

Preliminary Gap Analysis with Existing Safety Review Guidelines for Development and Evaluation of PSA: From the Perspective of Light-Water SMRs

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*Keywords: Probabilistic Safety Assessment, Small Modular Reactor, Safety Review Guidelines, Gap Analysis

1. Introduction

Small modular reactors (SMRs) are simpler in design than large conventional commercial reactors. They can maintain high safety for accidents by applying passive safety systems using natural phenomena. In addition, SMRs are manufactured in modules at factories, which can noticeably reduce the construction period and cost, and have high flexibility in the power grid because they can conduct load-following operation reflecting power demand. Thereby, SMRs provide diversity in energy supply.

In Korea, the innovative small modular reactor (i-SMR) development agency plans to apply for the standard design approval (SDA) by the end of 2025 and one of the docket packages is a preliminary accident management program (PAMP) [1].

When the SDA of i-SMR is applied for, a safety review by the Nuclear Safety and Security Commission (NSSC), the regulatory body, must be conducted. Regulatory Standards (KINS/RS-N series) and Regulatory Guidelines (KINS/RG-N series) referenced by safety review guidelines during license reviews are mainly organized for large conventional commercial light water reactors (LWRs). Recently, there has been a research to improve safety review guidelines to reflect the characteristics of multi-unit operation. Nonetheless, there is a need to check whether there are any additional elements required to reflect the characteristics of SMRs. Additionally, the development and assessment of domestic probabilistic safety assessment (PSA) are currently based on ASME/ANS (American Society of Mechanical Engineers/American Nuclear Society) PSA standard, which has also incompleteness in the viewpoint of SMR PSA development and assessment [2].

This study provides basic insight for investigating overseas SMR PSA examples, and regulatory/technical standards for multi-module risk assessment to support the establishment of a licensing review system related to risk assessment of light water type SMRs.

2. Overview of safety review guidelines

The review procedure for the applications of domestic nuclear facilities is as shown in the Figure 1. The review of a specific application is conducted based on the safety review guidelines for the application in question.

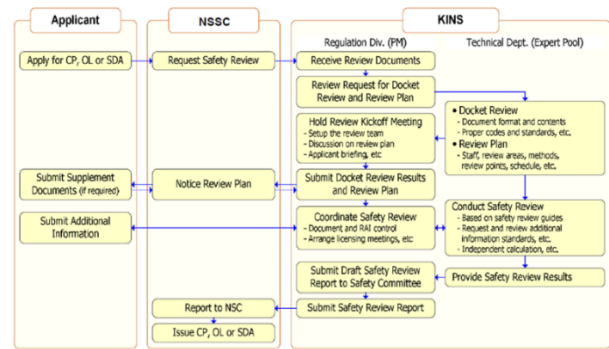


Fig. 1. Procedure for safety regulation review

The safety review guidelines of Korea Institute of Nuclear Safety (KINS) are documents that describe specific procedures and criteria used to assess and ensure the safety of nuclear facilities and activities. These guidelines provide systematic guidance for the review process to ensure safety at all stages of nuclear facilities, including design, construction, operation, and decommissioning.

3. Gap analysis of domestic regulation framework

3.1. Applicability of the current safety regulatory review framework

This section describes the evaluation of the applicability of the current safety review framework when applying to regulatory review of SMRs including PSA. Regulatory review of the proposed applications that include PSA is mainly referenced from the safety review guidelines of KINS. The safety review guidelines and corresponding chapters/sections for review applications that include PSA are as follows:

The applicability of the safety review guidelines for LWRs (KINS/GE-N001) and AMP (KINS/GE-N016)

was analyzed for the SMRs. The contents of the PSA in KINS/GE-N001 and KINS/GE-N016 are described with a focus on the purpose of the regulatory review. In addition, both safety review guidelines describe the content of confirming the technical feasibility of each analysis field of PSA in the “Review Procedure” section.

Table 1. Safety review guidelines and corresponding chapters/sections for PSA

Safety review guideline	Chapters/sections
KINS/GE-N001: Safety Review Guideline for Light Water Reactor	19.1 Probabilistic Safety Assessment
KINS/GE-N008: Safety Review Guideline for Continued Operation of Pressurized Light Water Reactor	KINS/GE-N018 is applied
KINS/GE-N016: Safety Review Guideline for Accident Management Plan (AMP)	4.5 Probabilistic Safety Assessment
KINS/GE-N018: Safety Review Guideline for NPP Periodic Safety Review	4 Probabilistic Safety Assessment

However, most of the contents described in the safety review guidelines refer to the regulatory guidelines of KINS to the extent of presenting high-level review principles for PSA. Therefore, it is judged that the above two safety review guidelines can be equally applied to SMRs, except for some specific modifications to terminology for large conventional commercial NPPs. That is, in terms of the applicability of the safety review guidelines to the PSA portion, it is judged that the existing safety review guidelines can be applied equally through very partial revisions, including modifications to some terminology, without developing separate safety review guidelines for SMRs.

3.2. Major technical issues for risk assessment review of SMRs

In order to identify detailed technical issues for risk assessment review of SMRs, we investigated the NuScale Power Module PSA [3], which is the most advanced SMR among the LWR type SMRs currently under development worldwide. Through the review, we identified the following items that show significant differences in the PSA technical aspects from large conventional commercial NPPs.

- Initiating event analysis reflecting SMR specific design/operation characteristics
- Component reliability data analysis reflecting SMR specific design/operation characteristics

- Thermal-hydraulic uncertainty analysis (passive system reliability analysis)
- Fire ignition frequency analysis
- Analysis of severe accident progression characteristics
- Development of new risk metrics or surrogates for PSAs of multi-module SMRs
- Analysis of common initiating events for PSAs of multi-module SMRs
- Modeling of shared systems for multi-modules
- Human reliability analysis (HRA) method related to simultaneous multi-module operation
- Analysis of accident propagation among modules

4. Conclusions

This paper presents the status of the safety review framework for nuclear facilities, and the characteristics of regulatory items related to risk assessment from the perspective of design/operation of SMRs.

It was found that the domestic safety review framework (safety review guidelines) related to PSA can be applied to SMRs with very little modifications and supplements. However, it is judged necessary to establish a technical foundation that can be referenced for performing regulatory reviews by identifying additional items that reflect the unique design/operation characteristics of SMRs, including the items described in Section 3.2, through additional research on SMRs in the future.

Acknowledgments

This work was supported by the Nuclear Safety Research Program through the Regulatory Research Management Agency for SMRS (RMAS) and the Nuclear Safety and Security Commission (NSSC) of the Republic of Korea (No. 1500-1501-409).

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