# Estimation of LOCA Frequencies for the Innovative Small Modular Reactor

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## EXTENDED ABSTRACT

Conventional commercial nuclear power plants estimate loss of coolant accident (LOCA) frequencies by integrating expert elicitation results with actual operational experience data. However, in the case of the Innovative Small Modular Reactor (i-SMR), such data are not yet available. Thus, LOCA frequency estimates are currently being extrapolated from existing commercial plants or other SMR designs. This paper reviews the LOCA frequency estimation methodology presented in NUREG-1829 and examines the specific design features of the i-SMR. Based on this review, it proposes an approach for estimating LOCA frequencies that reflect the unique features of the i-SMR, and presents example results through a case study.

In NUREG-1829, LOCAs are categorized into six groups based on leak rate, according to the definition of a LOCA. The total LOCA frequency is divided into two components: piping system and non-piping system. The piping system refers to the pipes and adjacent areas of the reactor coolant system (RCS), including the hot leg, cold leg and reactor pressure vessel (RPV) penetrations. The non-piping system includes components such as pumps, steam generators, reactor pressure vessels, pressurizers, and valves. The LOCA contribution from each subsystem is determined by the influence of five key factors: geometry, loading history, maintenance, material, and degradation mechanisms.

At the current status of the i-SMR, where only approximate design information is available, a top-down approach using operational experience data is deemed suitable for estimating i-SMR LOCA frequency. This approach is favored over methods such as probabilistic fracture mechanics (PFM), which require detailed input parameters that are not yet available. A key characteristic of this methodology is that it utilizes 2,600 LWR–years of operational data, in which cracks and leaks are treated as precursors to LOCAs. LOCA frequencies are estimated for each subsystem based on the degradation mechanisms that have historically led to LOCA events.

**TABLE 1. Design Features of the i-SMR Related to LOCA Occurrence**

| i-SMR Design Feature | Theoretical Impact on LOCA Occurrence |
|---|---|
| In-Vessel Control Rod Drive Mechanism (IV-CRDM) | No longer expected LOCA initiation from CRDM penetrations, In-Core Instrumentation (ICI) penetrations |
| SSC Design | Absence of cold leg, hot leg, safety injection system (SIS) lines, and surge line |
| Maximum Pipe Diameter | Maximum pipe diameter is 2 inches, eliminating medium and large LOCAs |
| Boron-Free Operation | Reduced impact of degradation mechanisms caused by boron, such as general corrosion |
| Electron Beam Welding (EBW), Powder Metallurgical Hot Isostatic Pressing (PM-HIP) | Reduced weld areas (e.g., heat affected zones) in the RPV, decreasing related degradation mechanisms |

Table 1 summarizes the design features of the i-SMR that may affect LOCA occurrence, compared to conventional PWRs. Since the CRDM is located inside the RPV, there are no RPV penetrations, and because the pressurizer is also integrated within the RPV, LOCAs originating from components such as the surge line and SIS lines are eliminated. Regarding piping, the maximum diameter does not exceed 2 inches, implying only SLOCA are possible. Additionally, the i-SMR is designed for boron-free operation, which is expected to reduce the impact of boron-induced degradation mechanisms such as general corrosion. Finally, advanced manufacturing technologies (EBW, PM-HIP) have been applied to components like the RPV, reducing the extent of weld zone vulnerable to material degradation and thereby enhancing structural integrity.

Figure 1 illustrates a partial example of the conceptual approach for estimating the LOCA frequency in the i-SMR, specifically focusing on the piping system. The left side represents a conventional PWR, where the contributions from the CRDM and CRDM piping are included. In contrast, the right side represents the i-SMR, in which these contributions are excluded. The same approach is applied to the non-piping system as well. The specific subsystems that do not contribute to LOCA frequency estimation for each system are as follows.

- Piping system: CRDM, CRDM pipe, ICI, Cold leg, Hot leg, SIS injection, SIS accumulation, Surge line
- Non-piping system: Loop isolation valve, Pressurizer isolation valve

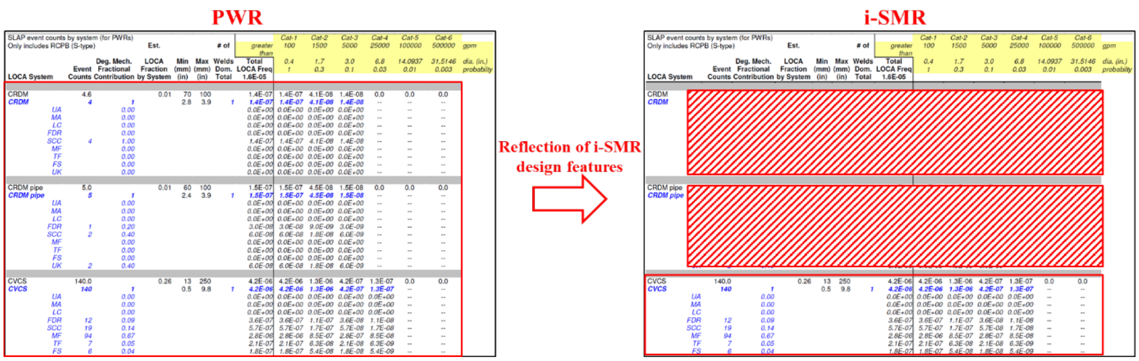


**FIGURE 1. Case Study Concept for Estimating LOCA Frequency in the i-SMR**

The number of precursor events for LOCAs in each subsystem is categorized by degradation mechanism, and mechanisms whose impact is reduced due to the design features of the i-SMR result in partial removal of their LOCA contributions. In this analysis, it is assumed that the occurrence rate of stress corrosion cracking in the RPV is reduced by 20% due to the advanced manufacturing methods applied.

**TABLE 2. Estimated LOCA Frequencies for PWR and i-SMR**

| LOCA frequency | Category-1 (Diameter > 0.4 inch) | | | Category-2 (Diameter > 1.7 inch) | | | SLOCA (Diameter 0.5-2.0 inch) |
|---|---|---|---|---|---|---|---|
| | Piping | Non-piping | Total system | Piping | Non-piping | Total system | Total system |
| PWR [rcy] | 1.64E-05 | 1.72E-04 | 1.89E-04 | 5.19E-06 | 5.44E-05 | 5.96E-05 | 1.27E-04 rcry |
| i-SMR [rcy] | 1.27E-05 | 1.46E-04 | 1.58E-04 | 4.02E-06 | 4.61E-05 | 5.01E-05 | 1.07E-04 rcry |
| Difference [%] | -22.7 | -15.3 | -15.9 | -22.7 | -15.3 | -15.9 | -15.7 |

Table 2 presents the estimated frequencies of SLOCA events for a PWR and the i-SMR, derived using the top-down operational experience approach. A plant availability factor of 0.9 is assumed. Detailed calculation procedures, including the linear interpolation method and subsystem classifications, can be found in the referenced literature. The comparison shows that the non-piping system is the primary contributor to LOCA frequency in both reactor types. Regardless of the absolute values, the estimated LOCA frequency for the i-SMR exhibits a decreasing trend compared to that of the conventional PWR.

In this study, a preliminary case study was conducted to estimate how the LOCA frequency for the i-SMR may vary, using estimation methods presented in NUREG-1829, which is currently applicable given the design maturity of the i-SMR. In the future, the LOCA frequency for the i-SMR will be refined through a systematic expert elicitation process, similar to the approach used in NUREG-1829.

## ACKNOWLEDGMENTS

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