

A Review of the Applicability of Technical Standards for Pre-service Inspection Reflecting i-SMR Design Characteristics

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1. Introduction

Pre-service inspection is an essential regulatory process for verifying that nuclear reactor facilities have been constructed and installed in accordance with approved design requirements and that their structures, systems, and components can perform their intended safety functions before plant operation. Existing pre-service inspection guidelines have been developed primarily based on the design and construction characteristics of conventional large nuclear power reactors. Therefore, their applicability to innovative small modular reactors (i-SMR), which adopt substantially different design and construction concepts, needs to be carefully evaluated.

The differences between i-SMR and conventional large nuclear power reactors extend beyond plant size to the configuration of major components, safety systems, plant structures, manufacturing and installation methods, and the allocation of safety functions. These differences may affect the applicability of individual inspection items as well as the timing and location of inspections. In particular, the modular approach allows major components and systems to be fabricated, assembled, and tested at manufacturing facilities before transportation and installation at the plant site. Thus, some existing inspection items may require modification, exclusion, or supplementation with new requirements to reflect the specific characteristics of SMR design and construction.

The i-SMR incorporates several design features that differ significantly from those of conventional large nuclear power reactors. The reactor coolant system (RCS) integrates the reactor core, pressurizer, helical once-through steam generator, and four reactor coolant pumps within a single reactor pressure vessel (RPV). By locating the major primary components within the RPV and eliminating large-diameter piping connections, the i-SMR is designed to fundamentally eliminate large-break loss-of-coolant accidents (LBLOCAs). It also adopts passive safety systems, including the passive emergency core cooling system (PECCS), passive containment cooling system (PCCS), and passive auxiliary feedwater system (PAFS), instead of conventional active safety systems.

The plant configuration and construction approach also differ from those of conventional large nuclear

power plants. The major buildings consist of the reactor protection building, control building, complex building, and turbine building. The reactor protection building accommodates four integrated reactor and containment modules, while the control building contains an integrated control room for the four reactor modules. In addition, the modular construction approach enables factory-based inspection and testing of major components before site installation, which may affect the applicability, location, and timing of pre-service inspections.

Accordingly, this study evaluates the applicability of current pre-service inspection guidelines to the i-SMR by comparing the requirements specified in the “Regulation on Pre-service Inspection of Nuclear Reactor Facilities (NSSC Notice No. 2024-13)” with the design and construction characteristics of the i-SMR. The existing inspection items for major structures, systems, and components are classified according to whether they should be applied as is, revised, excluded, or newly established. Differences in inspection timing and location resulting from modular manufacturing and installation are also examined. Based on these evaluations, revision measures for the pre-service inspection guidelines are proposed for both facility and performance inspections. The results provide a technical basis for establishing and revising pre-service inspection guidelines applicable to the i-SMR. An overview of the pre-service inspection for conventional large nuclear power plants and the i-SMR is presented in Fig. 1.

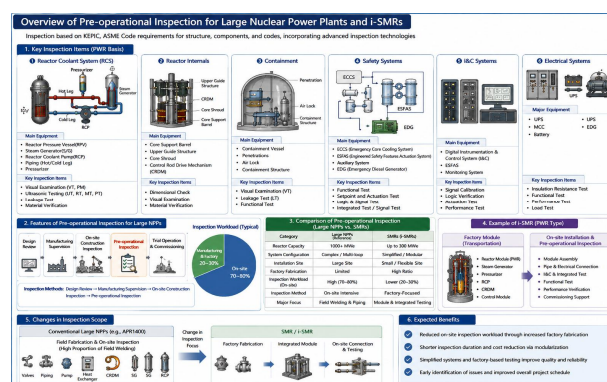


Fig.1 Overview of Pre-service Inspection for Large Nuclear Plants and i-SMR

2. Overview of Pre-Service Inspection

In Korea, the legal framework for pre-service inspection is established under the Nuclear Safety Act, with detailed requirements specified in the Enforcement Decree and regulations issued by the Nuclear Safety and Security Commission. The Enforcement Decree defines the inspection stages and timing in accordance with the construction and commissioning process. Accordingly, inspections are conducted progressively at major construction and testing stages, including structural inspection, installation inspection, cold functional testing, hydrostatic test and hot functional testing, fuel loading and commissioning inspection.

In the “Regulation on Pre-service Inspection of Nuclear Reactor Facilities (NSSC Notice No. 2024-13),” which defines the major inspection targets and requirements for nuclear reactor facilities. The inspection scope includes structures, reactor components, reactor coolant systems, instrumentation and control systems, safety systems, electrical systems, radioactive waste management systems, containment facilities, and other nuclear safety-related facilities.

Pre-service inspection is generally divided into facility inspection and performance inspection. Facility inspection verifies whether structures, systems, and components have been constructed and installed in accordance with the approved design and applicable technical requirements. Performance inspection verifies whether the completed facilities and systems perform their intended safety functions. Detailed inspection criteria and procedures for each inspection are further specified in the associated inspection guidelines.

3. Comparison of Inspection Locations and Timing

The timing and location of pre-service inspections for nuclear reactor facilities are specified in Article 29 of the Enforcement Decree of the Nuclear Safety Act. The timing and stages of pre-service inspection of nuclear facilities, as specified in Article 3, are illustrated in **Fig. 2**. Pre-service inspections are generally conducted in five stages according to the construction and commissioning sequence: (1) structural inspection when construction of major structures commences and strength testing becomes feasible; (2) installation inspection after completion of field installation; (3) cold functional testing when system functional testing becomes feasible; (4) hydrostatic test and hot functional testing when the corresponding tests become feasible; and (5) fuel loading and commissioning inspection.

The timing and location of the first, second, and fifth stages are expected to be generally similar for the i-SMR and conventional large nuclear power reactors. However, the third and fourth stages may differ due to the i-SMR's steel containment vessel, integral reactor configuration, and modular construction. Major components and systems are expected to be fabricated and assembled at manufacturing facilities, where inspections such as assembly inspections,

nondestructive examinations, and hydrostatic tests may be performed prior to site installation.

Therefore, the inspections associated with the third and fourth stages are expected to be conducted at both manufacturing facilities and the plant site. The inspection guidelines should accordingly distinguish between factory and site inspections and define their respective inspection items. However, since the specific manufacturing processes and testing facilities have not yet been finalized at the current SSAR review stage, detailed factory inspection requirements should be established based on the finalized manufacturing and testing arrangements during actual plant construction.

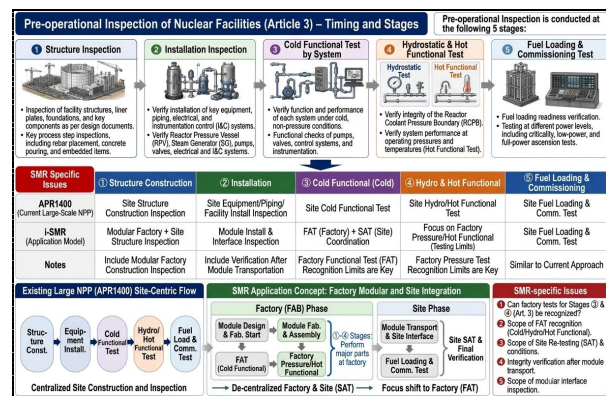


Fig.2 Pre-service Inspection of Nuclear Facilities (Article 3) – Timing and Stages

4. Evaluation of Pre-service Inspection Items

The applicability of the inspection items specified in Appendix 1 of NSSC Notice No. 2024-13 is evaluated based on the design characteristics of the i-SMR. Each inspection item is reviewed to determine whether the existing requirements should be maintained, revised, newly established, or excluded.

The reactor facilities subject to pre-service inspection are classified into five groups according to the major construction and commissioning processes. The five inspection groups consist of (1) structural inspection items, (2) installation inspection items, (3) cold functional testing inspection items, (4) hydrostatic test and hot functional testing inspection items, and (5) fuel loading and commissioning inspection items.

The inspection items are classified into four categories: A, existing guidelines applicable with minor modifications such as terminology changes; B, existing guidelines requiring substantial modifications of 30% or more; C, existing guidelines not required because the corresponding facilities or systems are not provided in the i-SMR; and D, new guidelines required specifically for the i-SMR. As summarized in Table I, a total of 219 existing facilities subject to inspection are evaluated, with 109 classified as Category A, 59 as Category B, and 51 as Category C. In addition, 10 new inspection items are identified as Category D. Since Category D represents newly identified inspection items that are not associated with the existing inspection facilities, these

items are not included in the number of existing facilities subject to inspection.

The overall results of the gap analysis are summarized in **Table I**. The applicability of the existing inspection requirements is then evaluated for each inspection group, with particular consideration given to whether the requirements should be applied as is, revised, excluded, or newly established. The detailed evaluation results are presented in Sections 4.1 through 4.5.

Table I. Gap Analysis Results of Pre-Service Inspection Guidelines

	Number of Facilities Subject to Inspection	Gap Analysis Results			D	Remarks
		A	B	C		
1	21	15		6		
2	79	39	22	18	6	
3	28	11	10	7		No Existing Guidelines for Safety and Relief Valve Testing
4	35	24	5	6		
5	56	20	22	14	4	
Total	219	109	59	51	10	

4.1 Inspection of Structures and Construction

The i-SMR adopts a steel containment vessel instead of the concrete containment building used in conventional large nuclear power plants. Accordingly, inspection items associated with concrete containment structures should be revised or excluded. In particular, liner plate inspections for the internal surfaces of the containment building, refueling water storage pool, and IRWST are not applicable to the i-SMR. Concrete masonry and internal containment coatings are also not adopted due to their limited applicability under the i-SMR design and accident conditions, and the corresponding inspection items should therefore be excluded. In contrast, the primary component cooling seawater system has a structural configuration similar to that of conventional large nuclear power plants despite being classified as a non-essential system. Therefore, the associated structural construction and inspection requirements can generally be applied without modification.

Construction-related comprehensive testing includes the containment structural integrity test and the Type A integrated leakage rate test. The containment structural integrity test, which verifies structural performance by pressurizing the containment to at least 1.15 times the design pressure and evaluating liner plate integrity and concrete cracking, is not applicable to the i-SMR because it does not employ liner plates or a concrete containment structure. The Type A test verifies containment leak-tightness under simulated design-basis accident conditions. However, the minimized containment volume of the i-SMR may result in a

pressure of approximately 5 MPa (725 psi) during a loss-of-coolant accident. Maintaining this pressure for more than 24 hours would require specialized pressurization equipment and could increase personnel exposure and test-related risks. Therefore, the i-SMR is pursuing an exemption from the Type A test, with its verification objectives to be addressed through dry-stage inspections and testing and in-service inspections.

4.2 Cold Functional Inspection of Individual Systems

The applicability of the existing cold functional testing requirements was evaluated for the major systems and facilities of the i-SMR based on their design characteristics. Because the reactor coolant system (RCS) is integrated within a single reactor pressure vessel, conventional inspection methods for reactor internals and reactor coolant pumps, including vibration monitoring, require modification. Differences in system venting arrangements and the absence of an acoustic leak monitoring system also require corresponding revisions or exclusion of the existing requirements.

For instrumentation and control systems, the inspection requirements should be revised or newly established to reflect the passive safety systems, including the PECCS, PCCS, and PAFS, and the diverse FPGA-based protection architecture. Similarly, inspection requirements for spent fuel handling and storage facilities should reflect the i-SMR-specific refueling strategy, cooling provisions, and safety-grade external emergency cooling water supply.

For radioactive waste management facilities, inspection items associated with treatment systems not provided in the i-SMR should be excluded or revised, while radiation monitoring requirements can generally be maintained. Conventional containment systems, such as containment ventilation, spray, cooling, and combustible gas control systems, are not provided in the i-SMR; therefore, the corresponding inspection items are not applicable. Instead, new inspection requirements should be established for the PCCS and PECCS to verify their passive safety functions.

The inspection requirements for electrical and power conversion systems should also be revised to reflect the absence of emergency diesel generators, the enhanced DC power system, and the PAFS, which performs the auxiliary feedwater function. Other auxiliary systems, including component cooling, service water, HVAC, ventilation, sampling, and chemical and volume control systems, require revisions according to their specific configurations and safety classifications. Inspection items for systems not provided in the i-SMR should be excluded, while new requirements should be established where i-SMR-specific safety functions require verification.

4.3 Hydrostatic Testing and Hot Functional Testing

The applicability of the existing hydrostatic testing requirements was evaluated considering the i-SMR-specific system configurations. The RCS is connected to the normal residual heat removal system and the modular makeup and purification system, while the steam generator secondary side is connected to the PAFS instead of the conventional steam generator blowdown system. These differences from conventional large nuclear power plants require revisions to the inspection guidelines to appropriately reflect the i-SMR design.

For hot functional testing, the thermal expansion test verifies that the piping and systems under test can move freely without excessive restraint during heating and return to their original positions without abnormal deformation or interference during cooling. Since the existing guidelines specify inspection methods and requirements for primary- and secondary-side components and piping of conventional large nuclear power plants, the guidelines should be revised to reflect the integral RCS and secondary-side system configurations of the i-SMR. Because most hot functional testing items are also addressed during cold functional testing, the corresponding requirements should be revised consistently based on the applicability assessment for the cold functional testing items.

4.4 Fuel Loading and Commissioning Inspection

The i-SMR adopts a boron-free operation concept, which eliminates boric acid-related corrosion and contributes to simplified system configurations, reduced radioactive waste generation, and enhanced core safety and accident tolerance through a strong negative reactivity feedback effect. Accordingly, the boron-related requirements specified in the existing inspection guidelines for conventional large nuclear power plants should be removed or substantially revised to reflect the i-SMR operating concept.

For core design and performance-related tests, including core performance evaluation, axial xenon testing, and moderator temperature coefficient measurements, further expert review is considered necessary to determine their applicability and appropriate inspection methods for the i-SMR.

4.5 Installation Inspection

The modifications, including revisions and exclusions, to the existing inspection guidelines for the installation inspection items are consistent with those identified for the corresponding items in Sections 4.2, 4.3, and 4.4.

5. Conclusions

This study evaluated the applicability of the pre-operational inspection process and timing to the i-SMR and performed a gap analysis of the existing inspection requirements based on the design and construction

characteristics of the i-SMR. The review indicated that the timing and locations of structural inspections, installation inspections, and fuel loading and commissioning inspections are expected to be generally similar to those of conventional large nuclear power plants. In contrast, cold functional testing, hydrostatic testing and hot functional testing may be conducted at both manufacturing facilities and the plant site due to the i-SMR's integral reactor configuration, steel containment vessel, and modular construction approach. Therefore, the inspection guidelines should clearly distinguish between factory and site inspections and define the applicable inspection items for each location.

The gap analysis identified inspection items that can be maintained, require revision, are not applicable, or require newly established requirements for the i-SMR. These results provide a technical basis for establishing pre-operational inspection guidelines that appropriately reflect the design and construction characteristics of the i-SMR. In particular, the classification of inspection items into five inspection groups and the identification of differences between factory and site inspections provide a systematic basis for developing inspection requirements applicable to the modular construction and integral configuration of the i-SMR.

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