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Simplified Method for Quantification of Multi-Unit STC

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1. Introduction

In Korea, the safety issues for multi-unit site are more important than those of other countries. Korea is one of the countries which have high density of NPPs at a single site. Currently, there are four NPP sites, and a total of twenty five NPPs are on operation. Each site has more than six operating units and includes additional units which are under and scheduled-construction. When multiple NPPs were constructed in Korea, the safety of the site had been assured by the domestic technical criteria based on the IAEA standards. However, the existing criteria for multi-unit sites are difficult to satisfy the public demands in the current status. Thus it is necessary to develop a clear and comprehensive method for assessing the multi-unit safety.

To perform multi-unit PSA, we should consider a lot of combinations between the units. So, it is necessary to reduce the number of combinations to appropriate level. For this, we aim to suggest a simplified method to quantify multi-unit STC combinations in this paper.

2. Methods and Results

In this chapter, the simple procedures and methods for quantifying the multi-unit Source Term Category (STC) are summarized. In Section 2.1, the structure of the multi-unit risk model is briefly described. Section 2.2 explains the details to quantify multi-unit STC.

2.1 Structure of a Multi-Unit Risk Model

The multi-unit risk model has the structure including both of single-unit damage state and concurrent multi-unit damage state. This can be simply expressed by the Boolean expression.

$$S = \sum_{i=1}^{n} U_i \tag{1}$$

Where, S is the site damage state and n is the number of NPPs at the same site. In the single-unit risk model, the damage state is expressed as a function of initiating events and their sequences because the states of the adjacent units are not considered. At the level of site, multiple damage states must also be considered.

For a simple example, the damage state including all possible combinations for a certain site which have three units can be illustrated as figure 1. In accordance with Boolean algebra, the damage state of unit 1 can be decomposed into four damage states. In terms of an individual unit, four damage states are considered as the same event.

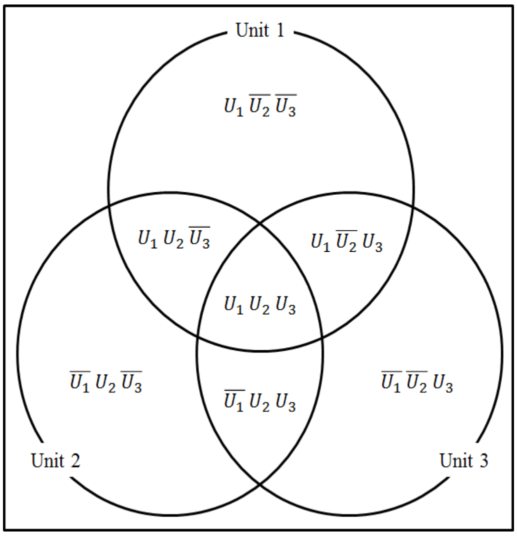

Fig. 1. The Possible Combinations for Three Units

However, they are practically different from each other because the consequence will be different in accordance with the number of damage units. For this, Eq.1 can be written in more detail [1, 2].

$$S = \sum_{i=1}^{n} U_i = \sum_{i=1}^{n} \left(U_i \prod_{\theta \neq i}^{n} U_\theta \right) + \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \left(U_i \cdot U_j \cdot \prod_{\theta \neq i,j}^{n} \overline{\Phi_\theta} \right) + \cdots + \prod_{p=1}^{n} U_p \tag{2}$$

If the site level damage states are determined by the above equation, multi-unit risk can be estimated by the following equation.

$$R = \sum_{i=1}^{n} f(S_i) \cdot C_i \tag{3}$$

Where, S_i is the event group which has the same consequence, $f(.)$ is their frequency, and C_i is the consequence of the i-th event group.

2.2 Simple method to Quantify STC

In the existing PSA framework to estimate the risk, the frequency in Eq.3 is addressed in Level 1 and 2 PSAs, and the consequence is calculated in Level 3 PSA. Multi-unit PSA to estimate the site level risk has a similar framework of the above.

For the consequence analysis, STCs which are one of the results of Level 2 PSA are needed as an input. The STC is generally quantified by the Containment Event Tree (CET) and Decomposition Event Tree (DET) analyses which use the Plant Damage State (PDS) of Level 1 PSA as an input.

In case of multi-unit site, as the number of damage states increases, there are many STC combinations. In addition, the consequences can be different according to whether the safety function/system succeeds or not even if their damage states are the same. Hence, the efficient method should be developed to quantify multi-unit STC.

The proposed method is to simply address multi-unit STC using the single-unit Level 2 PSA results without additional CET and DET analyses. The overall procedure consists of three steps as follows.

- Generate the relation information between PDS and STC using PSA results of each unit
- Using single-unit PSA result, assign PDS to each unit accident sequence included in multi-unit accident sequence identified by multi-unit level 1 PSA
- Quantify multi-unit STC using the proposed method

When Level 2 PSA is complete, we can get the information below.

- What PSDs are assigned to STCs
- What fraction is assigned to STCs

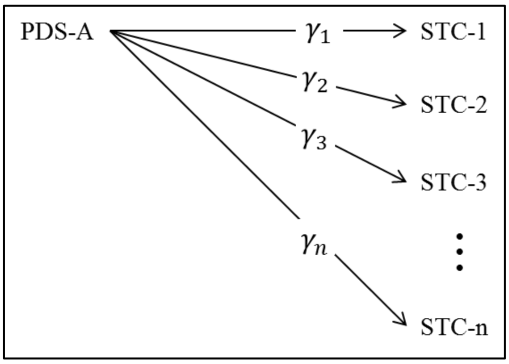

Fig. 2. The Relations between PDS and STC

The summation of all fractions, which are branched off from one PDS to each STCs, is "1" because they are conditional probabilities.

$$\sum_{i=1}^{n} \gamma_i = 1 \tag{4}$$

According to the first research project on multi-unit PSA in Korea, performed by Korea Atomic Energy Research Institute (KAERI) [3], multi-unit accident sequences are the combinations of each unit accident sequence. All the accident sequences of each unit have PDS determined through single-unit PSA. We can make the combination of PDS by using it. Finally, the combinations of STC and their fractions are quantified by using the relations between PDS and STC shown in Fig.2. Afterwards, the number of the combinations of STC increases according to the number of damage states and STC branched off from PDS. Therefore, it is necessary to reduce the number of combinations to appropriate level that can be assessed using the cut-off value.

If there are two identical units in the same site, Fig. 3 shows the structure to quantify multi-unit STC using the proposed method.

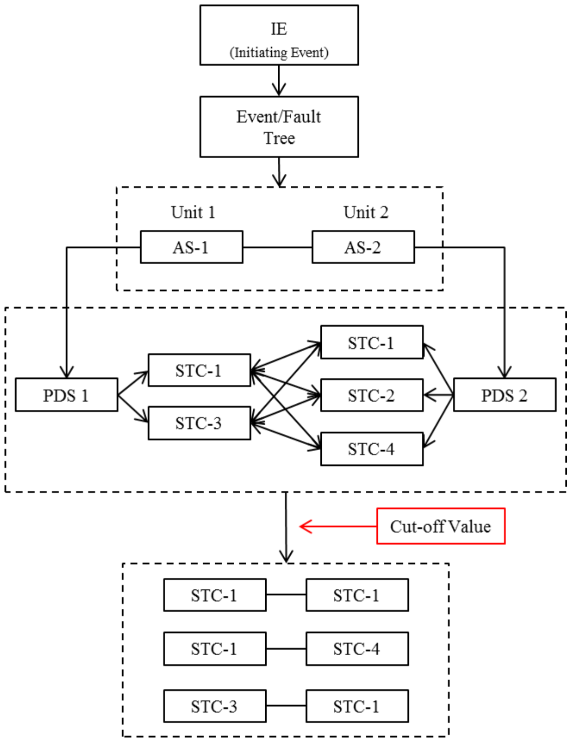

Fig. 3. The Structure of Proposed Method

It is assumed that the multi-unit accident sequence including Accident Sequence (AS) 1 and 2 are quantified by multi-unit Level 1 PSA. AS-1 and AS-2 are branched off to each two and three STC as the following figure.

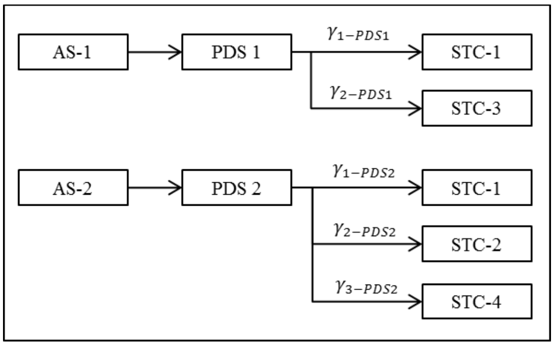

Fig. 4. The Structures of Each Accident Sequence

Using the proposed method, six combinations of STC are quantified as follows.

$$
\begin{aligned}
&PDS1 \cdot PDS2 \\
&STC-1 \cdot STC-1 = \gamma_{1-PDS1} \times \gamma_{1-PDS2} = \alpha_1 \\
&STC-1 \cdot STC-2 = \gamma_{1-PDS1} \times \gamma_{2-PDS2} = \alpha_2 \\
&\vdots \\
&STC-3 \cdot STC-4 = \gamma_{2-PDS1} \times \gamma_{3-PDS2} = \alpha_6
\end{aligned} \tag{5}
$$

Finally, they are screened out by the following equation to reduce the number of combinations by using the cut-off value.

$$\text{If } \alpha_i < Cut-off\ value\ then\ neglect \quad (6)$$

3. Conclusions

In this paper, the simple method to quantify multi-unit STC has been suggested. Without additional multi-unit Level 2 PSA, the proposed method can quantify the combinations of STC using the results of single-unit Level 2 PSA. However, this method is efficiently used under the assumptions that all units at the same site are identical at full power, and independent from each other. In the real world, various types and operation modes of the units are operated at the same site. In addition, it may be difficult to apply the considerations in terms of site level such as dependency between the units because the quantification using the proposed method is simply performed by multiplying each STC fraction. Therefore it is necessary to improve the proposed method for addressing the above weaknesses in the future research.

Acknowledgments

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