

Preliminary Single-code Analysis of Mass and Energy Release and Containment Vessel Response in i-SMR during Postulated Feedwater Line Break (FWLB) Using SPACE Code

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1. Introduction

As the Small Modular Reactor (SMR) market enters a growth phase driven by increasing demand for low-carbon electricity, a diverse range of SMR designs is currently under development worldwide. A significant number of these SMRs adopt a steel containment vessel (CV) for reactor containment [1]. Notably, the Innovative SMR (i-SMR) of the Republic of employs a steel CV in its designs.

The CV serves as the final physical barrier in the defense-in-depth strategy to prevent the release of radioactive materials and therefore must maintain its structural integrity during any accident. Regulatory requirements mandate the evaluation of containment integrity for both a Loss of Coolant Accidents (LOCA) and secondary system pipe ruptures in pressurized water reactors (PWRs) [2, 3].

The Main Steam Line Break (MSLB) accident is typically analyzed as the limiting secondary system pipe rupture in the PWRs. Since the steam release through the break generally contributes more to pressurization of the containment atmosphere than the release of subcooled liquid, the M/E release results of the MSLB accident are more limiting than those of the Feedwater Line Break (FWLB).

Although the MSLB accident is expected to be the limiting secondary side pipe rupture for the i-SMR, since the i-SMR is a newly developing design, it is necessary to perform a quantitative evaluation of the FWLB accident as well to confirm the limiting secondary side pipe rupture. Therefore, this paper analyzes the mass and energy (M/E) release as well as the CV response during a postulated FWLB accident in the i-SMR. A one-through analysis of M/E release and CV response was performed using the Safety and Performance Analysis Code for nuclear power plants (SPACE) [4], and a comparative evaluation was conducted with the MSLB accident analysis results reported in another paper presented at the same Transactions of the Korean Nuclear Society Autumn Meeting in 2025 [5].

2. Analysis Methodology

The M/E release and CV response during the FWLB accident were analyzed using the SPACE code. The analysis employed the same updated version of the

SPACE code and the same modified standard input deck used in the MSLB accident analysis reported in Reference [5].

The major assumptions, which were conservatively established to maximize the M/E release rate, are summarized in Table I. These assumptions provide conservative CV response results. A double-ended guillotine break of a single feedwater line with an area of 28,100 mm² inside the CV was assumed. The Henry-Fauske/Moody critical flow model [6, 7] with a discharge coefficient of 1.0 was applied to the break to maximize M/E release rate. The turbine stop valves were assumed to close at break initiation to maximize the discharge through the break. The availability of alternating current (AC) was assumed to maintain heat transfer to secondary side, and direct current (DC) was also assumed to be available. The single failure of feedwater isolation valve (FIV) was considered. However, no significant effect on the results was identified due to the series installation of the FIVs. The operating initial conditions were established either by incorporating uncertainties into the nominal values or by adopting conservative values.

Table I: Major assumptions for the M/E release and CV response analysis during FWLB in the i-SMR

Parameters	Assumptions
Initiating event	FWLB inside CV
Break size	Maximum
Critical flow model	Henry-Fauske (Sub-cooled) Moody (Two phase)
Core power	103% of full power (including instrument uncertainty)
Decay heat	1979 ANS Standard + 20% uncertainty
Turbine trip	At break
AC power	Available
DC power	Available
Single failure	FIV failure (no significant effect to results)
Low riser level Setpoint	Maximum in harsh environment
SOPM ¹⁾ Setpoint	Nominal

1) Spurious opening protection module

3. Analysis Results and Discussion

3.1 M/E Release Analysis during FWLB

Figures 1 and 2 present the M/E release rates during postulated FWLB accident. If a rupture occurs in the feedwater line, feedwater is discharged into the CV through the break. Although most of the feedwater is released in liquid phase, a portion undergoes flashing due to depressurization, vaporizing into steam. When a two-phase fluid is discharged into the CV, the CV pressure increases. If CV pressure reaches the high containment pressure (HCP) setpoint, the reactor trip is initiated, followed by the CV isolation and actuation of the Passive Auxiliary Feedwater System (PAFS). When the helical-coiled steam generators (HCSGs) are isolated for PAFS operation, a pressurization of the affected HCSG causes a temporary increase in the liquid mass release rate. Once the HCSG inventory is depleted, the blowdown is terminated.

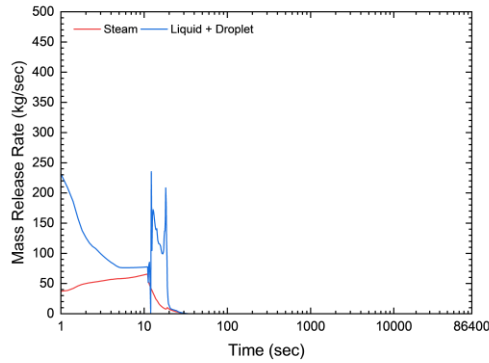


Fig. 1. Break Mass Release Rate during FWLB

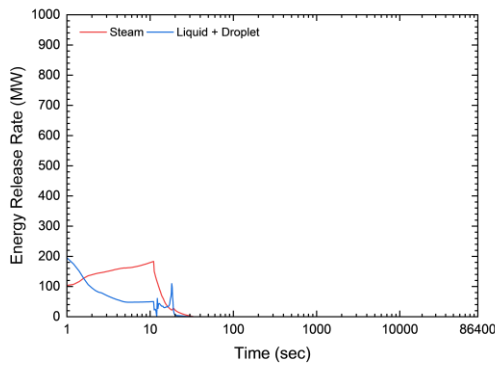


Fig. 2. Break Energy Release Rate during FWLB

3.2 CV Response Analysis during FWLB

Figure 3 shows the CV pressure behavior during the postulated FWLB accident compared with that during the postulated MSLB accident in Reference [5]. Although the M/E release from FWLB terminated at 30 seconds, the CV pressure continuously increases and reaches its peak at 68 seconds due to the heat transfer from the reactor coolant to the CV through the reactor

vessel wall. Compared to the MSLB accident, the FWLB exhibited a lower M/E release rate, resulting in a lower CV pressure. While the MSLB resulted in a peak pressure of 0.65 MPa at 8 seconds, the FWLB showed a peak pressure of 0.30 MPa at 68 seconds. This difference is attributed to the release of a large quantity of superheated steam during the MSLB, whereas the FWLB involves in the discharge of a two-phase mixture. Therefore, the limiting accident in the M/E release analysis of a secondary side rupture is qualitatively assessed as MSLB, not FWLB.

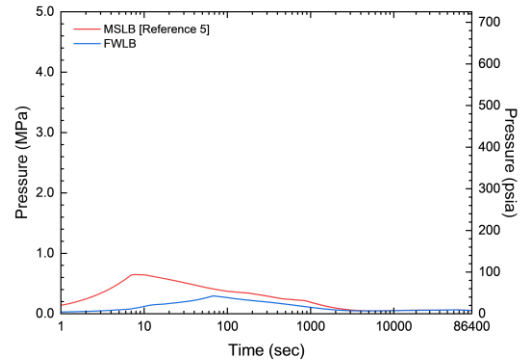


Fig. 3. CV Pressure during FWLB

4. Conclusion

In this study, the M/E release and CV response of i-SMR during postulated FWLB accident were analyzed using SPACE code. Additionally, the FWLB accident results were compared with the MSLB accident results reported in Reference [5]. The CV peak pressure during the FWLB accident was 0.30 MPa. Compared to the MSLB accident, FWLB exhibited lower CV peak pressure due to a higher release rate of liquid and droplet than steam during the early phase of the accident.

In conclusion, the limiting accident for the analysis of M/E release and CV response in the i-SMR secondary side pipe rupture is the MSLB, not the FWLB. Future work will focus on advancing methodologies for M/E release and CV response analyses by addressing current challenges, including the development of a two-step analytical approach and the effect of non-safety grade power, to support the standard design approval of the i-SMR.

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