REGULATORY CONSIDERATIONS FOR SMR APPLICATION: THE CASE OF SOUTH KOREA

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Abstract

Small module reactors (SMRs) are in the spotlight worldwide as a means of carbon neutrality primarily because of their safety and economic feasibility. South Korea is in the process of developing an innovative SMR(iSMR) with a licensing goal of 2028. It is necessary to reorganize regulatory requirements and improve the framework as the development of domestic SMRs, including iSMR, increases rapidly. For the above reasons, the KINS has promoted regulatory improvement R&D (2022-2028) to develop a safety regulatory framework specialized for SMRs and a pre-licensing safety review (PLR) program. In addition, the Korean regulatory bodies (KINS and NSSC) have prepared PLR procedures and policy statements for SMR regulation to improve SMR licensing efficiency. Thus, this paper suggests the consideration of regulators reflecting changes in the regulatory environment to SMR through the current status and readiness of SMR regulatory activities.

1. INTRODUCTION

The Korean and foreign new nuclear power development programs are shifting from the development of third-generation large nuclear power plants (NPPs) such as APR-1400, EPR, and AP-1000 to the development of small, multi-purpose and modular reactors (Small Modular Reactors) intending to improve safety and flexibility. In Korea, after the standard design approval of 'SMART' in 2012, the standard design approval of 'SMART100 small and medium-sized nuclear power plant' was applied for in December 2019 and is currently undergoing license review. Currently, Korea Hydro & Nuclear Power (KHNP) and the Korea Atomic Energy Research Institute (KAERI) are jointly designing an innovative SMR (i-SMR) and have reported that they will apply for Standard Design Approval (SDA) in January 2026.

Among the design features of the i-SMR are simplification, passive systems, and innovative technologies (e.g., soluble boric-free, non-safety class power systems). The regulatory framework and procedures of existing NPPs limit these features. To prepare for future SMR license applications, it is necessary to pre-emptively improve the regulatory framework and procedures for SMRs through safety regulatory Research & Development (R&D). In response, the Korea Institute of Nuclear Safety (KINS) has been conducting R&D since 2022 to develop a regulatory framework and technology for new designs and technologies. As the development of domestic SMRs, including the i-SMR, increases rapidly, Korea needs to reorganize its regulatory requirements and improve the existing licensing framework.

To prepare regulatory readiness for new design features, the NRC has prepared Pre-Application Review (PAR) procedures, Design-Specific Review Standards (DSRS), policy statements on the Regulation of Advanced Reactors (AR)[1], and the NRC's vision and strategies for AR. In addition, leading SMR countries such as the United States and Canada are developing and applying pre-licensing application review procedures to proactively understand regulatory issues and find solutions for SMRs different from large NPPs. Based on these overseas cases, Korean regulators can consider their respective roles in the future as follows: The regulatory bodies (KINS and NSSC) need to present policy directions, principles, and strategies for SMRs through a declaration of SMR policy to improve SMR licensing efficiency. Regulatory agencies also need to establish regulatory strategies that reflect regulatory verification technology, regulatory framework/procedures, and stakeholder communication. Furthermore, regulatory bodies need to develop domestic pre-licensing review procedures to lay the foundation for effective and efficient licensing review in preparation for innovative SMR standard design license applications.

Thus, this paper will introduce the direction of SMR safety regulation and the pre-licensing safety review (PLR) conducted in Korea to prepare to introduce SMRs.

2. SMR REGULATORY SAFETY DIRECTION

Unlike existing large-scale commercial reactors, SMRs are designed with novel features that make them small, modular, and multi-purpose. This creates challenges in verifying the safety of such reactors within the current regulatory framework. Regulatory bodies play a crucial role in overcoming these challenges. First, they need to establish a new regulatory framework, including systems and safety standards, to verify the safety of novel technologies applicable to SMRs effectively. They should also implement procedures to review technical issues from the early development stage to reduce uncertainties caused by ex-post regulation that reviews documents submitted by designers after completing the design. Furthermore, it is crucial for regulators to communicate with reactor designers about their expectations for achieving a high level of SMR safety aligned with the regulatory mission of protecting the public and the environment.

As such, it has become necessary to set a new regulatory direction with a specific emphasis on ensuring SMR safety, proactively establishing the required regulatory framework and facilitating communication from the early development stage. In this context, the Nuclear Safety and Security Commission (NSSC) and KINS have proposed a regulatory direction for SMR safety based on feedback gathered from various stakeholders, including designers and experts, through workshops, seminars, and forums. This communication process has led to establishing a regulatory direction that specifies general principles, fundamental objectives, and guidelines on design requirements.

2.1. Basic Directions

The basic directions emphasize regulatory perspective, approach, standards, and framework applicable to SMRs. These aim to ensure consistency and rationality in safety regulation while increasing the predictability of regulations applied to innovative design features. The details are as follows:

(1) Maintaining a regulatory perspective focused on "ensuring the highest level of safety" in line with technological advancements in SMRs with innovative design features;
(2) Applying a regulatory approach based on various assessment methods supported by scientific and technological evidence to demonstrate the safety of the technology, especially when existing technical standards are inapplicable due to the unique design characteristics of SMRs;
(3) Establishing internationally accepted and harmonized regulatory standards through more robust cooperation with international organizations, including the IAEA, and countries developing SMRs.

2.2. Design Guidelines

To achieve the goal of ensuring a high level of SMR safety and protecting the public and the environment, the following design considerations are recommended. These guidelines are based on the IAEA Safety Standards (SSR-2/1) and Korea's Nuclear Safety Act.

First, SMRs should be designed with sufficient capabilities to prevent and mitigate accidents, as listed below:

(a) Inherent safety features of nuclear reactors: The increase in the reactivity of a reactor core should be suppressed by inherent safety features to protect the nuclear reactors;
(b) Defense-in-Depth (DID): A step-by-step defensive measure should be introduced to prevent accidents or mitigate the impact of damage in case an accident occurs;
(c) Safety functions with high reliability: Safety-related structures, systems, and equipment should be designed to have high reliability depending on the importance of safety functions, considering their redundancy, diversity, and independence, and be periodically tested and easily inspected during operation;
(d) Integrated safety assessment: Deterministic and probabilistic methodologies should be used to conduct an integrated assessment of reactor safety, including the safety and reliability analysis of structures, systems, and equipment.

For technologies newly applied to SMRs, technical feasibility, and reliability should be ensured through the following measures:

(a) Design verification: It should be demonstrated that a new design concept is based on already proven technologies or that the design is feasible considering the actual operating conditions;

(b) Diagnosis and maintenance: Sufficient instrumentation is required to ensure proper diagnosis and maintenance before problems occur in relation to structures, systems, and equipment important for the safety of nuclear facilities;
(c) Introduction of innovative design features: If innovative design features such as passive or simplified safety systems are introduced, factors that may undermine reactor safety should be minimized, and the safe shutdown of the reactor should be reliably conducted.

Third, the possibility of nuclear power plant workers and nearby residents being exposed to radiation should be kept as low as possible, and radioactive wastes and materials generated and released into the environment should be minimized. Moreover, the ease of decommissioning should also be considered.

Lastly, by integrating safety, security, and safeguards into SMR design, factors necessary to secure nuclear security and proliferation resistance while promoting nuclear safety should be considered.

3. KOREA'S PRE-LICENSING SAFETY REVIEW(PLR)

3.1 Overview of Preliminary Safety Reviews for APR1400 and SMART Designs

In Korea, a preliminary safety review has been conducted for the APR1400, APR+, SMART-P, SMART, and SMART100 designs. These designs were anticipated to have several safety issues, including design concepts outside the scope of current regulatory standards. This report focuses on the cases of APR1400 and SMART.

APR1400 (Jan 2000 - July 2001): The APR1400 preliminary safety review was initiated as an administrative measure by the government in response to KHNP's request for a preliminary safety review. The application and review procedures were the same as those used for a license review. Funding was secured through a special agreement between KINS and KHNP. The review period was shortened by combining the preliminary safety review and the standard design certification review (application for standard design certification in July 2001 and approval in May 2002).

SMART (Feb 2010 - Dec 2010 [2-3]): The purpose of the SMART preliminary safety review was to identify potential issues in the standard design approval review and find solutions by reviewing documents submitted by the applicants in advance before applying for formal approval and permits under Article 12-2 (Standard Design Approval) of the Atomic Energy Act. Documents reviewed included system manuals, preliminary safety analysis reports of representative accidents, design methodologies, and code verification technical reports selected by operators in anticipation of potential issues. KINS reviewed whether the SMART system manual contained sufficient information to demonstrate the safety of the new design concept and whether the preliminary safety analysis report of representative accidents was sufficient to confirm the safety of the SMART reactor.

The preliminary safety review in Korea is a technical review, but a standardized program for pre-solving safety issues has not been established. During the APR1400 review, the Ministry of Education introduced an administrative circular and "Preliminary Safety Review Processing Regulations (draft)," but they were not regularized after the establishment of the standard design approval system. The administrative circular and processing regulations (draft) were not maintained after the establishment of the original draft committee due to issues like regulatory independence. However, the need for preliminary safety audits has resurfaced due to changes in the international and domestic environment. It is necessary to develop review criteria, such as the scope and level of the preliminary review, and to formalize administrative procedures, such as submission forms and review periods, to regularize the process.

3.2 Comparative Analysis of International Pre-Design Review Processes

A comparative analysis of the U.S. Pre-Application Review (PAR) [4-5], Canadian Vendor Design Review (VDR) [6], and U.K. General Design Assessment (GDA) [7] reveals commonalities: they are all procedures conducted prior to the formal licensing system, aimed at improving the understanding of expected licensing requirements through early information sharing between regulators and applicants. Regulators can efficiently use resources for licensing and prepare review guidelines at an early stage. For applicants, the benefits include minimizing licensing uncertainties and shortening the duration of the licensing process. The U.K. GDA can eventually obtain a Design Acceptance Confirmation (DAC). Steps 1-2 are similar to those in the U.S. and Canada, but there are differences in the depth of design, and the steps are organically linked, affecting step 3 (obtaining DAC). In the U.S., the review can be more detailed. In Canada, the review is divided into three stages, offering a broader scope of review from concept to basic design.

Similar to the goals of the U.S. PAR, Canadian VDR, and U.K. GDA, Korean pre-design reviews should aim to improve the understanding of expected authorizations through early information sharing between regulators and applicants. In Korea, it seems appropriate to establish a concept that encompasses the detailed review results of the U.S. PAR and Canada's three-stage review, from conceptual design to basic design (before applying for standard design authorization). The existing preliminary safety reviews in Korea are not systematized or proceduralized and are conducted at the completion of the basic design prior to standard design approval. The term "preliminary safety review" has also been pointed out as burdensome for approval. Therefore, Korea will systematize the procedure under "pre-licensing safety review (PLR)."

In the United States, PAR was implemented through a policy statement, and Canada introduced VDR through the RECDOC-3.5.4 regulatory document. Further discussion is needed on whether the domestic pre-design review process should be codified (processing regulations) or institutionalized (statutory provisions). Institutionalization would provide legal justification but might be perceived as influencing the actual license review, increasing the licensing burden, and hindering active discussion. On the other hand, regularization could establish processing regulations through administrative notices or rules but lacks a mandatory cost-collection basis and has limitations as a non-mandatory procedure.

3.3 Proposal for the Pre-Licensing Safety Review (PLR) Process for i-SMR

The i-SMR, currently in the conceptual design stage, is expected to encounter licensing and safety issues due to innovative design concepts and new technologies different from existing nuclear power plants. As in the U.S. and Canada, it is necessary to review whether the design concept meets the applicable regulatory requirements or positions from the early stage of development and to identify and prepare technical information required for safety assessment and verification for both the development (applicant) and regulatory sides. The regulatory side can identify safety issues early by understanding design concepts, preparing for examinations, and establishing regulatory directions by obtaining technical information necessary for regulatory technology development in advance, and developing guidelines for examinations and evaluation and verification technologies (codes, methodologies, etc.) through regulatory R&D. The applicant can derive, improve, and supplement the necessary parts to confirm and verify the safety of the design or technology development results, securing business stability through this.

A proceduralization method for domestic pre-design review is under consideration. As part of a proactive approach, a communication channel with innovative reactor developers before applying for a license is established, conducted through the development of internal procedures of the regulatory expert agency after the enactment of internal administrative rules of the NRC for transparent and standardized procedure operation. Institutionalization through law amendments is time-consuming, but administrative procedure regulations, though non-binding, allow for quick and flexible procedure establishment. The domestic PLR procedure intends to borrow the concept of conducting through an agreement from the Canadian CNSC, and in Korea, it is envisioned to be conducted through an agreement with the business operator and the regulatory expert agency KINS via internal administrative rules for standardized procedure operation.

For the PLR, the applicant should prepare the following documents and discuss them with the regulator:

(a) Regulatory Gap Analysis Report (by design stage) on the gap between the design characteristics of the i-SMR and current regulatory requirements.

(b) Solutions to the identified gaps (e.g., exemption requests). Safety evaluation factors for each significant design area and a demonstration plan for each evaluation factor (including analysis code development and simulation/experiment plan, design technology R&D plan, etc.). A plan to prepare TeRs demonstrating each exemption request's technical feasibility.

The pre-design review consists of two tracks. The first is the selection of the review scope and gap analysis with safety standards, which are common to all SMR designs. The scope of the review confirms the range of the standard design to be included when applying for a license throughout the nuclear power plant's life cycle. Gap analysis compares the overall design characteristics with current regulatory standards.

Technical report review involves the safety assessment of reports submitted by developers before applying for a license. These reports can be divided into those that satisfy regulatory standards but require in-depth review and those that need to resolve non-compliance with regulatory standards. The review results are documented in the technical report review report, which includes recommendations for improvements and the regulatory position.

The review of the plan to resolve inconsistencies with safety standards involves requesting developers to provide solutions to address items that do not conform to safety standards. After the developer's solution is reviewed, a safety assessment is performed for the feasible items. The remaining issues are identified and addressed in the licensing, construction, and operation stages roadmap. The review results are documented in regulatory positions such as interim staff positions.

The specific direction of the safety assessment is to classify current domestic nuclear regulations by function and evaluate whether the gap between safety standards and the proposed design can be accepted for each function.

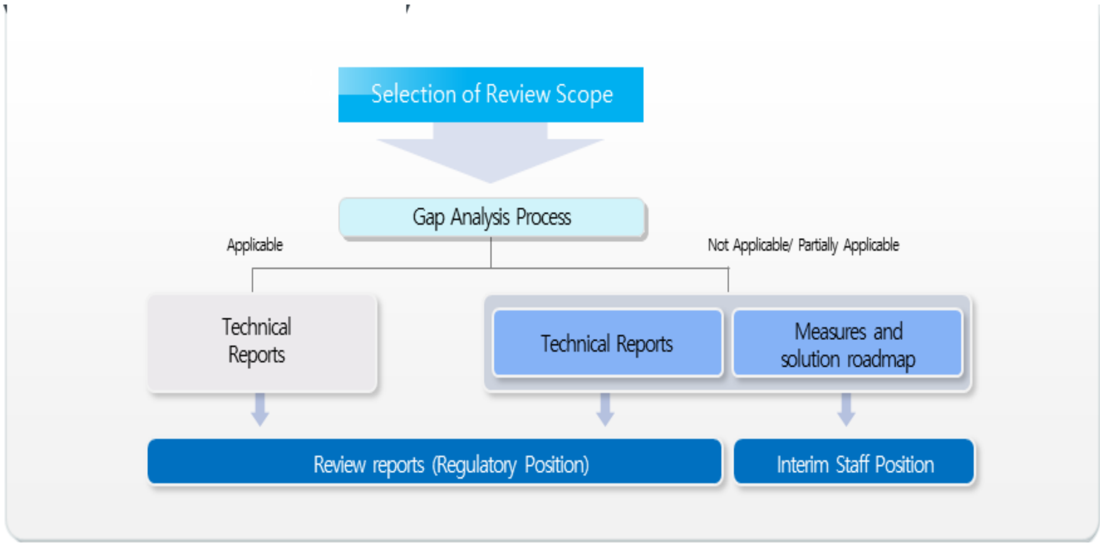

FIG. 1. Pre-licensing safety review (PLR) Process

The PLR for i-SMR began in October 2023. The regulatory side reviews the reasons for the gaps (e.g., the purpose of use, principle differences, or design characteristics) from the gap analysis report between regulatory requirements submitted by the design stage during the preliminary design review process. They review the TeR that demonstrates the technical feasibility of each request for exemption/partial exemption/alternative application and develop a plan to verify it through regulatory R&D. Through R&D, safety evaluation and verification methodologies and evaluation criteria will be developed, and i-SMR-specific regulatory guidelines (draft) will be prepared. The newly introduced pre-design review process will enable efficient licensing through necessary regulatory preparation when applying for licensing.

4. CONCLUSIONS

This paper introduces the status of preparations for SMR regulation in Korea, focusing on the direction of SMR safety regulation and the pre-licensing safety review. Although Korea is proactively preparing to regulate SMRs, several limitations exist.

First, more policies and systems need to address regulatory flexibility. In contrast, Canada's CNSC and the UK's ONR have systems that provide regulatory flexibility as an alternative approach. The U.S. is also applying risk-informed regulations to secure regulatory flexibility. It is enacting 10CFR53 regulations for technology-inclusive, risk-informed, performance-based regulations for regulating advanced nuclear reactors. SMRs require a flexible approach to the existing regulatory system due to the introduction of new technology. Korea may also need a strategy for a flexible regulatory approach.

For Korea's flexible regulatory approach, regulatory agencies acknowledge the need for various design innovations, such as system simplification and passive system applications, to develop new reactors. However, innovative technologies must not compromise "high levels of safety assurance" based on proven or demonstrated technologies through various means. Effective regulation through international cooperation with the IAEA and advanced countries in SMR is essential, based on regulatory capacity derived from domestic unique types (SMART, APR1400, etc.). Additionally, efforts to strengthen international cooperation and regulatory expertise are necessary to complete regulatory infrastructure development and regulatory technology development in a timely manner, ensuring faithful enforcement of regulations.

To prepare for potential issues in the current regulatory process resulting from innovative concepts that differ from existing design, production, and operation methods, the demand for legal revisions must be identified, and the system must be revised if necessary. Regulatory agencies also need to secure a continuous R&D budget for developing safety assessment and verification technologies to provide timely review and technical regulatory positions on innovative designs.

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