# A Sensitivity Analysis of Interfacing Systems LOCA Frequency of Korea Standard Nuclear Power Plants

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## 1. Introduction

An interfacing systems loss-of-coolant accident (ISLOCA) is a special kind of loss-of-coolant accident in which a low-pressure system interfacing with the reactor coolant system is breached due to the over-pressurization caused by the failure of isolation between them [1,2]. Because of its importance in the risk perspective, in probabilistic safety assessment (PSA), an ISLOCA is typically considered as one of the initiating events for each of which accident scenarios are derived and core damage frequency is calculated.

Although the existing PRA reports for Korea standard nuclear power plants (KSNPs; in this paper, OPR-1000 and OPR+ are included) include the results of sensitivity analyses as a part of the quantification results, none of those documented sensitivity analyses of ISLOCA frequency. Therefore, in this study, a sensitivity analysis of the ISLOCA frequency of KSNPs was performed.

## 2. Methods and Results

### *2.1 Current Status of ISLOCA Analysis for KSNPs*

As of 31 March 2014, twelve units of KSNPs have been constructed, and all units except one are in operation. They have the same structure, systems, and components, and they are also operated in the same manner. Therefore, probabilistic safety assessments of the plants (e.g., [3-5]) reached to the same conclusions for ISLOCA as follows.

Among the many lines interfacing with the reactor coolant system, six were selected as potential pathways through which an ISLOCA can occur: four low-pressure safety injection (LPSI) lines and two shutdown cooling system (SCS) suction lines. An ISLOCA through a LPSI line involves rupture or leakage of three check valves (CVs) in series and rupture of a motor-operated valve (MOV). An ISLOCA through a SCS suction line comes with rupture of two MOVs in series and the opening failure of a relief valve.

The mean ISLOCA frequency through the four LPSI lines is 5.08E-13/yr, and the mean ISLOCA frequency through the two SCS suction lines is 1.77E-09/yr, which is the total frequency of ISLOCA because it is much larger than 1.15E-12/yr. Therefore, in the current PSA of KSNPs, the ISLOCA frequency through the SCS suction lines dominates the total frequency of ISLOCA.

The failure rates and probabilities of the components were assumed to be log-normally distributed, and component reliability data that were used are as follows:

- Internal rupture of CV: 4.38E-5/yr (EPRI URD)
- CV fails to reclose on demand: 1E-3 (EPRI URD)
- Internal rupture of MOV: 5.43E-4/yr (assumed)
- Relief valve fails to open on demand: 4E-3 (YGN 3&4 PSA [5])

### *2.2 Difference in ISLOCA frequency between component reliability data sources*

Table I compares the ISLOCA frequency of KSNPs between component reliability data sources used in this study. The ISLOCA frequency derived from the existing data was compared to the frequencies obtained from four other data sources: NUREG/CR-5745 [6], NUREG/CR-5102 [2], NUREG/CR-6928 (published in 2007) [7], and NUREG/CR-6928 (updated in 2010) [8].

The frequency from the existing data is the highest. It is over 3 orders of magnitude greater than the lowest frequency obtained from the updated NUREG/CR-6928 [8].

Table I: Comparison of ISLOCA frequency of KSNPs between component reliability data sources used

| Component reliability data sources | ISLOCA through LPSI lines | ISLOCA through SCS suction lines | Total ISLOCA frequency |
|---|---|---|---|
| Existing data used | 1.15E-12/yr | 1.77E-09/yr | 1.77E-09/yr |
| NUREG/CR-5745 | 3.84E-11/yr | 1.15E-09/yr | 1.19E-09/yr |
| NUREG/CR-5102 | 7.54E-12/yr | 6.48E-10/yr | 6.56E-10/yr |
| NUREG/CR-6928 (2007) | 6.68E-15/yr | 9.90E-12/yr | 9.91E-12/yr |
| NUREG/CR-6928 (Update 2010) | 2.75E-15/yr | 1.26E-12/yr | 1.27E-12/yr |

### *2.3 Difference in ISLOCA frequency by the SOKC*

If the failure rates of two or more components are based on the same data, our state of knowledge is the same for the components. This is the so-called state of knowledge correlation (SOKC) which was first introduced by Apostolakis and Kaplan [9]. When the SOKC is taken into account, the expected value of the joint probability that all components fail, denoted by

$E[X^n]$, has a greater value than the mean value which is given without the SOKC by the product of the mean of the individual failure probabilities, $E[X]^n$, where X is a random variable corresponding to an individual component failure [1,9].

According to the ASME/ANS probabilistic risk assessment (PRA) standard [1], the effect of the SOKC has been found to be significant particularly in calculating the ISLOCA frequency involving the rupture of multiple valves. The standard requires ensuring that the SOKC between event frequencies or probabilities is taken into account when it is significant to satisfy the capability category II requirements. Although there are some technical reports that took into account the SOKC in an ISLOCA analysis [6,10], the PRA practices in Korea have not yet considered the SOKC.

In KSNPs, ISLOCA frequencies through LPSI lines and SCS suction lines involve failures of three check valves and failures of two motor-operated valves, respectively. The three check valves are identical and their failure rates are based on the same data, and likewise the two motor-operated valves. Therefore, the SOKC between the three check valves and between the two motor-operated valves exist. In this case, the expected value of the probability that all three check valves fail is given by $E[X^3]$ rather than $E[X]^3$, and the mean probability that both motor-operated valves fail is given by $E[X^2]$ rather than $E[X]^2$.

Table II shows the difference in ISLOCA frequency of KSNPs between two cases with and without consideration of the SOKC. When the SOKC is taken into account, the mean ISLOCA frequency is about 300 times greater. The reason why the difference in ISLOCA frequency through the SCS suction lines is relatively large is that the large error factor (50.0) was assumed for the MOV's rupture failure rate. When the failure rate of a component is assumed to be log-normally distributed and the SOKC is considered, the failure probability of two or more components with the same data depends only on its error factor. For this reason, the use of a large error factor can result in a significantly higher frequency than without considering the SOKC.

Table II: Difference in ISLOCA frequency of KSNPs by SOKC (with the existing data)

| ISLOCA paths | ISLOCA frequency without SOKC | ISLOCA frequency with SOKC | Factor |
|---|---|---|---|
| LPSI lines | 1.15E-12/yr | 2.29E-11/yr | 19.9 |
| SCS suction lines | 1.77E-09/yr | 5.06E-07/yr | 285.9 |
| Total | 1.77E-09/yr | 5.06E-07/yr | 285.9 |

Unlike the other data sources in Table I, both NUREG/CR-6928 [7] and its updated version [8] used beta distributions for failure probabilities on demand and gamma distributions for failure rates for several reasons. In case of beta and gamma distributions, the failure probability of more than two components with the same data depends largely on the parameter α. In NUREG/CR-6928 [7,8], the gamma distribution for the MOV's rupture failure rate has a shape parameter of α=0.3 and an error factor of 18.8. When the SOKC was taken into account, the ISLOCA frequency of KSNPs was increased by a factor of 4.33, as shown in Table III. In general, the use of beta and gamma distributions increases the expected value of the joint probability less than the use of lognormal distribution.

Table III: Difference in ISLOCA frequency of KSNPs by SOKC (data source: updated NUREG/CR-6928 [8])

| ISLOCA paths | ISLOCA frequency without SOKC | ISLOCA frequency with SOKC | Factor |
|---|---|---|---|
| LPSI lines | 2.74E-15/yr | 3.28e-15/yr | 1.20 |
| SCS suction lines | 1.26E-12/yr | 5.48e-12/yr | 4.33 |
| Total | 1.27E-12/yr | 5.48e-12/yr | 4.33 |

## 3. Conclusions

In this paper, a sensitivity analysis of the ISLOCA frequency of KSNPs was performed. The existing results of the ISLOCA analysis for KSNPs were first described, and to examine the sensitivity of the ISLOCA frequency to component reliability data, the results from other well-known data sources were compared. In addition, the effects of the state-of-knowledge correlation (SOKC) between two or more components with the same reliability data on the ISLOCA frequency were also analyzed.

The results of this study indicate that the ISLOCA frequency of KSNPs is very sensitive to which component reliability data is used and to whether the SOKC is taken into account or not.

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