A SINGLE-UNIT PSA MODEL BALANCING GUIDE TO BUILD A MULTI-UNIT PSA MODEL

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EXTENDED ABSTRACT

Probabilistic Safety Assessment (PSA) for Nuclear Power Plants (NPPs) has generally targeted a single-unit before the Fukushima NPP accident in 2011. However, interest in multi-unit risk assessment has increased after the Fukushima accident. Despite this situation, there are no widely accepted guideline used for developing a multi-unit PSA model.

In Korea, interest in site risk has also increased due to the earthquakes that occurred in Gyeongju and Pohang in 2017 because most sites have multiple units in Korea. Accordingly, nuclear power industry, namely KHNP (Korea Hydraulic & Nuclear Power) and regulatory body, KINS (Korea Institute of Nuclear Safety) have developed PSA models for site risk assessment.

Despite the inadequacies in terms of consistency in individual unit's PSA models (single-unit PSA models) within a site, the multi-unit PSA model was established in the past. Thus, there has been a lack of balance among single-unit models in past multi-unit PSA models. Maintaining a balanced level among single-unit PSA models used for developing a multi-unit PSA model is a very important factor in assessing the multi-unit risk profile at an appropriate level because multi-unit PSA combines and analyzes multiple single-unit PSA models.

In PSA, it is crucial to determine if the quantification results by initiating event (IE) and accident sequence are appropriate, as well as if the cut sets and event importance results are suitable. If model balancing is not achieved, a specific initiating event might account for most of the CDF, while the CDF of other initiating events appears to be unimportant.

In general, PSA reviews model suitability by comparing the results with those from other plants to check if there are any significant discrepancies in the PSA models. So far, balancing of PSA models has not been a major focus of review, and there is also no established methodology globally for this purpose.

Especially in multi-unit PSA, where multiple unit PSA models are combined, it becomes even more important to ensure that each unit's PSA model is appropriately developed and balanced. The necessity for balancing unit models is further increased due to the following reasons:

- ✓ Development of models by different institutions/developers for each unit
- ✓ Possibility of different assumptions, methods, and reliability data being used for each unit
- ✓ Inadequate review of the appropriateness of unit-specific PSA models and quantification results

Accordingly, it is necessary to review the balancing of the PSA model for each unit. The balancing of the PSA model should be reviewed together with the appropriateness of the PSA model.

This means that a single-unit PSA model should (1) maintain an appropriate quality level, (2) be standardized to become a component of a multi-unit PSA model, and (3) keep a level of equivalence among single-unit PSA models within a site. In this work, the 'quality level' can only be defined qualitatively, and is defined as revising a single-unit PSA model that applies similar assumptions, reliability data, and model scope, etc. to ensure consistency.

This guideline presents a method for reviewing PSA models and results together with the major elements of each plant design and characteristics of the CSFs (Critical Safety Functions).

Figure 1 shows the key points to be checked for quantification balancing in each single-unit model.

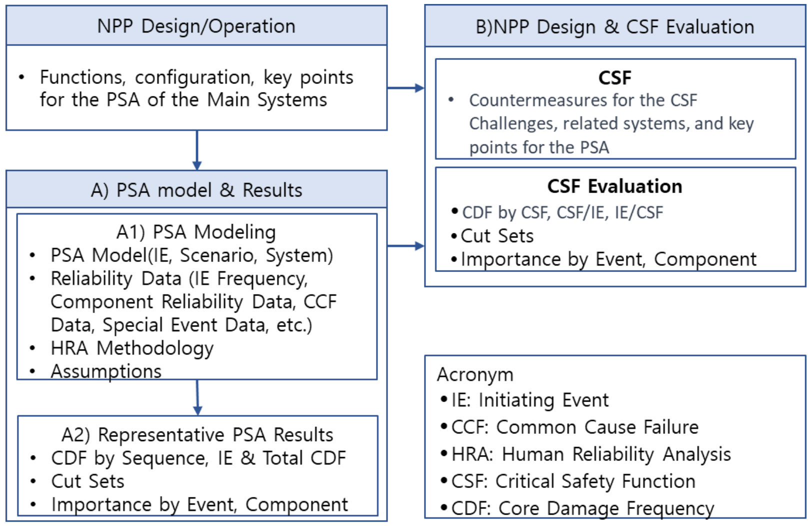

FIGURE 1. Key Checkpoints for Balancing PSA Models

At stage A1) in Figure 1, it is necessary to review whether the modeling method, reliability data, and assumptions for each unit are used similarly as follows:

- ✓ Review the consistency of the PSA model for each single-unit
- ✓ Compare the initiating events, accident scenario modeling level, reliability data, human reliability analysis (HRA) method, and assumptions analyzed for each unit

At stage A2), review representative results from the PSA quantification as follows:

- ✓ Review the main results of PSA quantification, such as CDF by initiating event, CDF by sequence, total CDF, cut sets and event importance.
- ✓ Review the above results to confirm whether there are any errors in the PSA model and its results. Additionally, it is necessary to compare the PSA results with those of similar NPPs to confirm that the PSA results of the NPP under review are not significantly different from those of similar NPPs.

At stage B), review the relationship between NPP design characteristics and CSF (Critical Safety Function), as well as quantification results. This part has not been used to review PSA results so far, but it can be considered a method to properly evaluate the design, function of the safety systems and their connection to PSA. Thus, in this guideline, the evaluation methods are summarized as follows:

- ✓ Organize the safety systems that perform CSF. Along with this, compile the factors that significantly affect PSA quantification results
- ✓ Summarize which CSF failures contribute to each core damage accident scenario
- ✓ Evaluate the CDF for each CSF
- ✓ Since the results may vary depending on the assumptions, it is necessary to review the results for each unit, considering the differences according to the assumptions.
- ✓ It is recommended to unify the assumptions for each unit regarding factors that are important for the quantification results

In this paper, to provide with a method to comparing the results among the units in multi-unit PSA, the relationship between CSF and PSA quantification was conducted experimentally by using the APR1400 MPAS model. In this experimental assessment, CSF was classified in more detail than usual to understand the characteristic of systems, as shown in Table 1.

TABLE 1. Example of CSF Classification for Quantitative Balance Check

Critical Safety Function	CSF Classification	Description
DHR	Decay heat removal	Loss of MFW/AFW, failure of F&B
DHR-CSR	Decay heat removal via containment spray recirculation	In the event of LOCA, failure of containment spray or containment spray recirculation
DHR-LT	Decay heat removal - long term	After MFWS/AFWS actuation, SCS/AFW Tank makeup/ failure of F&B (mainly, operator action failure)
EP	Electrical power - short term w/loss of AFW TDP	SBO, AFW-TDP failure, AAC/Recovery failure of off-site power (The recovery of AC power is required for the operation and cooling of major pumps in several scenarios.)
EP-DC	Electrical power – Battery Depletion	SBO, Battery depletion, AAC/ Recovery failure of off-site power (Scenarios which continuous cooling is possible by DC recovery.)
INV	Inventory makeup for LOCA	In the event of LOCA, Safety injection failure (Including recirculation)
RX	Reactivity control	Core damage due to Reactivity control failure
UHS	Ultimate heat sink	Total Loss of ESW/CCW

Also, to develop a multi-unit PSA model based on a single-unit model, it is necessary to standardize single-unit models used for the multi-unit model. The Korean multi-unit PSA model employs a method composed of a One-Top model as shown in Figure 2. As each single-unit model is added as a sub-logic to a single top logic, standardization of the single-unit models is essential. When generating a single-unit model according to the operation mode, if there are different operation modes, gates with different substructures (logic) must use different gate names.

For example, the full power operation mode and low power/shutdown operation mode have similar basic structures, but the lower logic is slightly different. If the gate names are not different in that part, a conflict error may occur when configuring the top logic. Additionally, inter-unit dependency must be considered such as DG operation and IA (Instrument Air) system, etc. When developing a multi-unit PSA model, inter-unit dependency that is not considered in a single-unit model must be taken into account. This is added when developing a multi-unit PSA model by integrating a single-unit model.

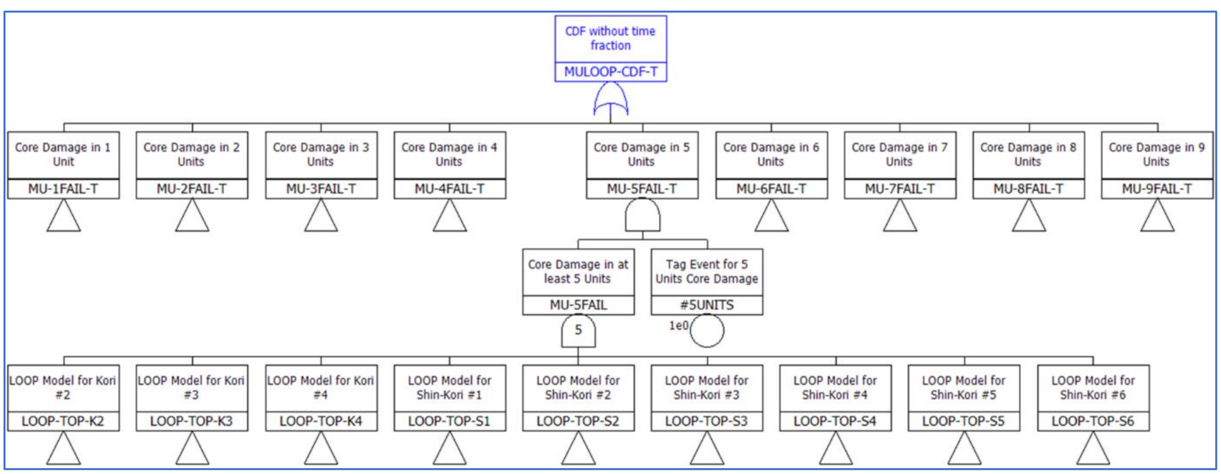

FIGURE 2. Example of Korean Multi-unit PSA One-Top Model

In general, PSA model adequacy is reviewed by comparing the results of other units to check for any errors in the PSA model, and to determine if there are any significant differences. Balancing PSA model has not been a major focus of reviews so far, and there is no established methodology for such work worldwide. Therefore, a method is needed to review the consistency and balance of a single-unit PSA model in order to develop a multi-unit PSA model. Based on the review of the core damage frequency assessment results categorized by CSF, it is determined that significantly different results can be identified. To analyze these results, the PSA modeling method is reviewed to verify its validity. It is expected that through this comparative review, the quality level of the PSA modeling and the quantification results can be balanced and harmonized.

A proposed guideline in this paper presents a method to review not only the PSA model and results, but also the main elements of each unit design and the CSF characteristics. By comprehensively reviewing the design characteristics, CSF characteristics, PSA model, and quantification results of each unit, it is possible to compare whether the PSA results are consistent with the design characteristics of each unit. Based on this work, it is expected that model balancing and adequacy can be improved for building a multi-unit PSA model.

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