A New Method for Level-2 PSA Quantification

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1. Introduction

As a part of the Mid & Long Term Nuclear R&D Program, we at KAERI are developing new method for Level-2 PSA (Probabilistic Safety Assessment) quantification to facilitate site risk model generation. Conventional approach for the generation of Level-2 PSA model uses implicit ITE (If Then Else) logic in cooperation with event tree (ET). Under this environment, it is not easy to generate explicit result such as minimal cut-set (MCS) which shows the accident scenario (AS) obviously.

New approach suggests a new method to generate MCS for the Level-2 PSA quantification.

2. Methods and Results

In this section idea for the new method is introduced.

2.1 Basic Idea for L2 PSA quantification

Widely used method of L1 PSA quantification is ET/FT linking. An ET describes global AS from an initiating event by considering various accident mitigation system/function. A FT is used to model a failure of a safety system used in the ET. By linking the ETs and FTs, the Core Damage Frequency (CDF) of a nuclear power plant (NPP) is described as follows:

$$CDF = \sum IE_i \cdot \coprod_{j(i)} S_{ij} \cdot \coprod_{k(i)} \overline{S}_{ik} \quad (1)$$

Where IE_i represent i'th initiating event and S_{ij} denotes a FT of system used in the ET for initiating event IE_i.

By similar manner, if one propagates L1 PSA scenarios into a CET (Containment Event Tree), one can obtain the following containment failure frequency.

$$CF = \sum IE_i \cdot \coprod_{j(i)} S_{ij} \cdot \coprod_{k(i)} \overline{S}_{ik} \cdot \prod_m L_{im} \cdot \prod_n \overline{L}_{in} \quad (2)$$

L_{im} is a failure event of a system/function used in the CET.

By comparing Eq. (1) with Eq. (2), one can easily find that if one can obtain ASs in Eq. (2), explicit result for L2 PSA such as MCS can be generated by Boolean manipulation.

2.2 Flow of Information in a L2 PSA

L2 PSA starts from the PDS (Plant Damage State) ET. PDS ET is generated from the normal ET of L1 PSA. Additional features for L2 PSA are added to model the containment integrity. The states of containment isolation system and coolant make-up to the reactor core are the example of the features. An AS in a PDS ET is written as follows:

$$IE_i \cdot \coprod_{j(i)} S_{ij} \coprod_{k(i)} \overline{S}_{ik} \quad (3)$$

As an example, when a large LOCA occurs and high pressure injection (HPI) system succeeded followed by the failure of low pressure injection (LPI) and containment spray (CS), the accident sequence is written as follows: $\%LLOCA \cdot \overline{HPI} \cdot LPI \cdot CS$

Then, all event scenarios in the PDS ETs are grouped according to their PDS states before propagating to CET. It is performed by so called PDS logic diagram. After the grouping, an accident sequence has the following form

$$IE_i \cdot \coprod_{j(i)} S_{ij} \coprod_{k(i)} \overline{S}_{ik} \cdot \prod_{l(i,j,k)} P_{il} \cdot \prod_{m(i,j,k)} \overline{P}_{lm} \quad (4)$$

Where P_{il} is a flag event which indicate this AS has some characteristic. As an example, P_{il} may be a flag that represent inventory make-up was succeeded.

Finally, after an accident sequence is propagated to CET, the accident sequence has the following form in the sense of Boolean:

$$IE_i \cdot \coprod_{j(i)} S_{ij} \coprod_{k(i)} \overline{S}_{ik} \cdot \prod_{l(i,j,k)} P_{l} \cdot \prod_{m(i,j,k)} \overline{P}_{lm} \cdot \prod_{n(i,j,k)} DET_{in} \cdot \prod_{o(i,j,k)} \overline{DET}_{io} \quad (5)$$

Where DET is an auxiliary ET to facilitate the failure probability allocation related to severe accident in the containment.

Under this flow of information, to obtain the MCS for L2 PSA, two main problems should be resolved as follows:

(1) Flag event addition in Eq. (4)
(2) Conversion of DET to a FT

In the following section, we suggest new L2 PSA quantification method to resolve these problems.

2.3 New Method

An AS from PDS ET is mapped as follows:

$$IE_i \cdot \coprod_{j(i)} S_{ij} \coprod_{k(i)} \overline{S}_{ik} \rightarrow IE_i \cdot \coprod_{j(i)} s_{ij} \coprod_{k(i)} s_{ik}$$

Which means that system failure event was mapped as basic event. Since the quantification process would be performed after all ASs is developed, the system failure event is treated as basic event to facilitate the whole process.

To attach flag event in an AS, a mapping tool or recovery rule can be used. SIMA [1] was developed to map various mapping in the external event PSA. However, up to now, these kinds of mapping can be handled without further upgraded of the program. In the developing stage of this method, recovery rule was used to flag an event.

Since the event probability in the DET cannot be handled with rare event approximation, conventional FT quantification tool cannot be applied to quantify Eq. (4). So, to obtain an analytical solution, FTBDD [2] was used to manipulate the accident sequence with negation. After Boolean manipulation of Eq. (5), the AS has the following Boolean form:

$$CF = \sum IE_i \cdot \prod_{j(i)} S_{ij} \cdot \prod_{k(i)} \bar{S}_{ik} \cdot \prod_{m} L_{lm} \cdot \prod_{n} L_{ln} \prod_{l(i,j,k)} P_l \cdot \prod_{m(i,j,k)} \bar{P}_{lm} \qquad (6)$$

By de-flagging P_{ij} from Eq. (6), L2 PSA scenario can be quantified with conventional FT quantification tool. The overall quantification process is shown in Figure 1.

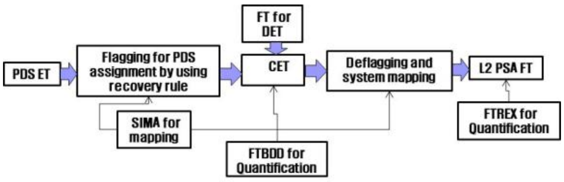

Figure 1 new L2 PSA quantification process

2.4 Pilot Calculation

Using new method, simple calculation was performed. In the pilot calculation, simple two PDS ETs were used to represent the L1 PSA result. Figure 2 shows the PDS ETs.

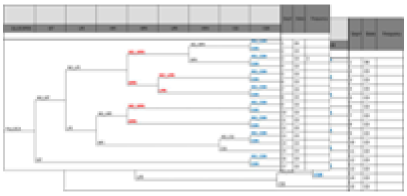

Figure 2 PDS ETs

PDS logic diagram shown in Fig. 3 was transformed with a recovery rule to attach flag event in the ASs. To propagate the PDS ET scenarios to the CET, all DET used in the CET was transformed into FTs. Figure 4 show an example of a DET transformed with a FT.

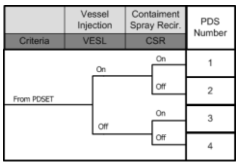

Figure 3 PDS logic diagram

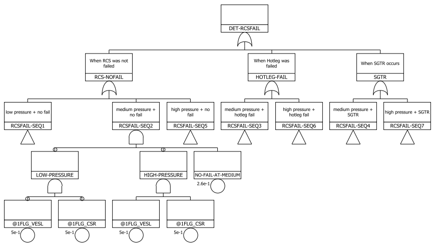

Figure 4 an FT transformed from a DET

Figure 4 shows the final result which shows the L2 PSA accident sequence. Thirty PDS ET scenarios were decomposed into six hundreds of L2 PSA accidents scenarios. Final MCS quantification was not performed since the de-flagging and mapping tool of the ASs was not provides yet.

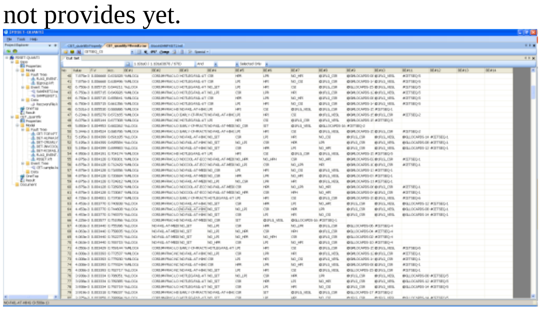

Figure 5 final L2 PSA scenarios

3. Conclusions

New quantification method of L2 PSA was suggested and pilot calculation with simple example was performed. New method can generate explicit L2 PSA result in terms of MCS. Furthermore, new method can reflect dependency between L1 and L2 PSA by considering a FT in a CET. Since this method is in developing stage, we expect that a more complete result can be generated in the future.

ACKNOWLEDGEMENT

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