Application of a New Approach for Estimating LOCA and SGTR Frequencies

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1. Introduction

The needs for more reasonable estimations for rare and extremely rare[1] initiating events (IEs) have been reported in US peer review results. The American Society of Mechanical Engineers (ASME) PRA standard [1] also proposes guidelines and requirements about the issues. Recently, US NRC addressed problems and the conservative assumptions on loss-of-coolant accident (LOCA) analysis and attempted to establish more rigorous methodology for estimating the frequencies depending on break size [2]. The results of peer reviews for KHNP reference plants also represented that the data used in estimating IEs were outdated and the methodology also needed to be improved [3].

In this paper, for more appropriate estimation of rare and extremely rare initiating events (IEs), e.g., LOCAs and steam generator tube ruptures (SGTRs), a new approach considering expert elicitation process is presented and corresponding core damage frequency (CDF) is calculated.

2. Method and Result

2.1. ASME PRA standard requirements for LOCA and SGTR frequencies

The ASME PRA standard recommends to use industry generic data and to include plant specific data for estimating rare IEs in its supporting requirement (IE-C11). It also mentions that engineering judgment could be proper estimation methodology to represent plant characteristics and to obtain more reasonable values in extremely rare IEs like large and medium LOCAs. Supporting requirement IE-C13 addresses that uncertainty band should be characterized providing mean values for quantification of the PSA results [1].

2.2. Estimation of LOCA and SGTR frequencies in ALWR URD and KHNP PSAs

In current KHNP PSAs, LOCA and SGTR frequencies are estimated by referring to advance light water reactor utility requirement document (ALWR URD) [4], which relies on statistical analysis of operating experiences from 1987 to 1995. Based on ALWR URD, no large and medium LOCAs are reported but two small LOCAs and three SGTRs are occurred in history. Since there is no experience of large and medium LOCA, this approach estimates IE frequencies with only reactor years (RYs). Specifically, ALWR URD chooses 660 RY with conservative attitudes and applies chi square distribution at the 50% cumulative probability level in Eq.(1).

$$\Phi(A) = X^2 (2n+1 ; 0.5) / 2T \quad (1)$$

Where, Φ(A), n and T present the frequency of a event, the number of failures, and the cumulative reactor operating years, respectively. The proposed large LOCA frequency is 3.4E-04. In KHNP PSAs, large and medium LOCAs are regarded as the same initiating event category, and the sum of the two frequencies is equal to the large LOCA frequency of ALWR URD. Thus, each event has a frequency of 1.7E-04.

The frequencies of small LOCAs and SGTRs are estimated using Eq. (2), which is based on the operating data.

$$\Phi(A) = n / T \quad (2)$$

The frequencies calculated using Eq.(2) are directly applied to KHNP PSAs. For uncertainty analysis, the frequencies are assumed as lognormal distributions with error factor of 5. Table 1 presents the frequencies in KHNP PSAs.

Table 1. Frequency distributions of LOCAs and SGTRs

	L & M LOCA	SLOCA	SGTR
Mean (ALWR URD)	3.4E-04	3.0E-03	4.5E-03
Mean (KHNP)	1.7E-04	3.0E-03	4.5E-03
EF (KHNP)	5	5	5
Distribution (KHNP)	lognormal	lognormal	lognormal

Note: The means have units of events/RY.

These estimates may not be sufficient to satisfy the ASME standard in terms of out-of-date data source and not including engineering judgment process.

2.3. Estimation of LOCAs and SGTR frequencies in NUREG/CR-6928

In NUREG/CR-6928 [5], large and medium LOCA frequencies are estimated based on expert elicitation process to consolidate service history data and probabilistic fracture mechanics studies with knowledge of plant design, operation, and material performance. This process is well-recognized for quantifying

[1] *A "rare event" might be expected to occur only a few times, and an "extremely rare event" would not be expected to occur even once throughout the world nuclear industry over many years.*

phenomenological knowledge when data or modeling approaches are insufficient.

For small LOCAs and SGTRs, expert elicitation method and statistical analysis referring to the initiating event database (IEDB) of US NRC are used to evaluate the frequencies. Between the results from the two methods, the more reasonable values are selected. Estimates of LOCA and SGTR frequencies for the 5th percentile, median, mean and 95th percentile are determined from each panelist's elicitation response. In this approach, the frequencies are assumed as gamma distributions with scale factor(α) and shaping factor(β). Table 2 shows the distributions of LOCA and SGTR frequencies.

Table 2. Frequency distributions of LOCAs and SGTRs

	LLOCA	MLOCA	SLOCA	SGTR
Source	Ref. [2]	Ref. [2]	IEDB	IEDB
5%	1.2E-09	5.0E-07	2.5E-06	1.5E-05
Median	4.0E-07	2.0E-04	2.5E-04	2.0E-03
Mean	1.2E-06	5.0E-04	6.0E-04	4.0E-03
95%	5.0E-06	2.0E-03	2.5E-03	1.5E-02
Type	Gamma	Gamma	Gamma	Gamma
α	0.40	0.40	0.50	0.50
β	3.33E+05	8.00E+02	8.33E+02	1.25E+02

Note: Percentiles and the mean have units of events/RY. The units for β are RY.

This approach provides more rigorous method to estimate LOCA and SGTR frequencies. Additionally, these results represent more up-to-date data than ALWR URD because NUREG/CR-6928 collected US industry initiating events from 1988 to 2002. For evaluating the frequencies of LOCAs and SGTRs, it is necessary to use this approach in order to improve the quality of KHNP PSAs.

2.4. Evaluation of CDF using the new approach in NUREG/CR-6928

Applying the new approach to LOCA and SGTR frequencies, CDF of the KHNP reference plant is evaluated and compared. Table 3 shows CDF and the increase rates depending on initiating events.

Table 3. Comparison of CDFs between the current PSA and the new approach

IE	CDF	New CDF	Increase rate
LLOCA	6.26E-07	4.42E-09	-99.3%
MLOCA	4.40E-07	1.29E-06	194.1%
SLOCA	7.97E-07	1.59E-07	-80.0%
SGTR	4.89E-07	4.35E-07	-11.1%
Total	5.44E-06	4.98E-06	-8.4%

Note: The units for CDF are events/RY.

While the CDFs resulting from large LOCA, small LOCA and SGTR are decreased at a rate of 99.3%, 80.0% and 11.1%, respectively, the CDF from medium LOCA is increased from 4.40E-07 to 1.29E-06. The differences are caused by applied methodologies and collected data period.

3. Conclusion

There have been two approaches used to assess LOCA and SGTR frequencies. While ALWR URD relies on statistical analysis of operating experiences, NUREG/CR-6928 applies expert elicitation process to consolidate service history data and probabilistic fracture mechanics studies with knowledge of plant design, operation, and material performance.

When applying the new approach, CDFs from the three IEs except medium LOCA are decreased, and the total CDF of the reference plant is decreased at a rate of 8.4%.

To improve technical adequacy in LOCA and SGTR frequencies considering the requirements of ASME PRA standard, it is necessary to use the methodology in NUREG/CR-6928 when performing the periodic revision of KHNP PSAs.

REFERENCES

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