhaustible energy in the near future. But this is destined to be a lasting and bumpy process, the joint efforts of all parties need to solve the engineering and technical problems, China should seize this opportunity to actively participate in the ITER project, for the future development of domestic nuclear fusion research to make strategic arrangements.

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