Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 27-28, 2016

Safety R&D Needs in Multi-Unit PSA from a Regulatory Viewpoint

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1. Introduction

This paper introduces the background, status, and technical issues investigated in the research project entitled "Development of a Regulatory R&D Roadmap for Multi-Unit Risk" funded by the Nuclear Safety and Security Commission (NSSC) in the Republic of Korea.

The NSSC's recent approval of the construction permits and operation licenses of Shin Kori units 3 to 6 has brought attention to the multi-unit probabilistic safety assessment (PSA). The disaster in Fukushima revealed the risks associated with the use of spent fuel pools (SFPs), and the linear (or non-linear) consequences of radiation leaks from multi-units in particular, has raised concerns.

The number of nuclear power plants (NPPs) in operation will increase to ten at the Kori and Shin Kori sites when the construction of Units 5 and 6 is complete – the highest concentration of power reactors in one region in world history. Nuclear disasters do not happen frequently, but when one does happen, its cascading effects can inflict massive human and environmental loss. Proper safety measures are needed as more nuclear installations are put in place.

This highlights the importance of multi-unit PSA, as a result of which the advisory committee of the NSSC has stated that the construction of Shin Kori units 5 and 6 was compliant with the multi-unit safety protocols of the International Atomic Energy Agency (IAEA) due to the appropriateness of its facility locations, promising environmental impact assessment, removal of shared facilities, and installation of an alternative AC power source for individual units [1]. To improve the safety levels of multi-unit nuclear installations, there needs to be a well-developed methodology of multi-unit risk assessment, separate from that of its single-unit counterpart, so as to prevent future radioactive disasters through thorough analysis of those in the past. The Korea Institute of Nuclear Safety (KINS) also emphasizes that multi-unit PSA is crucial when a new unit is added to an existing nuclear power site, and that external hazards and shared facilities require appropriate countermeasures [2].

Consequently, the NSSC has been active in re-evaluating domestic and global regulations and technologies regarding multi-unit PSA to create a safety research roadmap based on national consensus. By the end of 2016, these efforts will provide a list of both short- and long-term research subjects. After safety R&D has an unbiased foundation with verification of the results, it is expected that appropriate regulations will then be proposed through another steps of R&D.

2. Regulatory Status on Multi-Unit Safety

Although the multi-unit safety levels have been guaranteed by the deterministic regulatory approaches, the probabilistic approaches should be also used to determine if there is a significant increase in the risks associated with the inauguration of multiple nuclear reactor units.

2.1 International Status

Globally, there are a number of countries where multi-unit PSA has a high relevance: mainly, the United States, with a high level of expertise in enacting regulatory legislation based on probabilistic risk assessments; Canada, where reactors share many safety facilities due to their design conditions; and Japan, which realized the significance of multi-unit PSA after the Fukushima incident.

- USA
  - The US Nuclear Regulatory Commission (NRC) assigns safety margins for each nuclear reactor.
  - A multi-unit PSA had been conducted by a private company at the Seabrook Station NPP [3], but the results were not reviewed by a regulatory authority.
  - While the NRC reviewed the risks associated with multi-units, it was concluded that the increased risk can be negligible; multi-unit risk was therefore excluded from the evaluation of intrinsic safety properties [4].
  - The NRC has meantime been conducting Level 3 probabilistic risk research project, while simultaneously developing multi-unit risk assessment technologies [5].
  - The simultaneous use of two units had a level of risk that was low enough to qualify as that of a single unit, even when a very conservative set of assessment methodology so called scoping method were used.

- Canada
  - The Canadian Nuclear Safety Commission (CNSC) revised RD-337 in 2014 to publish REGDOC-2.5.2, where safety goals related to more recent units were listed. The document also recommends 'the potential for extensive societal disruption due to a nuclear incident should be practically eliminated.'.
  - The revision of Regulatory Guide S-294 (Probabilistic Safety Assessment for Nuclear Power Plants) to REGDOC-2.4.2 set out to evaluate the impact of multi-units [6].
  - Units that are currently in operation are not obligated to immediately comply with the protocols listed in the REGDOC. Moreover, there has not been a single report of a multi-unit PSA carried out according to the requirements in REGDOC-2.4.2.
  - Meanwhile, the CANDU Owner Group (COG) has announced its intent to conduct a pilot multi-unit PSA for the Pickering NPP by the end of 2017, based on a conceptual-level whole-site PSA methodology: After this, a kind of site safety goal seems to be suggested as a form of following:
    - Large Off-Site Release Safety Goal (LORSG): The aggregate of frequencies, LRF, of all event sequences that can lead to a total release from the site to the environment of more than X (Becquerel) of Y (Radionuclide) should be less than Z_{LRF} occurrences per site year; where it is confirmed that smaller releases in terms of X and Y in accident source terms representative of other event sequences do not require extensive long-term relocation of the local population.
    - Site SCDF: The aggregate of frequencies of all event sequences that can lead to significant core degradation in any of one or more reactors on the site should be less than Z_{SCD} per site year.

- Japan
  - Although since the Fukushima nuclear disaster Japan has strengthened the regulations on single units by demanding a mandatory external risk assessment on individual reactors, there are no requirements pertaining to multi-units in the recent safety requirements (July 2014) [2].
  - Japan's Nuclear Risk Research Center (NRRC), on the other hand, is developing code systems as well as new PSA methodologies to incorporate multiple dangers into the calculation of multi-unit risk.

2.2 Domestic Approaches

In Korea, there has not yet to be an instance where a PSA has been conducted as an approach to multi-unit safety problems. The following regulatory conditions will however prevent collateral damage at a nuclear site by ensuring the separation of all the units and minimizing the influence of external hazards through the selection of a more appropriate location for the facilities. These conditions reflect the discussions in Reference 1 and 2, which involve the practical application of multi-unit safety protocols.

- Article 10 of the Nuclear Safety Act (Construction Permits) states that any person who wishes to apply for a construction permit needs to submit two documents to the NSSC: a preliminary safety analysis report and a radiation effects and liability document.
- Article 10 (Multi-unit Construction) of Section 1 (Nuclear Facility Location) of Chapter 2 (Nuclear Facility Technical Standards) in the Ministerial Ordinances of Technical Requirements Applying to Nuclear Installations (see the NSSC Regulations, Vol. 13) states that facilities should be separated from each other.

One of the pending issues with PSA in Korea was recently resolved through revision of the Nuclear Safety Act in June 2015, which emphasized the significance of risk assessment in preventing and alleviating severe accidents. Article 9 of Public Announcement No. 2016-2 by the NSSC therefore contains a set of quantitative goals for single-unit nuclear reactor safety levels:

1. Each unit should have built-in safety features designed to keep cancer fatalities of local residents below 0.1 percent of the total risk in the event of a radioactive incident, and;
2. The total number of incidents where more than 100 TBq of the radionuclide Cs-137 is released should not exceed 1E-6 per reactor year.

While the introduction of risk assessment itself is deemed appropriate for improving safety levels, it is true that there is concern the aforementioned goals potentially defeat the very purpose of PSAs by emphasizing the role of risk estimation instead of risk reduction. Furthermore, single-unit safety goal should impact the provision of quantitative safety insights regarding multi-units either or both; positively and/or negatively.

3. Technical Issues in Multi-Unit PSAs

As shown in Chapter 2, the USA typically has a small number of multi-units operating in one location, and was able to avoid scrutiny despite conservative risk assessment criteria. However, in Canada, where the safety system is shared between facilities and in Korea, where a lot of multi-units are concentrated near populous cities, there is a need to come up with more stringent measures for analyzing risk.

Currently, the Korea Atomic Energy Research Institute (KAERI) is focused on expanding multi-unit PSA foundation research, based on the results of national nuclear R&D in the last five years, to further advance researches on the technical aspects of multi-unit PSA. Nuclear utility, on the other hand, will be required by the revised Nuclear Safety Act (mentioned in Chapter 2) to submit an accident management plan for all individual units, based on their own and KAERI's research methodologies.

Resolving technical issues related to PSAs while also considering domestic situations will prove crucial in finding the right set of regulatory viewpoints on the objective validity of the currently-used assessment criteria and multi-unit safety standards. The following contains an analysis of independently-collected data and consultations from both domestic and foreign experts on the matter.

3.1 Objective Validity

Multi-unit PSA raises validity issues from time to time, as does its single-unit counterpart; this paper intends to focus only on the issues of multi-unit PSA.

- Initiating Events

Classification of initiating events that lead to a series of multiple incidents, as well as analyzing their frequency are crucial.

Considering that domestic nuclear reactors are strictly separated from one another in terms of safety facility use, one internal event in an individual unit is not likely to influence the other units.

Reference 2, however, points out that external incidents on a large scale can still trigger multi-units to collapse simultaneously, leading to a nuclear disaster with significant consequences [2]. Furthermore, analyzing external incidents goes beyond the scope of general nuclear engineering – it incorporates multiple viewpoints from various fields of study such as geoscience, geology, meteorology, oceanography, climatology, and structural engineering – which makes technical sophistication all the more challenging.

- Dependency

Many technical problems related to multi-unit safety arise from the high degree of inter-unit dependencies between power plants. Considering that the total risk is characterized as the multiplication of the severity of possible consequences and the likelihood of their occurrence, inter-unit dependencies will have the following outcomes:

Normally in an independent event, the probability of simultaneous multi-unit failures is almost nonexistent; however, high levels of inter-unit dependencies will work against the element of isolation and eventually increase the likelihood of detrimental events. For instance, seismic events generally increase the likelihood by having a direct impact on multi-units. Inter-unit dependencies also heavily influence the severity of core damage, due to the non-linear impact of radiation sources, domino effects, and inter-unit common cause failures (CCFs).

The inter-unit dependency issues from a technical point of view would include the classification of multi-unit initiating events, scenario analyses, inter-unit CCF, staff/organization dependency, emergency preparedness, and so on.

Moreover, inter-unit dependencies increase the quantity of calculation workload at an exponential rate; therefore, conducting a multi-unit PSA should involve a set of criteria based on logical assumptions that determine which scenario should be included or be screened out.

3.2 Safety Criteria

Even if the technological issues were resolved, multi-unit PSA results would still need to provide insight into how the safety levels of units can be verified and trusted. To do so, a separate in-depth study in related fields would need to be performed simultaneously (It should be noted that this holds true for general PSAs as well).

- Balance between Frequency and Consequence

Conducting a PSA involves a balanced analysis of two feasible issues: the likelihood and the loss of possible accidents. Any approach that weighs one over the other is prone to ignoring the significant principles of PSA. The objective validity mentioned in 3.1 should therefore be impartially taken into account when measuring said quantities of risk through organized PSA research.

- Processes over Results

Experts on PSA agree that the end results of safety assessment (such as CDF) are not ultimately the goals of PSA.

Quantitative indicators may render the regulatory process more convenient, but the process of arriving at such results holds more significance in PSA.

The NPPs that have already produced satisfactory results based on certain indicators may technically stop putting more effort into improving safety standards, although PSA models are not meant to be used as a one-time solution due to the costly nature of its development. Another reason why the final indicative results are not reliable is that the number of initiating events that are included in PSA will keep increasing as time passes, which will consequently produce more risk; putting much effort and time into compensating for the increased risk not by facility improvement but by numerical calculation will prove disadvantageous to the development of PSA.

Furthermore, in the process of deriving a quantitative indicator from a multi-unit PSA, major accident scenarios can be deduced finally; therefore, more research on regulation needs to take place to determine which set of criteria, either quantitative or qualitative, should be used. This is also true for the PSA which is included in periodic safety review (PSR).

- Continuous Quality Improvement

It is previously mentioned that the regulatory viewpoint for the purpose of PSA should be sought not in the results but in the process. The statement by the NSSC, in Appendix 1 and 2 of the 2016-2 public announcement, that analyzing "incidents that must be closely inspected through PSA and incidents that are deemed to have similar levels of magnitude and probability of occurrence" is therefore accurate.

In addition, the term "multi-unit" is interchangeably used to mean "multi-reactor" these days; however, after witnessing the Fukushima incident and its devastating impact on SFPs, some have voiced the opinion that a more accurate term with an equivalent meaning to "multi-unit" would be either "multi-plant" or "whole-site". Canada has already begun trials of whole-site PSA, with a new series of safety examinations to be performed on all the facilities on site (including dry cask storage for spent fuel) which is not something that is required in regular PSA.

After the Fukushima incident, some have also mentioned that the mission time considered in PSA should be extended to at least a week (currently 24~72 hours as usual). Moreover, multi-units tend to be constructed at different points of time, with some being built a few decades after others, which means that the calculation of inter-unit CCF should take the ageing effect into account.

On the other hand, especially after the Fukushima disaster, nuclear utility has installed multiple safety facilities that PSAs have not provided due credits. Cooperation of utility in improving nuclear safety levels can only be ensured through conscientious regulation.

It is obvious that a single PSA result from a certain point in time cannot be used as the standard quantitative indicator for the whole unit; ensuring that the quality of PSA can be bettered through continuous improvement is therefore crucial. Whether such technical grounds would require a new legal system or understanding of stakeholders within the existing system still remains the question.

4. Conclusions and Recommendations

The legislation which has made PSA compulsory in order to prevent and mitigate severe accidents - almost two decades after the Nuclear Safety Policy Statement of 1994 and the Severe Accident Policy Enactment in 2001 - certainly seems like a step in the right direction in the future of nuclear safety; however, it is generally agreed that a lot of works need to be done to even the single-unit PSA to be utilized as an adequate regulatory measure. Nuclear regulators are forced to promptly produce a sufficient degree of realistic and objective risk assessment results to meet the rapidly-increasing demand for multi-unit PSA, while striving to achieve matching levels of technological development.

The issues with the technological aspects of PSA would still be inherent even after a few years of research, and ensuring the safety of multi-units would still prove challenging. Experts are however relieved that the general public is now much more familiar with the concept of PSA than in the past, which indicates a rise in the degree of public understanding of technology. More studies should be done on multi-unit regulation and safety so as to steer the government in the proper direction for enacting policies aimed to ensure the health of local residents.

In conclusion, the technical problems associated with multi-unit PSA that were not mentioned in this paper are essentially similar to their single-unit counterparts, therefore, reinforcing the base infrastructure of PSAs in general will work towards resolving such technical issues with multi-unit PSA. This is described in detail in the cited work written in July 2016 [7].

ACKNOWLEGEMENTS

This work was supported by the Nuclear Safety Research Program through the Korea Foundation of Nuclear Safety (KOFONS), and granted financial resources from the Nuclear Safety and Security Commission (NSSC), Republic of Korea (No 1601001).

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