Towards Practical Fusion Energy: Engineering Challenges and Development Strategies by the Perspective of CNPE

1 Background

Controlled nuclear fusion, as one of the ultimate solutions to the energy problems of all mankind, has the advantages of abundant resources, inherent and intrinsic safety and low environmental impact, etc. It can be used as a long-term base load clean energy under the global net zero emission and China's "Carbon Peaking and Carbon Neutrality Goals", and is an important supportive energy source to achieve the global energy transformation and long-term climate goals. Currently controlled nuclear fusion is still in the early stage of the engineering and commercialization, also faces the engineering and technical problems such as plasma control, irradiation resistant structure materials, tritium fuel supply and tritium self-sustaining. To advance the commercialization of FPP (Fusion Power Plant) as soon as possible, CNPE (China Nuclear Power Engineering Co., Ltd.) started from the perspective of engineering and system thinking, combined together the successful practices of the nuclear engineering in fission FOAK (First Of A Kind) nuclear power plant (NPP), including engineering, standardization, the experience of the nuclear industry chain, and finally propose development strategies towards practical fusion energy based on deeply analysis of the current FPP engineering challenges.

2 The concept of Fusion Engineering and the differences between fission and fusion

China’s nuclear industry is matured and complete, with the world's largest team of nuclear engineers and technical workers, with more than 40 years continuous experience in the construction of nuclear industry, with excellent technical ability and reliable nuclear safety and quality culture, with continuous research and development innovation of nuclear power equipment and technology, all the above are the good foundation for the FPP. China currently has 102 nuclear reactors in operation or under construction, with a total installed capacity of approximately 113 GW, ranking first globally in nuclear power capacity. So far CNPE has carried out EPCS (Engineering, Procurement, Construction, and Startup) contracting for 29 nuclear power units, 15 of which have been completed and 14 are under construction. CNPE has accumulated experience in the design, construction and management of demonstration projects, including HPR1000 and ACP100.

The fusion engineering development strategies proposed by CNPE focused on process management and system thinking to consider the design, construction, operations, decommission, during the transformation of fusion reactor from experimental device to demonstration reactor or commercial reactor. Integrate the industrial construction methodology, such as engineering design method, standardization design, lifecycle management to achieve the engineering reliability, availability, maintainability and inspectability.

3 The successful practice of CNPE in the fission FOAK Nuclear Power Plant

After decades of development, China’s fission nuclear power industry has established a comprehensive regulatory and standards system. Building upon this foundation, the project preparation work, engineering design, and construction of fission NPP are carried out in strict compliance. The project preparation work for NPP projects includes: site investigation and preliminary feasibility study, preparation of the project proposal, feasibility study and project application report, SSAR (Site Safety Assessment Report) and EIA (Environmental Impact Assessment) and the PSAR (Preliminary Safety Analysis Report), final application report for the construction license.

A digital collaborative design platform is utilized to execute the project’s conceptual design, general design, preliminary design, and construction design. Additionally, prior to project approval, preparatory work such as equipment/material procurement and on-site construction readiness must be advanced and after the project approval, the project will progress through three phases: civil construction, equipment installation, and system commissioning. As the EPCS contractor for nuclear projects, CNPE has developed an integrated lifecycle management system. It continuously enhances its EPCS capabilities across four key areas: project management systems, knowledge engineering, intelligent construction, and industrial collaboration.

4 Management system and innovation of CNPE in the EPCS construction of Nuclear Power Plant

A series of management systems and innovations have been formed in the EPCS construction of nuclear power plant, including:

First, the integration of design and construction, unite the engineering and construction units to carry out research on advanced construction technology, jointly promote the research and development of digital software, Internet of Things technology, civil construction technology, installation and erection technology, welding and nondestructive testing technology and engineering application.

Second, to foster an independent and controllable nuclear industrial chain, build an integrated and collaborative platform for design, procurement and manufacturing, and gradually realize the design-procurement-supplier-warehousing-construction "five-in-one" information convergence.

Third, to improve the performance of project management, build a project management system covering the company level, project level and domain level. The first reactor of HPR1000 has achieved the best global Gen III NPP construction performance.

Fourth, to build a high-level talent team covering various specialties such as the research and development, design, procurement, construction, commissioning and project management, all the specialists integrate as one team with high-quality performance and form the core technical talent echelon.

Fifth, to build a digital and intelligent engineering construction platform, supported by the "N Triple1" digitalization scheme of the CNPE with the top-level planning and implementation program integrated into the "N Triple1" digital platform.

Finally, make every effort to improve the safety and quality management, earnestly practicing the company policy of "absolute responsibility, highest standards, systematic operation and experience feedback" resulting the main safety performance indicators are in the domestic top level of the nuclear industry.

5 Problems and countermeasures related to Fusion Power Plant engineering

In recent years, controlled nuclear fusion has become a global research and development hotspot. Compared with the fission reactor, the engineering of the FPP still faces many problems in many aspects.

First, the regulations and standards for FPP are far from adequate. It is suggested that based on the different fusion technology configurations to formulate regulatory requirements considering the various aspects of the fusion principal and design and different fusion fuel to clarify the siting and licensing requirements and process of the FPP.

Second, the FPP engineering and design are still in the early stage, so the technical roadmap, research and development strength are relatively dispersed. While the FPP involves many specialties, which is more complicated than the large pressurized water reactor NPP. Usually, several design and research units shall work together to carry out the engineering design, a set of comprehensive design management system and digital collaborative design platform are necessary to integrate multiple design units and various specialties in design units.

Third, the FPP engineering construction, taking Tokamak as an example, the FPP systems are gradually complicated and the machine is more and more large-scale, resulting the project investment around hundreds of millions or even billions of dollars. Professional project management team with experience is required to fulfill management work. Meanwhile, due to the FOAK elements and complexity of the Tokamak, rich experience in nuclear engineering management, the ability to solve and coordinate complex engineering problems, and professional engineering construction technology are critical to the construction management.

Four, the development of the fusion supply chain and ecosystem as a whole is still in the primary stage, the FPP related materials and key equipment need to be further improved. One important solution is to rely on the current fission nuclear industry supply chain, to evolve into the fusion supply chain. At the same time through promoting technological innovation, research and development, international cooperation and openness and sharing, to accelerate the establishment of fusion supply chain and FPP commercialization.

6 Conclusion

In general, FPP engineering is a complex system engineering. In order to accelerate the pace of engineering and commercialization of FPP, it is necessary to use the practical experience of the existing nuclear industry, adopt the system thinking of nuclear engineering, and use scientific project management methods and construction technology to realize efficient engineering construction. Based on the above analysis, the following suggestions are put forward: firstly, establish the FPP supervision system as soon as possible to pave the way for the commercialization of the FPP and strengthen the cultivation of the industrial chain, and adopt EPCS design and management platform to improve the quality and speed of FPP engineering.