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Analysis and Research on the Requirements and Applicability of HPR1000 Commissioning Standards

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Abstract: ***China's nuclear power standards are parallel due to a variety of technical routes and different technology source countries, resulting in a situation of multiple standards parallel in the domestic nuclear power industry. Through the comparative analysis of nuclear power standards in the United States and France, domestic electric power industry and domestic conventional thermal power industry, this paper seeks for the combination point with domestic nuclear power commissioning standard system, and combs and analyzes the existing standard system. Through industry research and data collection and analysis, combined with the technical characteristics of HPR1000, the requirements and applicability elements of the commissioning standard system are determined, the framework of the commissioning standard system is optimized and improved, and the corresponding standard acquisition, formulation and revision plan of the standard system is formed, so as to guide the construction of commissioning standardization.***

Keywords: Nuclear power, HPR1000 (Hua-long Pressurized Reactor), Commissioning standard.

1. Introduction

As the last key link of nuclear power construction, the purpose of commissioning is to make the installed components and systems of nuclear power plant operate and carry out various tests, so as to verify whether their performance meets the design requirements and performance criteria. The standardization of nuclear power commissioning stage is not only the need of the development of nuclear power standardization in China, but also the need of preciseness and safety of commissioning itself. As one of the whole nuclear power standard system, commissioning is divided into eight fields: general and basic, preliminary, engineering design, equipment, construction, commissioning, operation and decommissioning [1]. It is urgent to build a scientific classification, orderly organization and clear-cut commissioning standard system to guide the construction of commissioning standardization. However, due to the parallel technology routes and different technology source countries, the domestic nuclear power industry has a situation of parallel standards. Due to the lack of unified planning, domestic nuclear power standards have not been able to form a complete nuclear power standard system.

HPR1000 is a large-scale advanced PWR nuclear power technology with complete intellectual property rights, which is independently developed in China. Its safety and technical economic indicators have reached the advanced level of the international third generation nuclear power technology, and it is the main component of China's nuclear power independent development strategy. Under the background of technology integration and export of HPR1000, a complete commissioning standard system of HPR1000 will be formed through simplification, unification, coordination and optimization, so as to build an independent pressurized water reactor standard system covering the whole nuclear power cycle, which will better guarantee the safety of China's nuclear power development and support China's nuclear power technology and equipment to go abroad.

2. Research Status

2.1 US Standardization

The United States is one of the first countries to develop nuclear energy. It is the country with the earliest development and the most mature technology of PWR nuclear power plants. It has accumulated rich experience in the use of nuclear energy. For a single nuclear power project, the unit commissioning program, system commissioning program, commissioning standard guidelines and commissioning procedures are published separately to guide on-site commissioning. For example, the unit commissioning program is based on RG1.068 "initial test program for water cooled nuclear power plants"; The system commissioning program is based on the design standard; The standard guidelines are collected according to the equipment standards.

Driven by original technology, American nuclear power standards have formed a general system (ASME, IEEE, ANS, ASTM and other standards) with specialty as the main line, complete categories and suitable for various technical development needs. American nuclear power standards can fully meet the needs of nuclear power site selection, engineering design, construction, operation and maintenance, and are widely used in U.S., North America, Asia and some European countries [2]. The logic relationship of U.S. nuclear power commissioning standards is summarized as shown in Figure 1, in which RG 1.068 and a small number of 10cfr documents are the top-level basis for nuclear power plant commissioning, and are at the top of the standard system; Other RG management guidelines with strong pertinence or fine standardization objects can be placed in the second level; ASME, IEEE and other relevant standards and documents are also placed in the second level [3].

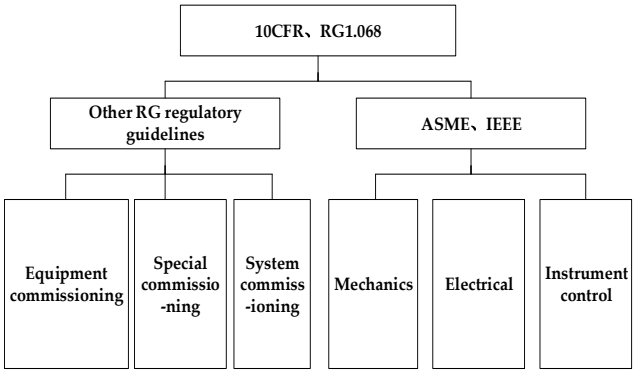

Figure 1: Standard logic relationship in U.S. nuclear power commissioning field

Regarding the nuclear power commissioning standard system, whether viewed from the perspective of its specific module structure division or the associations or societies responsible for the module standard systems, there currently exists no integrated framework for a specialized nuclear power commissioning standard system and its corresponding standard catalog. Most relevant standards are scattered across various modules within the overall nuclear power standard system. For instance, "ASME-BPVC-III NB Class 1 Components" comprehensively covers the definition, materials, design, manufacture, installation, inspection, testing, and other related aspects of Class 1 components, with NB-6000 specifically pertaining to the commissioning field.

2.2 France Standardization

France has formed a relatively complete and effective system of laws and regulations from top to bottom in the practice of nuclear industry, which is mainly realized through two ways: one is the laws and regulations formulated and revised specifically for nuclear power according to the technological progress and development of nuclear power; the other is the revision of nuclear power based on the original law. The construction of nuclear power standard system in France is carried out simultaneously with the standardization development process of PWR nuclear power plants. It is based on the American PWR nuclear power standard, introduces and absorbs the American nuclear power experience, and makes the transformation adapted to the national conditions. In 1980, AFCN and AFCEC were established to be responsible for the standard construction of nuclear island and conventional island respectively. In 1981, the first edition of "rules for design and construction of mechanical equipment for PWR nuclear island" (RCC-M) was published [4]. French nuclear power standards are highly systematic and integrate design and construction. RCC series standards are summarized in Table 1.

Table 1: RCC series standards

RCC series	*Abbreviation*	*Standards*
RCC	RCC-P	Rules for design and construction of PWR nuclear power plant system
Nuclear island series -	RCC-G	900MevRules for design and construction of PWR civil engineering
system structure	RCC-I	Rules for fire protection design and construction of PWR nuclear power plant
RCC	RCC-C	Rules for design and construction of PWR fuel assemblies
Nuclear island series	RCC-M	Rules for design and construction of mechanical equipment for nuclear island of PWR nuclear power plant
equipment	RCC-E	Rules for design and construction of electrical equipment for nuclear island of PWR nuclear power plant
RCC	RCC-EV	Rules for design and construction of feed water and steam systems in nuclear power plants
Conventional island series	RCC-TA	Rules for design and construction of steam turbine generator units in nuclear power plants

From the French nuclear power standard system, we can see that the French nuclear power standard system focuses on design and construction, and does not separate the commissioning. The standards required in the commissioning stage are more reflected in the design and construction standards.

Specifically, regarding the nuclear power commissioning standard system, similar to the US nuclear power standard system, there is currently no integrated or consolidated set of specialized nuclear power commissioning standards and their corresponding standard catalog framework. Most of the relevant standards are scattered across various modules within the overall nuclear power standard system. For instance, in Chapter 2, Section 2.1.2 of RCC-P, which discusses the reactor coolant system, Section 4, on testing and operational monitoring of the reactor coolant system, is related to the commissioning field.

Although there is no special commissioning standard for French nuclear power, there are test requirements for equipment and system of nuclear power plant, which are scattered in the corresponding volumes of design, manufacture and construction. These contents are applicable to Chinese M310, CPR1000 and other nuclear power models that use French technology for reference. At present, many contents have been converted into standards.

2.3 China Standardization

There are many types of nuclear power reactors in China, many kinds of technical routes are parallel, and the source countries of technology are different, which leads to the situation that many kinds of standards are used in parallel in the domestic nuclear power industry. Due to the lack of unified planning, the domestic nuclear power standards have not been able to form a complete nuclear power standard system. After the system construction in recent years, the standards in the field of nuclear power plant commissioning have gradually changed from scattered to systematic, and a standard system covering the field of nuclear power commissioning has been initially established, and its architecture needs to be optimized.

In 2007, the former Commission of science, technology and industry for National Defense issued the 11th Five Year Plan for the construction of the standard system of PWR nuclear power plant [5], and the standards related to the commissioning of nuclear power plant in the standard system table were blank. However, a few nuclear power commissioning standards have been issued, such as EJ/T 1045-1997 "requirements for preparation of commissioning program for pressurized water reactor nuclear power plant". In 2009, the national energy administration and the National Standardization Administration jointly issued the

"construction plan of PWR nuclear power plant standard system" [6]. In the field of nuclear power commissioning, it was proposed to "complete the preparation and revision of commissioning program, pre-operation test standard and charging, start-up, criticality, physical test and power test standard" before 2011. In the same year, the National Energy Administration issued the project list of standard system for PWR nuclear power plant [7], which set 680 standards and 15 standards for commissioning. In 2012, the National Energy Administration issued the "PWR nuclear power plant standard system project table (Revised Edition 2011)" [8], set up 833 standards, including 17 sets of commissioning standards. 2014, the National Energy Board issued the "PWR nuclear power plant standard system project list (Revised Edition 2013) [9]", general purpose and nuclear island 932, added conventional islands and ancillary facilities 189, set up 1121 standards, including 37 sets of commissioning standards, including 25 general purpose and nuclear island, 12 conventional island and auxiliary facilities.

2.4 Development of Commissioning Technology and the Adoption of Standards in Demonstration Projects

In the field of commissioning technology, there are a number of technological innovations and researches, for example, a power supply method for cold functional test of nuclear power plant technological innovation on cold functional test, and research results on open cover cold functional test in "CPR1000 unit test innovation and Implementation" [10], It can be used to provide useful reference in the process of compiling joint commissioning test standard. "Safety injection method for pre-criticality control panel power failure test of nuclear power plant" and "test analysis for loss of off-site power supply of CPR1000 Nuclear Power Plant [11]" can be used for reference in compiling special test [12]. "The research and application of pump inlet protection system in megawatt nuclear power station [13]" can absorb the relevant achievements or ideas and be used to compile the equipment commissioning test standard.

In 2023, the standard list for Unit 3 of the Fang Cheng Port Nuclear Power Plant, which is engaged in grid-connected power generation, represents a standard system established based on work processes. This system fully incorporates international, domestic, industrial, and local standards, specifications, and procedures, while also taking into account the plant's own needs. Specifically, the commissioning process adopts 46 standards.

3. Research Methods

This research method includes data collation, collection and research of standard literature, industry research, etc. through the data collation, compilation and comparative analysis of American and French nuclear power standards, domestic electric power, domestic conventional thermal power industry standard systems, the combination point of domestic nuclear power commissioning standard system is found, and the existing standard system is analyzed. Through industry research and data collection and analysis, using causal analysis method, combined with the technical characteristics of HPR1000, determine the requirements and applicability elements of the commissioning standard system, optimize and improve the framework of the commissioning standard system, and form the corresponding standard acquisition and revision plan of the standard system. Aiming at the different problems in the process of system commissioning, this paper analyzes and corrects them. In the specific commissioning design, the system framework and elements are repeatedly confirmed and corrected through the HPR1000 simulator preview verification commissioning program.

4. Standard Requirements and Adaptability Analysis

The purpose of the standard requirements and applicability analysis corresponding to the nuclear power commissioning stage is to verify whether its performance meets the design requirements and performance criteria through the implementation of the commissioning standards. The overall framework of HPR1000 commissioning standard system is planned according to the test stage and function, and the existing commissioning standards in China are sorted out according to the framework. By comparing the design characteristics of HPR1000 demonstration project, this paper analyzes sorted out commissioning standards. Some standards can be directly adopted after applicability analysis and demonstration, and some standards can be adopted after appropriate revision. At the same time, a series of new standards are sorted out.

4.1 Standard Requirements

The standard system of the commissioning part of HPR1000 will absorb and digest the requirements of ASME and RCC related to commissioning, and divide the overall framework according to the stages and functions. According to the overall framework, the existing commissioning standards are sorted out, and the design characteristics of HPR1000 demonstration project (Fu Qing nuclear power project unit 5, Fujian Province, Fang Cheng Port nuclear power project unit 3, Guangxi) are compared, analyzed, studied and adopted. Some of them can be directly adopted after applicability analysis, and some of them can be adopted after appropriate revision. Analyze and sort out the new standards and supplement the new standards. Through continuous improvement of the existing standard system, a complete commissioning standard system suitable for HPR1000 is formed.

4.2 The Framework of the Standard System of Adjustment Based on Adaptability Analysis

Combined with the technical characteristics of HPR1000, the commissioning technical standard system of HPR1000 is studied and analyzed according to the division of commissioning specialty. After studying the test structure and test stage characteristics of HPR1000, the commissioning technical standard system framework of HPR1000 is built to ensure its integrity.

According to the project table of PWR nuclear power plant standard system (revised in 2014) issued by the national energy administration and the technical standard system of enterprise standard system (GB/T 15497), the commissioning standard system can be divided into three parts: General requirements for commissioning, pre operation test and test

with nuclear fuel, study on revision and construction planning of PWR nuclear power plant commissioning standard system, HPR1000 commissioning standard system (Figure 2) is divided into five parts, including commissioning management, general test, pre operation test, charging and start-up test, and special test [14].

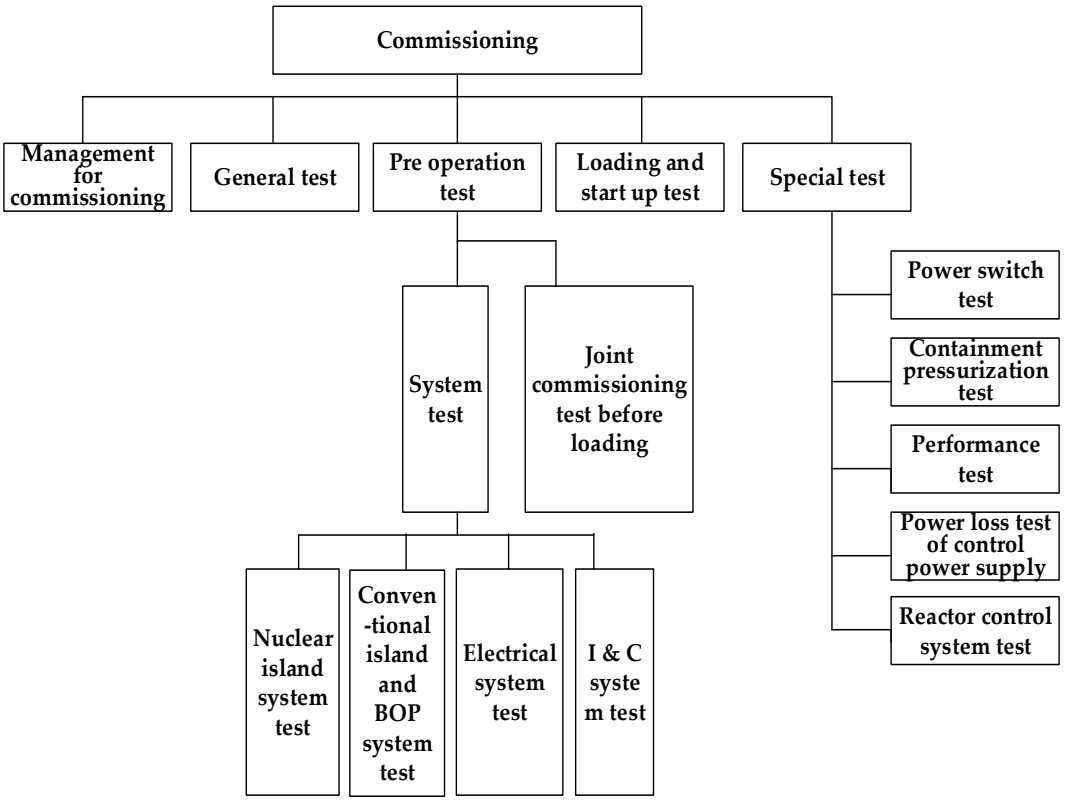

Figure 2: Framework of commissioning standard system

According to the corresponding standards of the framework of the commissioning standard system, various tests are carried out on the installed components and systems of the nuclear power plant according to the nuclear safety regulations and commissioning standards. The main commissioning tests include pre-operation test (cold performance test and hot performance test); Loading, initial criticality and low power tests. According to the comprehensiveness, specialty and complexity of the test, the commissioning test can be divided into single system test, partial start-up test, overall start-up test and special test.

The advantages of American and French standard system, domestic electric power standard system and domestic conventional thermal power commissioning standard system are absorbed and comprehensively considered. The first is to focus on the construction of special standards for nuclear power commissioning, and give priority to general industrial standards for non-nuclear parts, such as conventional thermal power standards; Second, coordinate the development of technology and management standard subsystem; The third is to learn from the domestic power standard system architecture, cut the modules and reserve the openings. Based on the established standard framework, a comprehensive review of the existing commissioning standard system has been conducted. An expert group has been established to assess the applicability of the reviewed standards, including whether they are suitable for the commissioning of HPR1000 units, whether revisions are necessary for inapplicable standards, and whether new standards should be formulated to enhance the commissioning standard system, ultimately meeting the requirements for the commissioning of HPR1000.

4.3 Making Plans to Promote Commissioning Work and Commissioning Standard Formulation

The revision and improvement of nuclear power commissioning standard system should be completed by the whole industry. At present, the National Energy Administration should coordinate the work of this aspect, and several major domestic nuclear power commissioning units should carry out special projects separately. The first is to expand the standards in the field of nuclear power commissioning within the framework of the existing standards issued by the National Energy Administration, and the granularity can be refined to a certain technical guideline or test specification; The second is to carry out relevant special research work to provide technical support for the follow-up overall system optimization. According to the new standard system list, improve the standards that need to be revised; Finally, a complete HPR1000 commissioning standard system will be formed.

The commissioning work of HPR1000 nuclear power plant is mainly divided into two parts: commissioning preparation and commissioning implementation, and others include commissioning cooperation, commissioning support, etc [15].

4.3.1 Subsystem test of HPR1000

The subsystem test of HPR1000 mainly includes subsystem handover from installation to commissioning, subsystem commissioning isolation and tagging, subsystem equipment basic function verification, etc.

The nuclear island subsystem test mainly includes 82 commissioning tests of 20 main and auxiliary systems of the nuclear island, including preliminary tests of reactor coolant system, chemical solvent control system, residual heat removal system and other nuclear main and auxiliary systems.

Conventional island and BOP subsystem tests mainly include 44 subsystem commissioning tests of 38 systems of CI/BOP, covering preliminary tests of ventilation system, chilled water system, fire water system, fire alarm system, conventional island water supply system, etc.

The electrical subsystem test mainly includes 39 subsystem commissioning tests of 34 electrical systems, including low-voltage electrical, medium voltage electrical, DC electrical, emergency diesel generator and other systems.

The I&C subsystem test mainly includes 30 subsystem commissioning tests of 15 I&C systems, including special I&C, three wastes I&C, steam turbine I&C and other systems.

4.3.2 Overall test of HPR1000

The main content of the overall system test is to verify the overall performance of the system, or to verify the preliminary or local linkage performance of two or more (sub) systems with physical connection and performance logic interlocking.

The overall test of the nuclear island system mainly includes 51 overall tests of 20 main and auxiliary systems, including the acceptance test of the emergency diesel generator system, the functional verification of the designed safety system and other tests.

The overall test of conventional island and BOP (CI/BOP) system mainly includes 131 overall tests of 38 systems, including performance acceptance test of ventilation and refrigeration system, functional verification of water supply system of conventional island and other tests.

The overall test of the electrical system mainly includes 40 overall tests of 34 electrical systems, including the acceptance test of the main power supply system, the whole group startup test of the auxiliary power supply and the main power supply.

The overall test of I&C system mainly includes 21 subsystem commissioning tests of 16 I&C systems, including reactor control system regulation performance test, DCS system performance verification and other tests.

4.3.3 Comprehensive test of HPR1000

The comprehensive commissioning test of HPR1000 nuclear power plant mainly includes the unit performance test and comprehensive test from the CFT of the unit to the completion of the provisional acceptance of the unit. It mainly includes the cold performance test of the nuclear steam generator system (NSSS), the hot performance test of the unit, the first filling of nuclear fuel for the unit, the first hot test before reaching criticality, the first reaching criticality of the unit and the test of increasing the thermal power to 50% FP, the reactor power gradually increased from 50% FP to full power test, the first nuclear steam impulse test of the steam turbine generator unit, the first grid connection test of the unit, the load test of the steam turbine generator unit, the 24h continuous variable load operation test and the 168h continuous stable operation acceptance test at full power, etc.

4.4 Analysis and Revision of Standard System.

Before the formal operation of the nuclear power unit, the response of the unit under different transients will be verified through commissioning tests to demonstrate that the safety and operation capacity of the unit meet the requirements. In the process of unit commissioning test, if unexpected transient response causes unit trip and reactor trip, it will cause potential risks to the safety of the unit, and may cause disturbance to the normal operation of the power grid and affect the commercial operation and operation of the unit. Therefore, the verification and pre-risk identification of some typical operation transients and commissioning test transients by simulation analysis method not only help to demonstrate the reliability of HPR1000 in operation, but also provide effective ways and means to ensure the safety and economy of nuclear power plant operation. Based on the structure and operation principle of the first to third circuits of HPR1000, a simulation analysis platform for the first to third circuits of HPR1000 was established to study the matching of the first to third circuits of the unit.

In view of the different problems in the system commissioning process, the paper analyzes and corrects them. In the specific commissioning design, the system framework and elements are repeatedly confirmed and corrected through the HPR1000 simulator preview verification commissioning program.

5. Conclusion

This study analyzes the requirements and applicability of the standards in the nuclear power commissioning stage, and verifies whether the performance meets the design requirements and performance criteria through the implementation of the commissioning standards. The overall framework of HPR1000 commissioning standard system is planned according to the test stage and function, and the existing commissioning standards in China are sorted out according to the framework. By comparing the design characteristics of HPR1000 demonstration project, this paper analyzes the sorted-out commissioning standards. Some standards can be directly adopted after applicability analysis and demonstration, and some standards can be adopted after appropriate revision. At the same time, a series of new standards are sorted out. It will better guarantee the safety of nuclear power development.

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