

Development of Preliminary Review Guideline for Multi-Unit PSA

Yongjin LEE¹⁾ *, Dongwon LEE¹⁾, Dongju JANG¹⁾
¹⁾Korea Institute of Nuclear Safety (KINS)
*k730lyj@kins.re.kr

1. Introduction

After the Fukushima accident, domestic and foreign interest in the safety of multi-unit has been increased. In Korea, a total of 25 nuclear power plants are currently in operation at four sites: Kori, Wolsung, Hanul, and Hanbit. In addition, each site is a multi-unit site in which at least five units are operating, and the population density near nuclear power plants is relatively high compared to other countries, raising public concerns about the safety of multi-unit site.

When the Nuclear Safety and Security Commission deliberated on the construction permit for Shin-Kori Units 5,6, the need for safety evaluation of multi-unit risk within a single site was raised. Accordingly, the Nuclear Safety and Security Commission launched a Multi-Unit Risk Research Group(MURRG), which is conducting research on regulatory methods and evaluation methodologies for site risk assessment. Therefore, in this study, as a part of the development of the site risk assessment regulatory methodology of MURRG, a review guideline(draft) for Multi-Unit PSA(MUPSA) was developed.

2. Domestic conformity assessment to establish MUPSA review guideline

In this chapter, preliminary candidates for MUPSA review guideline were derived by reviewing the literature of international organizations and regulatory requirements of various countries. The derived candidates for MUPSA review guideline should be selected as the final regulatory review guideline by comprehensively considering the domestic regulatory environment and other considerations. Therefore, in Section 2.1, the evaluation system was developed to perform domestic conformity assessment, and in Sections 2.2, the details of each evaluation step were described based on the evaluation system developed in Section 2.1.

2.1. Development of domestic conformity assessment system for MUPSA review guideline

In this section, a system was developed for the domestic conformity assessment of preliminary candidates for MUPSA review guideline, and the diagram is shown in Figure 1 below.

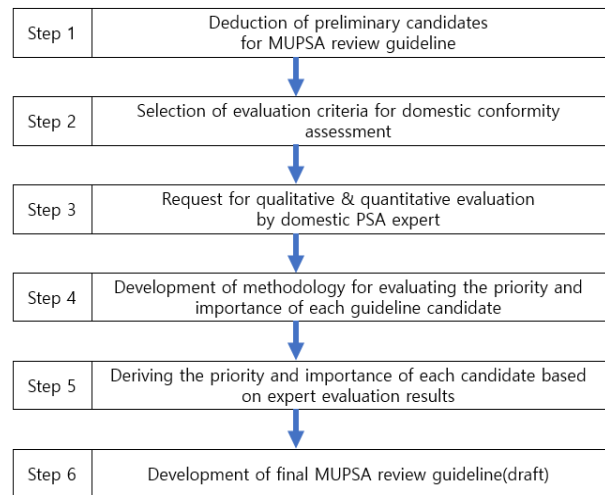


Fig. 1. Domestic conformity assessment system for MUPSA review guidelines

2.2. Development of MUPSA review guidelines based on the domestic conformity assessment system

This section describes the details of each step based on the assessment system developed in Section 2.1. The detailed contents of each step are as follows.

- Step 1) Deduction of preliminary candidates for MUPSA review guideline

In 2020, IAEA safety report series No. 96 and other domestic and foreign documents which are related to MUPSA were reviewed to derive preliminary candidates for MUPSA review guideline. In addition, this study additionally derived the candidates presented in IAEA SSR-3, which is currently being revised in 2021.

- Step 2) Selection of evaluation criteria for domestic conformity assessment

Evaluation criteria were selected for the evaluation of a total of 49 candidates for MUPSA review guideline derived in the step 1. Three items are selected as evaluation criteria: 'Analysis possibility (current level of technology)', 'Regulatory necessity (whether or not overlapping with Single-unit PSA requirements, etc.)', and 'Licensee acceptability'. The reasons for selecting each evaluation criteria are as follows.

· 'Analysis possibility' is the criteria to evaluate the technical level of each candidate. Each evaluator evaluates the relevant items as 'possible' or

‘impossible’ by judging whether the analysis of the candidate is analyzable at the present time based on the experience of single-unit and multi-unit PSA.

· The ‘Regulatory necessity’ is the stage to evaluate the regulatory necessity for each candidate based on the current domestic regulatory environment. This item evaluates ‘Yes’ or ‘No’ by comprehensively considering redundancy and consistency with the current PSA regulatory requirements for single-unit.

· ‘Licensee acceptability’ is a stage to evaluate the acceptability of licensee for each candidate and comprehensively evaluate the cost-benefit of applying the requirements. In this item, the evaluator classifies licensee acceptability into ‘high’, ‘medium’, or ‘low’.

- Step 3) Request for qualitative & quantitative evaluation by domestic PSA expert

The preliminary MUPSA candidates analyzed in step 1 are requested to be reviewed by PSA experts in Korea Institute of Nuclear safety (KINS) based on the evaluation criteria selected in step 2. The evaluation was conducted by a total of 11 experts, ranging from members with at least 3 years of PSA review and research experience to experts with up to 30 years of experience. When it is difficult to judge the evaluation of each sub-item during expert evaluation, it is possible to select ‘Neutral’ to avoid biased analysis.

- Step 4) Development of methodology for evaluating the priority and importance of each guideline candidate

Step 4 is to develop a methodology that can evaluate the priority and importance by collecting the evaluation results of the preliminary MUPSA review candidates evaluated by each expert in the step 3. The methodology used to collect and analyze the evaluation results is similar to that of general survey statistics. The response rate for each evaluation criteria was analyzed, and the final score was calculated using the weight for each evaluation criteria.

- Step 5) Deriving the priority and importance of each candidate based on expert evaluation results

This step is to derive the priority and importance for each candidate based on the methodology developed in step 4. Examples of priorities and importance evaluation among preliminary candidates for the MUPSA Review Guidelines are as follows.

Table 1 shows the results of each expert's evaluation of the candidate No. 5 for the MUPSA review guideline drawn as a result of the study.

Table 1. Expert evaluation result for preliminary candidate No. 5

5. When screening and removing initiating events, it should be checked whether the MUCDF	Analysis possibility		
	Possible	Impossible	Neutral
	82%	9%	9%
	Regulatory necessity		
	Yes	No	Neutral

contribution is less than 1% for multiple sites and is an initiating event affecting two or more units.	45%	18%	36%
	Licensee acceptability		
	High	Medium	Low
	20%	70%	10%

Table 2. Weight and detailed score for each evaluation criteria

Evaluation Criteria	Answer	Score
Analysis possibility (Weight: 0.5)	Possible	1
	Impossible	0
	Neutral	0.5
Regulatory necessity (Weight: 0.3)	Yes	1
	No	0
	Neutral	0.5
Licensee acceptability (Weight:0.2)	High	1
	Medium	0.5
	Low	0

Using the expert evaluation results in Table 1 and the weights in Table 2, the score for candidate No. 5 of the preliminary review guideline can be calculated as follows.

- Scoring Formula for Preliminary MUPSA Review Guideline No. 5
 $[Analysis\ possibility(0.5) \times \{possible(82) \times 1 + Neutral(9) \times 0.5\}] + [Regulatory\ necessity(0.3) \times \{Yes(45) \times 1 + Neutral(36) \times 0.5\}] + [Licensee\ acceptability(0.2) \times \{High(20) \times 1 + Medium(70) \times 0.5\}] = 73.15$

- Step 6) Development of final MUPSA review guideline(draft)

In this step, the final review guidelines were derived based on the priority and importance derived through steps 1 to 5 and the qualitative review opinions of each expert.

3. Development of MUPSA review guidelines(draft)

In this chapter, the MUPSA review guidelines(draft) were derived based on the contents described in chapter 2. The preliminary MUPSA review guideline candidates were reclassified by each PSA step and detailed element, and the results of the expert's qualitative evaluation are reflected as follows.

3.1 General aspect of MUPSA

If the MUPSA is developed based on the single unit PSA model, the staff will determine whether the single unit PSA model that satisfies the quality requirements reflect the characteristics of each unit. The staff will

determine whether the scope of MUPSA is selected by comprehensively considering the results of single-unit PSA and internal and external events that can cause simultaneous multi-unit accidents. When performing a MUPSA, the staff will determine whether the combination of the operation status of each unit is properly considered in consideration of the power plant operation experience and risk importance. Also, the staff will determine whether the time fraction of each combination of each operating condition is evaluated. If the combination of each operating condition is simplified, the staff will determine that the combination of key plant operating condition are not excluded from a multi-unit risk point of view, and verify that the assumptions are clearly documented.

3.2. Level 1 MUPSA

3.2.1 Analysis of initiating events that cause multi-unit simultaneous accidents

The staff will determine whether the common cause initiating event(CCIE) that can cause multi-unit simultaneous accidents is properly selected, including common cause failures of facilities that share multiple structures and systems. Also, the staff will determine whether combinations of units affected by CCIE are properly presented.

In case of screening the initiating event, the staff will determine whether the effect on the multi-unit risk is properly considered, and it will be determined that the effect of screening is sufficiently small.

When evaluating the frequency of CCIE, the staff will determine whether the evaluation is performed based on the site year, operation experience of domestic and overseas nuclear power plants, characteristics of the site to be evaluated, design data.

3.2.2. System analysis

The staff will determine that systems and structures shared by multi-units within a single site are properly considered in MUPSA. In case of a simultaneous multi-unit accident, the staff will determine that the availability of systems and structures shared by each unit is evaluated, and that the priorities of shared systems are properly considered. The staff will determine that multi-unit shared systems and structures are clearly documented and that the impact on each unit in the event of shared system and structure failures were assessed.

3.2.3 Accident scenario analysis

When analyzing the multi-unit accident scenario, the staff will determine that whether shared systems and structures that commonly affect multi-unit are properly considered. In addition, the staff will determine that human actions necessary to manage multi-unit accident

are properly considered, and that performance shaping factor of human factors due to site-level accident conditions are evaluated correspondingly to multi-unit simultaneous accident.

The staff will determine that the dependencies between the human actions of other units should be considered, and the interaction with the shared system, common main control room, and common technical support center, and the impact of internal and external disasters were properly considered. The staff will determine that whether human errors are evaluated in consideration of sufficient human resources for the implementation of emergency operation procedure(EOP) and severe accident management guidelines(SAMG).

3.2.4 Common Cause Failure

The staff will determine that the inter-unit dependency factors that may affect the occurrence of CCIE and the subsequent accident progression are properly considered.

The staff will determine that whether selection of the following inter-unit dependency factors and evaluation of their impact are properly performed.

- Dependency due to identical SSCs
- Dependency due to shared SSCs
- Dependency due to physical proximity
- Dependency due to human aspect
- Dependency due to organizational aspect
- Dependency due to other causes

The staff will determine that whether the characteristics of the site to be evaluated, design data, and operation experience are considered in the selection of these dependency factors and the evaluation of their impact. In addition, the staff will determine that the rationale for the excluded dependency factor is confirmed through qualitative or quantitative screening analysis.

3.2.5 MUPSA quantification

The staff will determine that whether the MUPSA quantification is performed by comprehensively considering accident conditions such as the core damage state of each unit within the single site. The staff will determine that whether the minimal cut set derived as a result of MUPSA quantification is analyzed in consideration of all important factors from the viewpoint of multi-unit risk such as CCIE and shared systems, etc.

3.3. Level 2 MUPSA

3.3.1 Multi-unit plant damage state

In the evaluation of multi-unit simultaneous accidents, the staff will determine that plant damage state for each unit was defined, and it will be

determined whether the combination of the plant damage state of each unit was properly considered. If the plant damage state for each unit is assumed to simplify the analysis, the staff will determine whether the assumptions for each unit are clearly documented.

In addition, when the same plant damage state is assumed for each unit, the assumption of different plant damage state reduces the probability of simultaneous release of radionuclides, the staff will determine the impact of the difference from assuming the same plant damage status.

3.3.2. Multi-unit operation status

When MUPSA is performed for all operating conditions including full power and low power shutdown operation mode, the staff will determine whether source term analysis corresponding to the operation mode of each unit is performed.

3.3.3. Multi-unit containment failure frequency

The staff will determine that whether the major containment damage scenarios analyzed from the single-unit PSA result and the major containment damage scenarios due to the combination of the containment damage in multi-unit is included.

3.3.4 Multi-unit source-term analysis

The staff will determine that whether the analysis includes the operating state and operation mode at the time of the accident for each unit, the definition of the accident scenarios, the release duration, release location, and sensible heat.

3.4 Level 3 MUPSA

3.4.1. Source term for off-site consequence analysis

The staff will determine that all the source-term derived from Level 2 MUPSA should be considered, and the evaluation is made in consideration of the combination of source-term released from each unit.

3.4.2 Multi-unit health impact assessment

When multi-unit health impact assessment is performed by multiplying the source-term released from single unit, the staff will determine that whether the dose model used in the early and latent health impact assessment is properly selected.

3.4.3 Multi-unit emergency preparedness

When considering emergency response measures for external disasters that cause multi-unit accidents, the staff will determine that whether the emergency response measures are modeled in consideration of the damage to the infrastructure that can realize the protection measures.

4. Conclusion

In this study, domestic conformity evaluation system for candidates of preliminary MUPSA review guideline was developed, and expert evaluation was performed to develop the MUPSA review guideline(draft). The priority and importance of each preliminary candidate were derived using the expert evaluation results, and detailed reviews were performed on the preliminary candidates that obtained less than the specific score. The final MUPSA review guideline(draft) were developed by comprehensively analyzing the expert evaluation results and domestic single-unit PSA review guideline.

The developed MUPSA review guideline is expected to be used as a basis for review when evaluation of MUPSA is required as a national policy in the future.

Acknowledgement

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