Transactions of the Korean Nuclear Society Autumn Meeting
Kyungju, Korea, October 29-30, 2015

Pilot Application of an Integrated Accident Sequence Analysis for a Loss of Coolant Accident in a PSA model

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1. Introduction

An Integrated accident sequence analysis for a loss of coolant accident have been proposed to properly apply for the safety functions which are considered in the accident [1]. A single event tree (ET) construction for LOCA was suggested to incorporate a safety system/function and its applicable break spectrum into the ET.

The present paper performs a pilot application for a reference plant.

2. Methods and Results

In this section overall procedures and the results are described. In Section 2.1 application procedure of the pilot application is described. Section 2.2, 2.3, and 2.4 explain the details to construct the integrated ET for LOCA and the quantification. Finally, the results are compared with the conventional result in section 2.5.

2.1 Overall procedure for an integrated accident sequence analysis for LOCA.

The procedure composed of several tasks as follows

a. Initiating event frequency estimation
b. Break set point identification and determination
c. ET construction
d. Quantification

Each procedure is explained in the following sub-section, 2.2 to 2.4

The reference plant was selected as OPR-1000.

2.2 Initiating event frequency

To apply the present method, an LOCA initiating event frequency as a function of break size is needed to restrict the feasible break range of the safety functions used in the LOCA ET. In this paper, the recent expert elicitation for LOCA frequency estimation performed in the U.S. nuclear regulatory commission (NRC) [2] was used since it provides a continuous occurrence frequency for all break spectrum. Table 1 show the original estimation results for PWR LOCA.

Table 1: LOCA initiating event frequency

LOCA Category	gpm	Effective Diameter (in)	Mean Value
1	>100	0.5	1.90E-03
2	>1500	1.625	4.20E-04
3	>5000	3	1.60E-05
4	>25k	7	1.60E-06
5	>100k	18	2.00E-07
6	>500k	31	2.90E-08

To obtain a break frequency at a specified point, an interpolation is needed. Since the frequency of break have a tendency of exponential decrease with the break size, a power law fits is applied [3] as follows:

$$y = a \cdot x^{b} \quad (1)$$

Where ‘y’ and ‘x’ are occurrence frequency and break size respectively. The constant ‘a’ and ‘b’ is determined by two neighboring points in Table 1.

The occurrence are finally compensated for the critical reactor year of the plant. We used 90% of the reactor critical year.

2.3 Determination of a break size for a safety function

As described in the reference 1, this pilot application considered the 7 break set points for safety functions. Table 2 shows the safety function considered.

Table 2: Break set point for safety function

Set point	Safety function	description
1	IM, DR	A break point below which RCS cooling via S/G is needed(insufficient energy release to break)
2	IM	A break point below which RCS can be depressurized using S/G
3	RT	A break point below which

		Reactor trip is required
4	IM	A break point above which SIT and LPSI are allowable without depressurization
5	IM	A break point above which hot and cold leg injection is required to prevent flow path blocking from boron deposition
6	IM	A Break point below which one HPSI pump can perform inventory make-up function
7	IM	A break point below which two HPSI can supply coolant

- S/G cooling set point

This set point is defined as the largest break size under which S/G cooling is needed to depressurize the RCS and make high pressure safety injection (HPSI) be operable. By the thermal hydraulic calculation [4], 0.8 inch diameter is known as the critical point to require S/G cooling.

- Depressurization for low pressure injection

This set point is defined as the largest break size under which depressurization by S/G cooling can make LPSI be operable when HPSI cannot be used. By the same calculation in the ref. [4], it was estimated that the break size is located near the point of 1.4 inch diameter.

Unfortunately, this set point is not used in the pilot calculation since the reference plant does not have the recirculation function using LPSI. It means that, when HPSI is not usable and LPSI is operable by the depressurization using S/G, the plant does not ultimate heat sink (recirculation cooling) for the accident mitigation

- Reactor trip set point

In conventional ET for LOCA, the reactor trip are considered to needed when the break size is smaller than 2 inch. Since the information for the break set point for reactor trip is not available, it is assumed that the reactor trip set point is identical with the conventional approach. For the realistic calculation, the thermal-hydraulic calculation with the reactor physics model should be performed in the future.

- Break set point of LPSI operable

This set point means a smallest size of a break above which LPSI can be operable without any RCS depressurization process. When a break size is sufficiently large therefore coolant inventory and the energy are released to the break, RCS pressure rapidly lowered. According to the T/H calculation [5], the break size is determined to be 3.2 inch diameter.

As in the case of "Depressurization for low pressure injection", this break set point is not used in the pilot calculation since the reference plant does not have the function of LPSI recirculation.

- Break set point of hot and cold leg injection

This set point is defined as the smallest break size above which hot and cold leg injection is needed to prevent from boron precipitation. According to the calculation result [6], the break set point is assumed to be 2 inch. However, the assumption used in the calculation is not realistic, supplementary calculation is needed to fix the set point

- Break set point of one HPSI

This set point is defined as the smallest break size under which one HPSI can makeup coolant inventory of the RCS. According to the calculation result [5], the break size is determined to be 20 inch

- Break set point of two HPSI

This set point is defined as the largest break size above which HPSI cannot makeup the coolant inventory of the RCS according to the calculation result [5], the break size is determined as 30 inch

2.3 Construction of LOCA ET

The conventional PSA model for the reference plant has three categories of LOCA ET, small, medium, and large LOCA. It has 20 Accident sequences, 9 for small LOCA, 6 large LOCA, and 5 for medium LOCA.

Using the new method, all LOCA sequence is expressed with the 33 accident sequences as shown in fig. 1

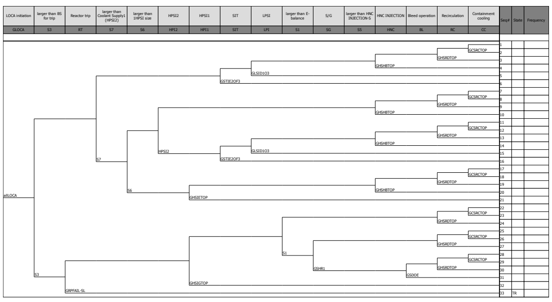

Fig. 1. Integrated Event Tree for LOCA

2.4 Quantification

The event tree is quantified to identify the important accident sequences using AIMS-PSA [7] As explained in the reference [1], the accident sequence has multiple break size therefore it needs a Boolean manipulation. Table 3 shows the overall results.

Table 2: quantification results

LOCA frequency	**Break size**	**Conditional Probability**	**Frequency**

1.71E-03			
	S(1)	4.522E-01	4.86E-07
	S(3)	9.269E-01	3.95E-07
	S(13)	4.747E-01	5.11E-07
	S(36)	7.302E-02	2.32E-07
	S(67)	5.525E-05	1.24E-10
	/S(7)	1.715E-05	4.03E-11
	total		1.624E-06

In the table S(i) and S(ij) means a break size smaller than set point i and break size between set point i and j respectively.

2.5 Comparison with conventional LOCA model

Table 3 shows overall comparison between the present pilot application and the conventional LOCA model

Table 3: Comparison of the results

LOCA category	Existing method	present method	Break size discrimination
Small	1.40E-06	1.39E-06	S(1),S(13),S(3)
Medium	2.69E-07	2.32E-07	S(36)
Large	5.34E-09	1.64E-10	S(67), /S(7)

As shown in the table, overall result is similar each other. For small LOCA, the present model shows slightly low frequency compared to conventional results. It is due to the set point 1 above which S/G is not required to remove decay heat. For the medium range, present methods shows slightly low results. It is not certain what makes the difference since the IE frequency is similar and the FT is identical. Further investigation of the result are needed to fix the difference. As for the large LOCA, the difference is meaningless because some part of the IE frequency are included in the medium LOCA.

3. Conclusions

Pilot application of integrated accident sequence analysis in terms of ET for LOCA was performed in the present paper. The accident sequence results show that the accident sequence is described more detailed compared with the conventional results and the quantification results shows similar trend.

Further study may be needed to fix the break set point and to develop system fault tree.

ACKNOWLEDGMENT

This work was supported by Nuclear Research & Development Program of the National Research Foundation of Korea (NRF) grant, funded by the Korean government, Ministry of Science, Ict & future Planning (MSIP).

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