RESEARCH STATUS OF MULTI-UNIT PSA METHODOLOGY IN KOREA

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Recently since Fukushima nuclear power plant accident, strong needs to estimate site risk has been increased to identify the possibility of such a tremendous disaster and to characterize its risk. Especially, in a site which has large fleet of nuclear power plants, reliable site risk assessment is very emergent to confirm and/or improve the safety. Korea has several nuclear power plant site which have more than 6 NPPs, which motivated to develop a methodology to assess a site risk focused on the simultaneous occurrence of multi-unit accident. This paper describes the overall research status of multi-unit risk assessment activities in Korea

I. INTRODUCTION

Since Fukushima nuclear power plant (NPP) accident, strong needs to estimate site risk has been increased to identify the possibility of occurrence of such a tremendous disaster and to characterize its risk. Especially, in a site which has large fleet of nuclear power plants, reliable site risk assessment is very emergent to confirm the safety. In Korea, there are several nuclear power plant site which have more than 6 NPPs, which motivated to develop a methodology to assess a site risk focused on the simultaneous occurrence of multiple unit failure event. This paper describes the overall research status of multi-unit risk assessment activities in Korea. In Section II, theoretical approach for treating multi-unit risk is introduced. The development of computational program for multi-unit risk assessment is briefly described in Section III with an application of developed methodologies in Section IV. Finally, further works needed to make the methodology be more robust are discussed in Section V

II. THEORETICAL APPROACH

Since the site risk can be modeled as a failure of a site as a whole system, a similar approach such as PSA for a single NPP may be used to characterize the site risk under the condition that a proper definition for a site damage is given. The following sub-sections describe the overall approach for the site risk quantification

II.A. Overall Procedure for Site Risk Assessment

The site risk model may be similar to the procedure of a normal PSA model if a system which one want to know its risk is replaced with a site which have several NPPs. If it is, the following general procedures may be applied to construct site risk model

1. Define site risk
2. Construct top logical structure of site risk model
3. Develop individual unit logical risk model
4. Treat dependencies among units
5. Quantify site risk

Each procedure is explained in the following sub-section, I.B to I.E

II.B. Definition of Site Risk

At the level of site, one can regard an event as a site damage event if one or more than one unit in the site has a damage event. Let U_i be a damage event in the i'th unit in a site. Using Boolean expression, site damage event can be expressed as follows

$$S = \sum_{i=1}^{n} U_i \qquad (1)$$

Where S is site damage event and n is the number of NPPs in a site

Depending on the definition of a damage event in a unit, S may means a site core damage event or site radioactivity release event.

II.C. Top Structure of Site Risk Model

Eq. (1) shows that a site risk can be estimated by Boolean summation of unit risk models. If one wants to know the site risk by simply estimating a frequency of site damage event, the procedure may be similar to the conventional fault tree quantification under the condition that the unit PSA model in terms of FT constructed and the dependencies among units are sufficiently considered.

In case that a damage state of a site should be identified to consider the consequence of each damage state, simple frequency calculation may not be applied since direct FT calculation generate minimal cut-set (MCS) which multiple units failures are subsumed to a simple minimum failure scenario. To overcome this faculty, Eq. (1) should be decomposed to the set of exclusive events. Figure 1 shows an example of decomposition for three events using Venn diagram

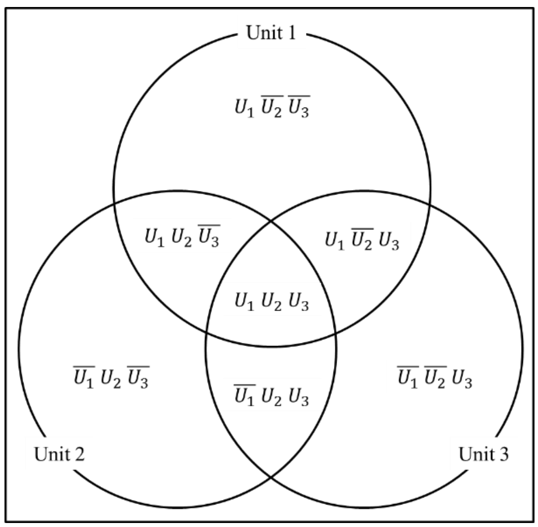

Fig. 1. Decomposition of three event.

For the site of n units as shown in Eq. (1), the decomposition can be expressed as follows

$$\begin{aligned} S &= \sum_{i=1}^{m} U_i \\ &= \sum_{i=1}^{m}\left(U_i \cdot \prod_{\theta \neq i}^{m} \overline{U_\theta}\right) + \sum_{i=1}^{m}\sum_{j=i+1}^{m}\left(U_i \cdot U_j \cdot \prod_{\theta \neq i,j}^{m} \overline{U_\theta}\right) + \cdots \\ &\quad + \sum_{i=1}^{m}\cdots\sum_{l=k+1}^{m}\prod_{\rho=i}^{l} U_\rho \cdot \prod_{\theta \neq i,\cdots l}^{m} \overline{U}_\theta + \cdots + \prod_{\rho=1}^{m} U_\rho \end{aligned} \qquad (2)$$

As shown in Eq. (2), if one wants to quantify the site damage frequency for each damage state, 2^{n-1} times of independent FT quantifications are required

II.D. Development of Individual Unit Risk Model

As shown in Eq. (1), to develop site risk model, individual unit damage model in term of FT should be developed. A unit damage model is basically constructed for the operation mode of a NPP. By considering operation mode, unit damage model can be described as follows

$$U_i = \sum_{j=1}^{nm(i)} m_{ij} \cdot U_{ij} \qquad (3)$$

Where nm(i) means the number of operation mode for i'th unit as a function of i, m_{ij} is the event that i'th unit is in operation mode j, and U_{ij} is the damage event of unit i in operation mode j.

Furthermore, a unit may experience variety of initiating events depending on the root causes of hazards. For example, a unit may experience damage event from internal causes, external causes of seismic event, flooding, and so on.

Considering such an event types, a unit damage event of i'th unit in operation mode j can be expressed as follows

$$U_{ij} = \sum_{k=1}^{nc(j)} U_{ijk} \qquad (4)$$

Where nc(j) is the number of hazard of unit I in operation mode j as a function of j, and U_{ijk} is the damage event of unit i in operation mode j by hazard k.

Integrating Eq. (3) and (4), the structure of unit damage event can be obtained as follows

$$U_i = \sum_{j=1}^{nm(i)} \left(m_{ij} \cdot \left(\sum_{k=1}^{nc(j)} U_{ijk} \right) \right) \qquad (5)$$

By the practice of conventional PSA model development, full power and low power & shutdown (LPSD) PSA model is developed for a NPP as an operation mode. For the hazard type, an internal event, fire, flooding PSA model are considered. However, as experienced in the Fukushima accident, external event such as seismic and Tsunami is very important hazards to estimate site risk in Korea. As for the Korea, it is very important to identify Korea specific external events which has possibility of multiple unit failure

II.E. Treatment of Dependencies among Unit Risk Model

Once a unit damage model has been developed, dependencies among unit damage event is important factor to develop site damage event model. Dependencies may be treated manly for the followings

a. Common initiating event
b. Common system, structure, component (SSC)
c. Common cause failure (CCF)

For most of external event such as earthquake, the effect of this event may reach all the unit in a site. In such cases, all the unit in a site may experience this initiating event simultaneously. . Common SSC may also make dependencies in the initiating event and safety system failure event in the accident scenarios. When modeling site damage event model, CCF make a problem more complicated. As a typical example, when a site is regarded as a whole system, the number of SSCs to be modeled as a CCF group increases to make logical model be complex. Also, in the seismic PSA model, seismic correlation is difficult to be considered realistically

II.F. Quantification of Site Risk Model

Compared to conventional NPP PSA, the quantification of site risk model may have some problems as follows

- Size of logical model
- Resolution
- Error of estimation

As expected from Eq. (1) and (5), site damage model may be more complicated compared to unit damage model. By this reason, although the site damage model may be computable, calculation resource mainly in terms of calculation time may increase dramatically.

As mentioned in Section II.c, to distinguish the damage state from the site damage events (see Eq. (1)), the calculation loads increase exponentially. Also, the generation of logical model may not be easily handled manually.

Finally, there may be some problem in quantifying the site damage event frequency when applying conventional approximation method such as rare event approximation. As an example, when developing site damage model by seismic event, it is not easy to quantify the frequency using conventional FT quantifying program such as AIMS-PSA [1]. It is due to the failure event probability to be fairly large compared to other random failure event.

In this paper, two types of quantification methods are proposed. One is to use Monte Carlo sampling of FT. This method is to calculate top event probability of a FT by sampling basic events in the FT. This method can calculate the damage frequency exactly under the condition that the sampling number is sufficiently large. However, since this method cannot generated accident scenarios such as MCS, detailed information for the improvement the site safety may be lost.

The other is to use conventional FT quantifying program. As mentioned in Section 2.3, to apply this method, decomposition of an event should be proceeded to identify damage state. When NPPs in a site increase, it is not easy to treat this work manually. It is recommended to develop a computational program to treat this problem effectively

III. COMPUTATIONAL PROGRAM DEVELOPMENT

For the characterization of site risk, we have experienced several problems for using existing computer program such as AIMS-PSA and FTREX. The following sections describe the status of computer program development

III.A. Improvement of AIMS-PSA

AIMS-PSA code is a total platform for overall PSA works. Basically, it contains ET/FT editor. It integrate logics and data, which finally generate results for PSA.

For the quantification of site risk, a logic model for the source term release event should be provided. However, in Korea, we have used a two-step approach for the quantification of source term release event frequency in a normal NPP PSA. At the level 1 state, a core damage frequency is obtained by using ET/FT linking. Then, a containment event tree is constructed to calculate source term release event. During this two-step process, logic information such as minimal cut-set is lost to make one be difficult to trace the whole scenario of an accident. To overcome this difficulty, we developed the logic model construction method from the L2 PSA results and the method was successfully implemented in the AIMS-PSA code. Figure 2 show an example of the logic model for L2 PSA

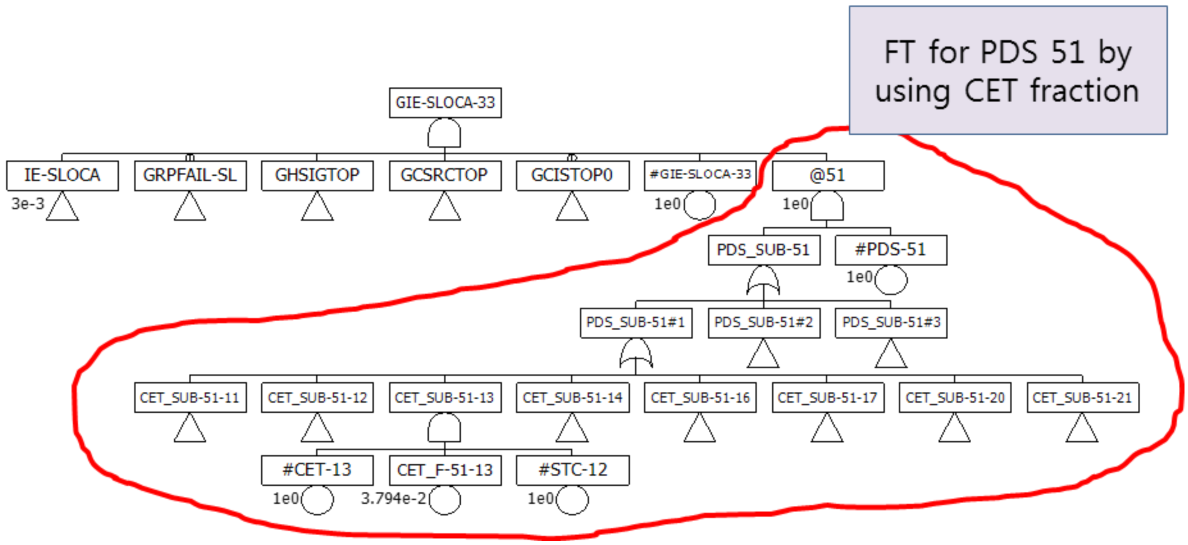

Fig. 2. Logic model for L2 PSA.

III.B. FTeMC for Monte-Carlo Simulation

When a logic model is very large or rare event approximation is not valid, Monte-Carlo simulation has been used widely in the quantification of a FT. In case of site risk model which has very large logic structure, Monte-Carlo simulation is suitable to calculate a failure probability of a FT. In addition, multi-unit risk is dominantly due to external event and relatively large failure probability is frequently used in the logic model. By these reason, we developed a computer code for Monte-Carlo simulation of a FT named as FTeMC (Fault Tree estimation by Monte-Carlo)

III.C. SiTER for Pre and Post Processing of Logic Model for Site Risk

Although a Monte-Carlo simulation of a FT can calculate a failure probability/frequency of a logic model, detailed information such as MCS should be given to make risk-informed activities. Currently, we are developing computer program to help FT quantification in term of MCS named as SiTER (Splitting and integrating for Total Event Risk). This program facilitate to generate logical model automatically and to help the post processing after FT is quantified in terms of MCS.

IV. APPLICATION

Based on the developed methodology and computer program, we have performed pilot application of multi-unit risk for a reference site. Figure 3 shows an example calculation of multi-unit risk in terms of occurrence frequencies for multiple loss of off-site power accident. [2]

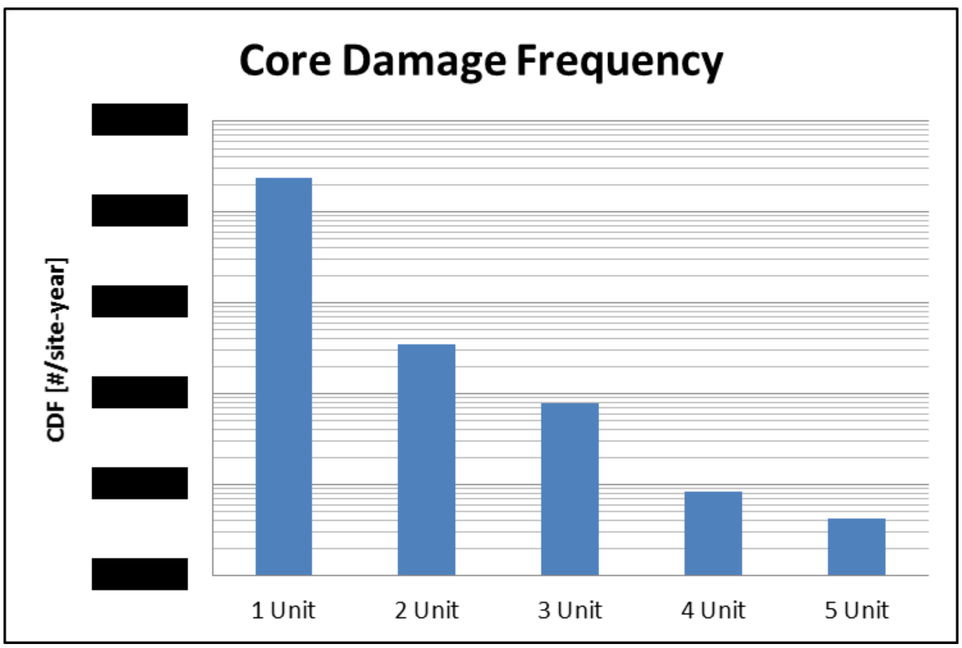

Fig. 3. Multi-unit risk for multiple loss of off-site power accident

V. FURTHER WORKS

In the development of site risk assessment methodology, we have experienced several problems which need research works. The followings are considered to be an important issues to be resolved.

a. Multi-unit accident by the propagation of effect by an independent accident at a single unit in a site
b. Effect of accident in a unit on the performance of individuals/organization which is relevant to normally operating units in a site

c. L3 PSA for multi-unit accident
d. Common cause failure modeling for inter-unit SSC
e. Common cause failure modeling for seismic event (correlated event)
f. Improvement of FT quantification code

VI. CONCLUSIONS

Developmental status of site risk assessment methodology in Korea was presented in this paper. Theoretical basis was developed in addition to the computer program. We have confirmed that the methodology and computer programs are applicable to site risk assessment through the pilot application for a reference plant. It is expected that further development of methodology including computer program are needed to assess site risk more realistically.

In the reference section below, Refs. 2, 3, and 4 provide examples of the formats for books, journal papers, and proceedings papers, respectively. Listing paper titles is not mandatory; however, it is encouraged as an additional help to readers.

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