Review on Safety Goal for Small Modular Reactor in U.S.

Ar Ryum Kim [a], Dohyoung Kim [a*], Dong-ju Jang [a], Seung Woo Lee [a], Chang-Ju Lee [a]
[a] *Korea Institute of Nuclear Safety, 62 Gwahak-ro, Yuseong-gu, Daejeon, Korea, 34142*
[*]Corresponding author: dohyoung@kins.re.kr

1. Introduction

Recently, necessity for developing multi-unit probabilistic safety assessment (MUPSA) has been raised since the Fukushima nuclear power plant (NPP) accident occurred in March, 2011 [1]. This accident has highlighted that the multi-unit events can occur in reality [2], and the public concern about the occurrence of the multi-unit events has been significantly increased. However, there are few researches conducted to estimate multi-unit risk since the safety evaluation has been performed based on each unit [3].

Korea Institute of Nuclear Safety (KINS) has started a long-term research aimed at developing a site risk safety index. The purpose of this paper is to review the safety goal of Small Modular Reactor (SMR) in USA in order to develop various options of a site risk safety index. To do that, current regulation of SMR PSA, NuScale SMR FSAR (Final Safety Analysis Report), and SER (Safety Evaluation Report) for NuScale SAR were reviewed.

This paper is a part of research conducted by KINS and it should be noted that this result does not show regulatory positions of KINS.

2. Current Regulation of SMR PSA

The SRP (Standard Review Plan) of US NRC and ACRS (Advisory Committee on Reactor Safeguards) letter were reviewed in order to figure out how regulatory institute of USA introduces safety goal for SMR.

2.1 US NRC SRP (NUREG-0800)

The SRP pertains to the staff review of the PRA for design certification (DC) and PRA for a combined license (COL) application, respectively [4]. In the SRP, the review procedures specific to integral pressurized water reactors (PWRs) are addressed as follows [4].

i. Used a systematic process to identify accident sequences, including significant human errors, that lead to multiple module core damages or large releases and described them in the application
ii. Selected alternative features, operational strategies, and design options to prevent these sequences from occurring and demonstrated that these accident sequences are not provided reasonable assurance that there is sufficient ability to mitigate multiple core damages accidents.

2.2 ACRS Letter (ACRS-2072)

The ACRS proposed options and recommendations for policy issues related to licensing non-light water reactor (LWR) designs as follows [5].

i. The Quantitative Health Objectives (QHOs) apply to the site as a whole. The sum of the contributions from each reactor on the site to acute and latent fatalities should be bounded by the QHOs.
ii. The Committee has not reached consensus on the approach that should be taken to determine the core damage frequency (CDF) goal due to many troublesome issues. There are two options for CDF goal.

The above mentioned troublesome issues are (1) it introduces a new safety goal that likely will supersede the latent fatality safety goal, and (2) this concept would tend to lead to lack of regulatory coherence and stability, and so on.

3. NuScale SMR Multi Module PSA in FSAR

3.1 Overview of NuScale SMR Multi Module PSA

NuScale SMR is an integral PWR, designed by NuScale Power, LLC [6]. NuScale power submitted NuScale SMR DC application to US NRC. The applicant's FSAR provides information to support the NRC's approval and certification of standard NuScale SMR design. The chapter 19 of FSAR contains PSA result for a single module and the multi modules.

The level 1 PSA for a single module provides the basis for evaluating the risk associated with a multiple module plant. The intent of the multi module PSA is to identify and quantify postulated accident sequences that lead to core damage in multi modules [7].

The multi module PSA uses the single module PSA accident sequence logic and makes parametric adjustments to single module basic event. The parametric adjustments to the single module model are made at the cut-set level using multi-module adjustment factors (MMAFs) and multi module performance shaping factors (MMPSFs). A MMAF is a conditional occurrence or failure probability that an event which has occurred in one module occurs in more than one module,

and a MMPSF accounts for the added complexities associated with a multi module plant configuration. Thus, the multi module CDF and LRF (Large Release Frequency) are quantified using the single module PSA and applying MMAFs and MMPSFs. Multi module CDF and LRF are 4.1E-11/mcry (module critical year) and 1.7E-13/mcry, respectively [7].

3.2 Conformance with safety goal

The quantitative results of the single module PRA demonstrate that the risk associated with operation of an NuScale is substantially less than defined by the safety goal (CDF<1.0E-04/ry, LRF<1.0E-06/ry) [7]. Also, the additional risk associated with multiple module operation is small [7].

i. The mean value of the single module CDF is 3.0E-10 per mcry as compared to the safety goal of 1.0E-04 per reactor year.
   - With regard to a multi-module configuration, MM-CDF (Multi-Module CDF) is about 10 percent of single module CDF.

ii. The mean value of the single module LRF is 2.3E-11 per mcry as compared to the LRF safety goal of 1.0E-06 per reactor year.
   - With regard to multi-module configuration, MM-LRF is about 1 percent of the single module LRF.

4. SER for NuScale SMR Multi Module PSA

The NRC staff reviewed the chapter 19 of NuScale SMR FSAR. The staff used the relevant guidance in SRP (NUREG-0800) in order to evaluate the multi module risk. The staff review found that the applicant's approach is reasonable as it is thorough in scope and uses a systematic approach to evaluate the multi module risk. Also, they found that applicant's approach is acceptable for the DC stage even the approach relies heavily on assumptions using engineering judgment (MMAFs and MMPSFs), and the results of multi module risk evaluation contain large uncertainty [8].

The NRC staff found the conformance with safety goal for single module CDF and LRF; however, they do not identify whether or not multi module CDF and LRF meet the safety goal.

5. Conclusions

As necessity to evaluate the site risk safety index has been raised, the safety goal of SMR in USA was reviewed. In this paper, current regulation of SMR PSA, NuScale SMR FSAR, and SER for NuScale SAR were reviewed. The US NRC SRP, for integral PWR, suggests to review the accident sequences leading to multiple module CDF or LRF; but there was no guidance for safety goal of integral PWR. In ACRS letter, the ACRS proposed that the QHOs apply to the site as a whole; however, they have not determined the CDF goal due to many troublesome issues. In NuScale SMR FSAR, the single module CDF and LRF were compared with safety goal (CDF<1.0E-04/ry, LRF<1.0E-06ry), and it was identified that the multi module CDF and LRF were sufficiently lower than single module CDF and LRF. In SER for NuScale SMR FSAR, the NRC staff reviewed FSAR based on the SRP. The NRC staff review found that the approach to evaluate multi module risk was reasonable; however, they do not identify whether or not multi module CDF and LRF meet the safety goal.

Acknowledgements

This work was supported by the Nuclear Safety Research Program through the Korea Foundation Of Nuclear Safety (KoFONS) using the financial resource granted by the Nuclear Safety and Security Commission (NSSC) of the Republic of the Korea (No. 1705001).

REFERENCES

[1] Ar Ryum Kim et al., Preliminary Study to Identify the Initiating Events for Multi-unit PSA, Transactions of the Korea Nuclear Society Autumn Meeting, Gyeongju, Korea, Oct. 26-27, 2017.
[2] Inn Seok Kim et al., Holistic Approach to Multi-unit Site Risk Assessment: Status and Issues, Nuclear Engineering and Technology, Vol. 49, pp. 286-294, 2017.
[3] Seungwoo Lee et al., A Study on Multi-Unit Initiating Event, Transactions of the Korea Nuclear Society Spring Meeting, Jeju, Korea, May 17-18, 2018.
[4] US NRC, Standard Review Plan (NUREG-0800) Rev. 3, 2015.
[5] Advisory Committee on Reactor Safeguards, Options and Recommendations for Policy Issues Related to Licensing Non-Light Water Reactor Designs, ACRSR-2072, 2004.
[6] nrc.gov/reactors/new-reactors/design-cert/nuscale.
[7] NuScale Power LLC, Chapter Nineteen, Probabilistic Risk Assessment, NuScale Standard Plant Design Certification Application, 2016.
[8] US NRC, NuScale Safety Evaluations, Probabilistic Risk Assessment and Severe Accident Evaluation, 2019.