Trend Analysis for Estimating Initiating Event Frequencies

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1. Introduction

The initiating event (IE) analysis is an essential part of probabilistic safety assessment (PSA), and it includes the identification of all possible initiating events, grouping according to mitigation requirements, and the estimation of the annual frequency of each IE group. Here, the IE frequency can be estimated using generic, plant-specific, or combined (e.g., by a Bayesian update process) data.

The ASME/ANS probabilistic risk assessment (PRA) standard [1] includes 15 supporting requirements for estimating the IE frequency, and among these, a supporting requirement (IE-C7) is about time trend analysis. It has no requirement for Capability Categories I and II, but the following requirement for Capability Category III is stated:

"USE time trend analysis to account for established trends (e.g., decreasing reactor trip rates in recent years). JUSTIFY excluded data that is not considered to be either recent or applicable (e.g., provide evidence via design or operational change that the data are no longer applicable). Acceptable methodologies for time-trend analysis can be found in NUREG/CR-5750 and NUREG/CR-6928."

According to this requirement, the initiating event frequencies at U.S. commercial nuclear power plants have been estimated and updated using time trend analysis [2-3]. However, in the existing PSAs in Korea, time trend analysis was not performed, and hence the IE frequencies were estimated using generic data (e.g., NUREG/CR-5750 [4], NUREG/CR-6928 [5]) or using all or part of the Korean nuclear industry data.

This paper describes the methods and results for a time trend analysis for the initiating events that occurred in Korean nuclear power plants (NPPs), and the effects on the IE frequencies and the Level 1 PSA results for an OPR1000 plant.

2. Methods

In this study, time trend analysis and the estimation of IE frequency distribution for each IE category were performed using the methods used in NUREG/CR-6928 [6]. Firstly, for each IE category that has occurred at least once in Korean NPPs, the IE data (i.e., number of events and total reactor critical years for each calendar year) was collected based on the Korean NPP experience during the period from 1978 to 2012. The IE categories that have never occurred in Korean NPPs (e.g., Loss of coolant accident) are not covered in this study.

Secondly, these data from 1978–2012 were examined to determine a baseline period that best characterizes the IE data by starting with 2012 and working backward in time. As in NUREG/CR-6928 [6], a minimum of 5 years was used for potential baseline periods (i.e., the shortest baseline period 2008-2012).

Thirdly, statistical trend analysis was performed for each potential baseline period, and the one with the highest p-value (i.e., the weakest evidence for the existence of a trend) was chosen. For the trend analysis, the Reliability Calculator (ver. 1.3.3.2) [7] was used. It is a web-based software tool developed by the US NRC in conjunction with the Idaho National Laboratory (INL) to evaluate data for use in PSA.

For IE categories that have occurred only once during 1978-2012, the entire period was chosen as the baseline. SGTR (steam generator tube rupture) and LODC (Loss of a Class-1E DC bus) initiating events belong to this case.

After the baseline period was determined, the IE data from the baseline period were analyzed to obtain the IE frequency distribution. For each IE category, the empirical Bayes analysis at the plant level was performed also using the Reliability Calculator. In cases where the empirical Bayes analysis failed to converge (indicating insufficient variation between plants), the frequency distributions were obtained from a Bayesian update of the Jeffreys' non-informative prior using all the Korean industry data.

3. Results

Table I shows the mean frequency and the baseline period for each IE category. It also compares the IE frequencies with and without trend analysis. Except the LOOP in shutdown operations and two IEs (i.e., LODC and SGTR) for which the entire period was chosen as the baseline, all the other 6 IE frequencies decreased when using the results of time trend analysis.

In a recently updated at-power internal events Level 1 probabilistic safety assessment (PSA) for an OPR1000 plant [8], the frequencies of the initiating events that have occurred at least once in Korea were estimated based on data from the most recent 20 years (1993-2012) without time trend analysis.

Table I: Comparison of the Initiating Event Frequencies Obtained Without and With Trend Analysis (TA)

IE category	Without TA	With TA	
	Mean freq. (/rcry)	Mean freq. (/rcry)	Baseline period
General Transient	1.25E+00	3.85E-01	2008-2012
Loss of Condenser Vacuum	9.16E-02	4.84E-02	2005-2012
Loss of Main Feedwater	6.30E-02	1.69E-02	2008-2012
Loss of Offsite Power (in critical operation)	2.49E-02	3.12E-03	2004-2012
Loss of Offsite Power (in shutdown operation)	1.56E-01*	3.93E-01*	2006-2012
Loss of Instrument Air	1.97E-02	2.83E-03	2003-2012
Partial Loss of CCW	1.03E-02	3.12E-03	2004-2012
Loss of a C-1E DC Bus	4.40E-03	4.40E-03	1978-2012
Steam Generator Tube Rupture	4.40E-03	4.40E-03	1978-2012

* frequency per shutdown year

Table II compares the IE frequencies used in the existing PSA and those obtained from the trend analysis. Except the LOOP frequency in shutdown operations, all the other IE frequencies decreased when using the results of time trend analysis.

Table II: Comparison of the IE Frequencies with Those Used in the Level 1 PSA for an OPR1000

Initiating event	Mean freq. used in the existing PSA (/rcry)	Mean freq. obtained from TA (/rcry)
General Transient	7.44E-01	3.85E-01
Loss of Condenser Vacuum	7.76E-02	4.84E-02
Loss of Main Feedwater	4.31E-02	1.69E-02
Loss of Offsite Power (in critical operations)	2.48E-02	3.12E-03
Loss of Offsite Power (in shutdown operations)	1.74E-01*	3.93E-01*
Partial Loss of CCW	5.18E-03	3.12E-03
Loss of C-1E DC Bus A	2.59E-03	2.20E-03
Loss of C-1E DC Bus B	2.59E-03	2.20E-03
Steam Generator Tube Rupture	5.18E-03	4.40E-03

* frequency per shutdown year

To examine its effect on the Level 1 PSA results for an OPR1000 (i.e., contributions of each IE to core damage frequency), the accident sequence quantification was performed after applying the revised IE frequencies.

As a result, the total internal events core damage frequency (CDF) while the plant is at-power decreased by about 30%. In terms of each IE contribution, the contributions from the SBO which is transferred from the LOOP IE was highly decreased from 26.5% to 4.7%, and the contributions from the other IEs increased accordingly (e.g., the TLOCCW IE: 17.6% → 25.0%).

In contrast, the total internal events CDF while the plant is shutdown increased by 54% because the LOOP IE frequency in shutdown operations increased by a factor of 2.3. In this case, the contributions from the SBO (29.4% → 43.1%) and the LOOP (13.8% → 20.2%) IEs increased, and the contributions from the other IEs decreased accordingly.

4. Conclusions

In this study, time trend analysis was performed based on the Korean NPP operating experience during the period from 1978 to 2012. Compared to the IE frequencies obtained without trend analysis, the most of the frequencies decreased by a factor of two to eight. It indicates that there is a statistically significant decreasing trend for those IEs. In addition, the effects of the IE frequencies obtained from the trend analysis on the Level 1 PSA results (CDF and contribution from each IE) for an OPR1000 plant were examined.

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