Introduction to Regulatory Methodology Development for Risk Assessment of Light Water SMRs

Gyunyoung Heo[a]*, Dong-San Kim[b], Seong Kyu Park[c], Joonseok Lim[a]
[a]*Department of Nuclear Engineering, Kyung Hee Univ., Deogyeong-daero, Giheung-gu, Yongin-si, Gyeonggi-do 17104, Republic of Korea*
[b]*Korea Atomic Energy Research Institute, 111 Daedeok-daero 989beon-gil, Yuseong-gu, Daejeon, Republic of Korea*
[c]*Nuclear Engineering Services & Solutions, 6, Jiphyeonjungang 7-ro, Sejong-si, Republic of Korea*
[*]*Corresponding author: gheo@khu.ac.kr*

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1. Introduction

The innovative small modular reactor (i-SMR) development agency plans to submit preliminary accident management program (PAMP) among the documents required for standard design approval (SDA) by the end of 2025 [1]. Specifically, based on the results of the Probabilistic Safety Assessment (PSA) performed on the single module of i-SMR, the agency plans to verify the overall site safety by additionally evaluating the accident sequence in multi-modules. The agency's safety assurance measures are classified into three topics. In the risk assessment topic, measures such as considering design characteristics such as passive safety systems, risk impact assessment considering the flexibility of multi-modules and site selection, and presenting results satisfying regulations and design goals (top tier requirements) are being discussed. In the multi-module design topic, measures such as performing PSA of four module designs and deriving safety improvement measures, and presenting safety assessment results for sharing non-safety systems between modules are presented. The topics in the design of a multi-module integrated main control room (MCR) include controlling multi-modules from one integrated MCR, designing a passive safety system, achieving a nuclear power plant (NPP) safety without requiring operators to respond for 72 hours in the event of a loss of power, and adopting a design that minimizes the number of MCR operators.

Accordingly, the Nuclear Safety and Security Commission (NSSC) and the Korea Institute of Nuclear Safety (KINS) established the regulatory research management agency for SMR (RMAS) in preparation for reviewing the SDA of i-SMR, based on Article 12 of the Nuclear Safety Act. The major issues for regulatory agencies in line with the safety assurance measures of the i-SMR development agency are summarized in Table 1. As a result, the goal of the risk part among the detailed projects of the RMAS is to develop regulatory methodology and regulatory verification models for licensing review related to risk assessment of light water SMRs, including i-SMR [2].

This paper was organized to introduce an overview and the main performance items of the risk assessment tasks being performed at RMAS in relation to this.

2. Research Strategies

Since i-SMR has the unique characteristics presented in Table 1, there are parts where PSA should be performed differently from general large light water reactors (LWRs). Therefore, a comparative analysis is required on which parts are different from large LWRs. This analysis is expected to include analysis of risk assessment methods and issues performed on SMART100 and NuScale's US600, which have already gone through the licensing process as SMRs. Since domestic PSA and risk assessment regulatory requirements/guidelines and review guidelines are currently focused on large LWRs, the gap analysis with overseas cases is also necessary for i-SMRs.

2.1. Development of single-module MPAS model

For a single module, the initiating event selection/failure tree (FT) and event tree (ET), etc. will be developed to create an MPAS (Multi-purpose Probabilistic Analysis of Safety) model. The core damage frequency (CDF) and large early release frequency (LERF) quantification will be evaluated, and a preliminary analysis will be performed with a simple SMR design. To this end, a preliminary model will be initiated based on the experience of domestic light water SMR (e.g., SMART100) with reference to the ASME/ANS standards [3]. The selection of the initial events related to this, accident sequence, system analysis, human reliability analysis (HRA) related to this preliminary model will be implemented in stages. All of the above will be analyzed and applied using the latest PSA methodology and will be accompanied by internal and external peer reviews. Basically, we plan to proceed with level 1, 2 internal events PSA at full power, and level 1, 2 external(seismic) events PSA at full power.

2.2. Development of multi-module MPAS

Based on domestic multi-unit PSA experience, a multi-module PSA model is developed and related common initiating events, accident sequence, system analysis, reflection of common cause failures (CCFs), and multi-module HRA are performed in stages. Through this, we will develop a multi-module accident scenario, analyze CCFs of the multi-module accident mitigation system, analyze operator errors in response to multi-module accidents, and develop a model for evaluating the CDF and LERF in multi-modules. As in the case of a single module, the latest PSA methodology will be analyzed and applied, and internal and external expert reviews will be conducted.

We will stabilize the multi-module MPAS and independently perform sensitivity analysis, uncertainty analysis, etc. Through this, we will confirm the importance and risk increase amount by module number and component, and as a result, we will conduct a quantitative evaluation of the safety level of multi-modules, analyze the main contributors on multi-module accidents, and review safety improvement measures for responding to the multi-module accidents.

2.3. Development of a classification framework based on risk

The classification of structures, systems, and components (SSCs) of domestic nuclear facilities can be divided into seismic categories, system quality groups, quality grades, electrical grades, and safety grades. Currently, grade classification is performed according to Article 12 of the 'Regulations on Technical Standards for Nuclear Reactor Facilities, Etc.' during the review. As non-LWRs are developed in near future, a new grade classification framework is needed, and risk-informed classification is a representative example. Therefore, materials for establishing a risk-informed classification framework will be produced through the use of policy research results such as the graded approach and risk informed regulation. Based on this framework, a methodology for classification of safety and non-safe grades for light water SMRs will be presented.

3. Conclusions

The final results of this study are to present a review guideline for SMRs that can be utilized by regulatory agencies, and to develop an MPAS that can be used when reviewing PSA models for SMRs and to independently identify major technical issues by utilizing it.

Additionally, we plan to independently develop new PSA methodologies for boron free operation, load-following operation, and functional failure for passive systems, which are rarely seen overseas so far.

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Table 1. Major issues raised by developers and regulators regarding i-SMR.

Topic	Major issues for developers	Major issues for regulators
Risk assessment	○Design characteristics such as passive safety systems ○Risk impact assessment considering flexibility in site selection and multi-module ○Presentation of results satisfying regulatory and design goals (top tier requirements)	○Verification method for reliability assessment of passive safety systems ○Development of guidelines for multi-module risk assessment methodology ○Establishment of risk regulation standards or guidelines for multi-modules
Multi-module design	○PSA of four-module designs to secure safety, economy, and flexibility and derive safety improvement plan ○Presentation of safety assessment results for sharing non-safety systems between modules	○Increased frequency of CCF due to shared facilities ○Methods for assessing the risks and safety impacts of multi-modules ○Establishment of regularization measures such as regulatory standards or guidelines for the installation of four modules in a single reactor building
Multi-module integrated MCR design	○Controlling multiple modules from one integrated MCR ○Designing a passive safety system, achieving a nuclear power plant (NPP) safety without requiring operators to respond for 72 hours in the event of a loss of power ○Adopting a design that minimizes the number of MCR operators	○Confirm the appropriateness of safety analysis, emergency operating procedure, accident response, etc. ○Confirm the appropriateness of operating and accident response procedures suitable for the changed design

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