Transactions of the Korean Nuclear Society Autumn Meeting
Changwon, Korea, October 30-31, 2025

Gap and Applicability Analysis of Regulatory Inspection Systems for Application to i-SMRs

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***Keywords :** ROP, cROP, RISC, SMR, combined license, manufacturing and transport inspections*

1. Introduction

The purpose of regulatory inspection is to ensure that nuclear power plants and its related facilities can operate safely and reliably under normal conditions in order to prevent large-scale radiation releases or environmental contamination in the occurrence of an accident. This is an activity to check whether the safety design bases and technical criteria, etc. are met during the design, manufacturing, construction, and operation processes of nuclear power plants and its related facilities. Unlike existing large-scale nuclear power plants, the light-water SMRs are manufactured and assembled as reactor modules in a factory, then transported to the site and built as multiple modules. Therefore, the regulatory inspections for SMRs should be considered differently from the procedures and methods for existing nuclear power plants [1].

The objective of this study is to identify the anticipated regulatory issues related to the light-water i-SMR regulatory inspections (e.g. pre-operational, periodic, vendor, quality assurance, decommissioning verification-checks) and to conduct the preliminary research on their countermeasures. To achieve this objective, this study analyzes the gaps of domestic and foreign regulatory inspection systems and suggests the improvements for applicability.

2. Characteristics of Light-Water SMR Regulatory Inspections

The following key technologies and systems are adopted, taking into account the innovative design and safety characteristics of SMRs [6,7]:

- Technology neutrality
- Risk-informed approach
- Performance-based approach
- Graded approach

The SMR regulatory inspections should reflect the design characteristics of SMRs and complement the existing inspection systems for large nuclear power plants as follows:

- Modularization and Factory Fabrication Inspection: Since SMRs are manufactured in modules at factories so the quality assurance and safety inspections for the factory fabrication processes and on-site assembly are being strengthened.
- Supply Chain Inspection: Inspecting the quality management systems and safety-related activities of various suppliers involved in a module fabrication is crucial.
- Pre-operational Inspection: Prior to fuel loading and commissioning, the extensive inspections are conducted to ensure that all safety-related systems and components are installed and functioned according to applicable design requirements.
- In-Service Inspection (ISI): For operating SMRs, the periodic inspections are conducted to verify the integrity of safety-related structures, systems, and components (SSCs).

3. Gap Analysis

3.1 Institutional Gap Analysis

The gap analysis between Korea and Leading countries from institutional points perspectives is in Table 1 and summarized as follows:

- The NRC's SMR regulatory inspection system in the United States accepts the innovative potential of SMR technology with prioritizing public health and safety. It pursues a flexible, risk-informed and performance-based approaches. It conducts comprehensive and systematic inspections throughout the entire life cycle of SMRs from design to operation.
- The CNSC's SMR regulatory inspection system in Canada focuses on supporting the safe introduction of new nuclear technologies with enhancing the regulatory predictability and efficiency.
- The ONR's SMR regulatory inspection system in the United Kingdom employs a pre-qualification process for design through Generic Design Assessment and the flexible on-site inspections using principles-based and risk-informed approaches.
- Pursuit of flexibility and predictability: All three countries are moving away from existing regulation-based approaches to accept the innovative nature of SMRs and to promote more predictable licensing processes (e.g., risk-informed, performance-based).

- Importance of licensing processes and pre-design assessments: Pre-design assessments play a key role in streamlining the overall licensing process by assessing regulatory compliance from a design perspective and addressing potential issues prior to site licensing.
- Modularization and supply chain management: Modularization and factory fabrication of SMRs enhance production efficiency, but also highlight the importance of quality control and inspection throughout the supply chain.

3.2 Technical Gap Analysis

The gap analysis between the current domestic regulatory inspection system and the regulatory inspection system under the 10 CFR 52 requirements are summarized in Table 2.

The purpose of technical gap analysis is to identify technical improvements needed for the domestic i-SMR regulatory inspection system, in light of the regulatory inspection system under the US 10 CFR 52 requirements [8].

10 CFR Part 52, "Licensing, Certification, and Approval for Nuclear Power Plants," governs the issuance of early site permits, standard design certifications, combined licenses, standard design approvals, and manufacturing licenses for nuclear facilities licensed under Section 103 of the Atomic Energy Act of 1954 and Title II of the Energy Reorganization Act of 1974. Among these, the regulatory inspections under the Combined Licenses (COL) regulation can be categorized into Initial Testing Program (ITP), Inspection-Test-Analysis, and Acceptance Criteria (ITAAC), Quality Assurance (QA) inspections, Vendor inspections, ISI/IST inspections, Maintenance, Surveillance and Periodic Tests, and Decommissioning Inspections, as shown in Table 2.

In order to derive the improvements in the regulatory inspection of the light-water i-SMRs, pre-operational inspection, ITAAC inspection, quality assurance inspection, vendor inspection, ISI/IST inspection, periodic inspection, and decommissioning inspection have been analyzed in the gap analysis of the regulatory inspections. The analysis also considered the perspectives of the NRC's ROP and cROP systems.

- Most of the domestic regulatory inspection system is similar to the regulatory inspection system under the US combined license, but it was confirmed that there are significant differences in the scope, timing, and method of inspection from the domestic inspection system due to the application of 10 CFR 52, combined license, 10 CFR 50.69, risk-informed safety class (RISC), and ROP system in the US system [8].
- The ITAAC inspection adopted as part of the combined license of 10 CFR 52 is an inspection that does not exist in the domestic inspection system.
- In addition, it was confirmed that the US inspection system adopts a risk-informed (RI) and a graded approach based on cROP and ROP, and that the inspection procedure and inspection graded criteria are clear and specific, and that the safety performance of the nuclear power plant is graded using the Action Matrix.

Table 2. Gap Analysis Results

	Korea	USA	Remarks*
.Regulatory inspection system	Pre-op. inspection	Initial Test Programs	Similar
	No ITAAC system	ITAAC inspection	Need to reflect
	QA inspection	QA inspection	Similar
	Inspection of suppliers, etc.	Vendor inspection	Similar
	ISI/IST inspection	ISI/IST inspection	Similar
	Periodic inspection	Maintenance, Surveillance, and Periodic Tests	Similar
	Decommissioning inspection	Decommissioning inspection	Similar
. cROP system	No cROP system	Application of cROP	Need to reflect
. ROP system	No ROP system	Application of ROP	Need to reflect

imilar: There are significant differences in the scope, timing, and method of ıspection compared to Korean inspection systems due to the application of 10 FR Part 52, Combined License, 10 CFR Part 50.69, Risk-Informed Safety lass (RISC), and cROP/ROP systems.

Through the gap analysis of the domestic and foreign regulatory inspection systems, in order to improve the domestic light-water i-SMR regulatory inspections and to promote the regulatory efficiency, it is necessary to adopt the following risk-informed (RI) and graded approaches similar to that in the United States [6].

- Application of the Risk-Informed Safety Class (RISC) system
- Selection of safety-related and safety-significant inspection items (①)
- Selection of non-safety-related but safety-significant inspection items (②)
- Development of graded regulatory inspection methods and criteria for the inspection items ① and ② above
- Securing personnel with sufficient technical capabilities and expertise to carry out these processes etc.

3.3 Institutional and Technical Improvements Required

Based on the gap analysis on regulatory inspection systems and methods, the necessary regulatory technologies identified for applying to i-SMR regulatory inspections are as follows:

- Evaluation technologies for the application of risk-informed, performance-based, and graded approaches throughout the entire life cycle of i-SMRs, including design, construction, and operation.
- Quality management and inspection technologies throughout the entire supply chain, including factory fabrication and transportation of i-SMR modules.
- Comprehensive safety verification technologies for unproven FOAK (First-of-a-Kind) facilities.
- Demonstration technologies for the passive safety systems that reflect the innovative design and safety characteristics of i-SMRs.
- Inspection technologies related to i-SMR site installation, construction, and operation.

4. Review of the Applicability for i-SMR Regulatory Inspections

Based on the results from "Institutional and Technical Improvements Required," we propose a system and inspection plan related to the domestic light-water i-SMR regulatory inspections.

The regulatory inspection system for the domestic i-SMRs is proposed as shown in Figure 1, considering the characteristics of the manufacturing, installation, and construction of i-SMR modules under the current nuclear safety laws and regulations. Since small-capacity SMR modules can generally be manufactured and assembled at the factory, the regulatory inspections need to be conducted at that time. Thus, module manufacturing and transport inspections are separately stipulated, as shown in Figure 1. In addition, the current safety classification methodology needs to be revised to the "Risk-Informed Safety Class (RISC)" to reduce the number of regulatory inspection items and to adopt the graded approaches. In the end, the regulatory inspection system for the domestic i-SMRs includes 1) module manufacturing and transport inspections, 2) pre-operational inspections after module installation, 3) quality assurance inspections, 4) vendor inspections, 5) in-service inspections (including "in-service tests"), 6) periodic inspections, and 7) decommissioning inspections, and considers the RISC methodology.

The blocks marked in red in Figure 1, including module manufacturing and transport inspections, pre-operational inspections after module installation, vendor and periodic inspections, and risk-informed safety class system, are not addressed in the current nuclear-related laws or regulations, and so will need to be established and/or revised.

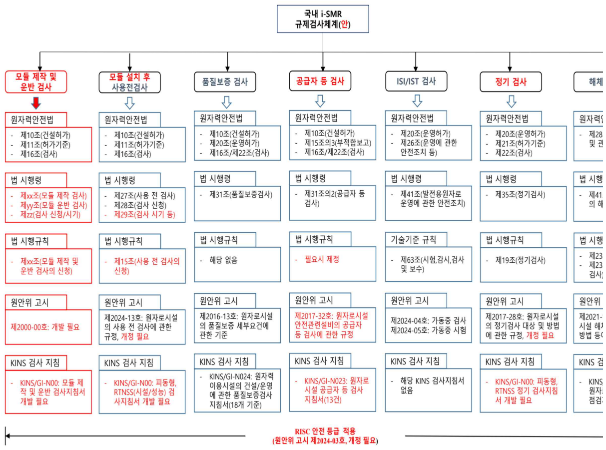

Figure 1. Proposed Regulatory Inspection System for i-SMRs in Korea

3. Conclusions

This study is to identify the anticipated regulatory issues related to the light-water i-SMR regulatory inspections and to conduct the preliminary research on their countermeasures. This study also analyzes the gaps of domestic and foreign regulatory inspection systems and suggests the improvement measures for applicability.

Since the domestic inspection system is a statutory inspection, the inspections are conducted according to the deterministic methods prescribed in laws, regulations, and inspection guidelines. However, the US inspection system adopts a risk-informed (RI) and a graded approach based on cROP and ROP, and the inspection procedures and their graded criteria are clear and specific, and the plant safety performance is graded using the Action Matrix. The gap analysis verified that there are significant differences in the scope, timing, and method of inspection compared to Korean regulatory inspections due to the application of 10 CFR Part 52, Combined License (ITAAC), 10 CFR Part 50.69, Risk-Informed Safety Class (RISC), and ROP system in the US.

Therefore, considering the characteristics of SMR module manufacturing, installation, and construction, the regulatory inspection system for the i-SMRs is proposed as shown in Figure 1, under the current nuclear safety laws and regulations. The feature of this proposal is that the module manufacturing and transport inspection has been added to the current Korean regulatory inspection system, because of the need to be conducted at manufacturing and transport time.

To implement this system, the new regulations and procedures for module manufacturing and transport inspection, pre-operational inspection after module installation, vendor and periodic inspections, and the risk-informed safety class system will need to be established and/or revised in the near future.

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Table 1. Gap Analysis of Regulatory Inspection Systems in Korea and Leading Countries

	Korea (NSSC)	United States (NRC)	Canada (CNSC)	United Kingdom (ONR)	Remarks
Regulatory Philosophy/ Approaches	• Application of prescriptive -based and statutory inspection systems.	• Shift from prescriptive to risk-informed/performance-based: Seeking flexibility through the transition from Part 50/52 (large nuclear power plants) to Part 53 (SMRs/advanced reactors). • Technology-inclusive.	• Principles-based and graded approach: Adjusting the intensity of regulatory requirements based on the risk of the SMR. • Technology neutrality.	• Principles-based and SFAIRP (So Far As Is Reasonably Practicable) principles: Demonstrate that the licensee has reduced risks to the lowest level reasonably practicable. • Preliminary assessment centered on Generic Design Assessment (GDA).	• Regulatory approaches: Different from each other.
Key Pre-Review/ Approval	• Design Certification (DC): Standardized certification for a specific design. • 2 stage permits (CP/OL): Site-specific construction and operating permit.	• Design Certification (DC): Standardized certification for a specific design. • Combined Licensing (COL): Combining site-specific construction and operating permits.	• Vendor Design Review (VDR): Optional pre-review. • Site Preparation Permit, Construction Permit, and Operating Permit: Phased permitting process.	• General Design Assessment (GDA): A comprehensive safety, security, and environmental assessment of the design. • Site Permit: Construction and operation permit for a specific site.	• Licensing system: Different from each other.
Primary Inspection Areas	• Application of statutory regulatory inspection system. • Utilization of large-scale nuclear power plant inspection guidelines and manuals. - Supplementation is needed	• Utilize existing large-scale nuclear power plant inspection manuals and improve them to reflect SMR characteristics. • Relax emergency preparedness requirements (reflecting SMR characteristics). • Emphasize cybersecurity	• Inspection based on 14 safety and control areas (SCAs). • Emphasis on supply chain inspection and modular construction process inspection.	• GDA Compliance: Verify that the design conforms to the GDA-approved specifications. • Risk Mitigation Validation (SFAIRP). • Supply Chain and Factory Quality Assurance Inspection.	• Korea: Statutory regulatory inspection. • Other country: Risk-based inspection.

	to reflect the characteristics of SMRs.	requirements.			
Regulatory Document Systems	• Nuclear Safety Act, its enforcement decree, and enforcement regulations. • Technical regulations for nuclear reactor facilities, etc. • NSSC Notices, etc.	• 10 CFR Part 50, Part 52, Part 53 (under development). • RG, NUREG, SRP.	• REGDOC-series (Regulatory Documents).	• Safety Assessment Principles (SAPs). • Technical Assessment Guides (TAGs), Technical Inspection Guides (TIGs).	• According to the specific documentation system of each country.
Regulatory Independence	• Independent government agency.	• Independent federal agency.	• Independent parliamentary agency.	• Independent government agency.	• Guaranteed independence.

Abbreviations:

NSSC: Nuclear Safety and Security Commission
NRC: Nuclear Regulatory Commission
CNSC: Canadian Nuclear Safety Commission
ONR: Office of Nuclear Regulation
CP/OL: Construction Permit/Operating License
RG: Regulatory Guide, NUREG: Nuclear Regulation, SRP: Standard Review Plan
REGDOC: Regulatory Documents