A Study on the Effects of Passive Auxiliary Feedwater System on Mass and Energy Release During A Postulated Main Steam Line Break Accident in APR1000

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1. Introduction

The passive auxiliary feedwater system (PAFS) is a key passive safety system incorporated into the Advanced Power Reactor 1000 MWe (APR1000), a Generation III+ pressurized water reactor (PWR) developed in Republic of Korea. The PAFS removes residual heat from the reactor core by natural circulation [1]. The PAFS replaces the conventional active auxiliary feedwater system (AFWS), such as that in the Optimized Power Reactor 1000 MWe (OPR1000, and enhances the safety and reliability by operating independently of electric power sources.

An analysis of mass and energy (M/E) release during main steam line break (MSLB) accidents is required for the design of reactor containment. The discharged high-energy steam from a ruptured main steam line increases containment pressure and temperature (P/T). Given the connection of the PAFS and the main steam line during normal operation, the inventory of PAFS could be released into the containment through the ruptured main steam line. Furthermore, the transient conditions induced by the MSLB can result in the opening of the PAFS isolation valve, allowing PAFS coolant to enter the steam generator via the main feedwater line and subsequently be discharged into the containment through the ruptured main steam line. Therefore, the effects of PAFS on the M/E release and containment P/T behaviors during MSLB should be investigated.

In this study, the M/E release analysis of postulated MSLB accidents in APR1000 was conducted comparing various PAFS scenarios. The SPACE-ME methodology, developed by Korea Electric Power Corporation Engineering and Construction Company Inc. (KEPCO E&C), was used to calculated the M/E release rates [2,3,4,5]. The containment P/T behaviors was analyzed by the stand-alone CAP 3.1 code.

2. Analysis Methods

The SPACE-ME code linking the SPACE 3.3 and with CAP 3.1 code predicted thermal-hydraulic behavior of nuclear steam supply system (NSSS) of APR1000 during MSLB accident. Figure 1 shows the SPACE node modeling of APR1000 NSSS for the MSLB M/E release analysis, including two trains of PAFS, used in this study. Conservative assumptions and initial conditions to maximize M/E release, described in Table I and II, were applied in the analysis.

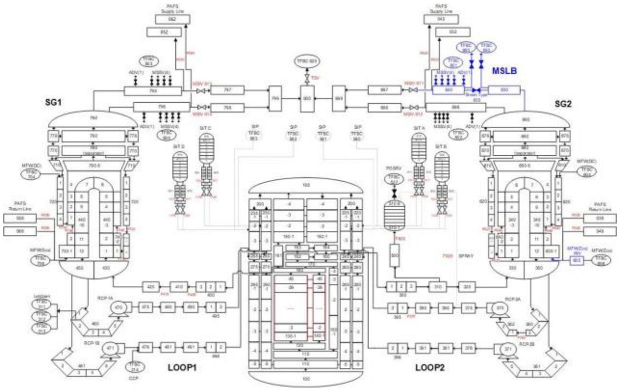

Fig. 1 SPACE node modeling of APR1000 NSSS for MSLB M/E Release Analysis

Table I: Major assumptions for the M/E release analysis during the postulated MSLB accidents in APR1000

Parameters	Assumptions
Analysis time	30 min. from the break initiation
Break type	Double-ended (guillotine)
Break size, m^2	0.5582
Volume of NSSS	Maximum
Turbine trip	At the accident initiation
Offsite power	Available
Feedwater flow to SG	Maximum only to broken-side SG (BSG) with maximum enthalpy
Passive Auxiliary Feedwater Actuation	Only to BSG by high containment pressure (HCP) reactor trip signal
Safety injection flow	Minimum delivery
Single Failure	Containment spray system failure (CSSF)
Containment condition	Minimum back pressure (B/P)

Table II. Initial conditions for the M/E release analysis during the postulated MSLB accidents in APR1000

Parameter	Value
Core power, %FP (% of full power, 2,815 MWt)	102
Pressurizer (PZR) pressure, MPa (psia)	16.03 (2325)
Core inlet temperature, K (°F)	573.15 (572)
Reactor coolant system (RCS) flow rate, %	95
PZR water level, %	60
SG water level, %NR (% of narrow range)	50

The analysis was conducted under the four PAFS scenarios depending on the auxiliary feedwater assumptions. The first scenario (wo BSG PAFS) considers the case where the PAFS is not accounted for on both BSG and ISG. The second scenario (w BSG AFWS) assumes only the OPR1000 AFWS for the BSG. The third scenarios (w BSG PAFS) assumes only the PAFS on the BSG. The fourth scenario (w BSG/ISG PAFS) assumes the PAFS on both the BSG and the ISG. The effects of the PAFS on the M/E release rate was evaluated by comparing the results of the four scenarios.

The M/E release rates for each scenario were calculated by SPACE-ME code. Subsequently, the stand-alone CAP 3.1 code calculated the containment P/T behaviors within the previously obtained M/E release data and containment input of maximum P/T condition.

3. Results and Discussion

3.1 Mass and Energy Release Analysis

Immediately after the break, a massive amount of M/E are released into the containment, causing the containment P/T increase. The containment pressure increases and reaches to the HCP reactor trip analysis setpoint. The HCP signal shuts down the reactor core and generates the main steam isolation signal (MSIS) and the passive auxiliary feedwater actuation signal (PAFAS). The main steam isolation valves (MSIVs) and main feedwater isolation valves (MFIVs) are sequentially closed by MSIS. The main feedwater supply is cut off, and the PAFS isolation valves are opened by PAFAS. The containment pressure continues to rises, eventually reaching the high-high containment pressure (HHCP) analysis setpoint, which triggers the containment spray actuation signal (CSAS). The M/E release continues until the BSG is depleted.

Figure 2 and 3 illustrates the M/E release rates for four PAFS scenarios during the postulated MSLB accident in APR1000. In the early stage of accident, the steam M/E release rates are high but decrease rapidly immediately after the MSIVs closure at 9.3 seconds. Subsequently, the steam M/E release rates decrease gradually until the BSG is depleted. In the wo BSG PAFS scenario, the steam M/E release rates are higher than those of other scenarios since there is no auxiliary feedwater injection to cool the BSG. The steam M/E release rates of the w BSG PAFS scenario are lower than those of the w BSG AFWS scenario. It means that the APR1000 PAFS appears to be more effective in cooling the SG compared to the OPR1000 AFWS. The steam M/E release rates of the w BSG/ISG PAFS scenario are the lowest by removing heat from the RCS by PAFS cooling of ISG. After the depletion of BSG, there is no steam M/E release at the all scenarios except the w BSG AFWS scenario. In the scenarios with the BSG PAFS, the additional inventory of the PAFS delays the depletion of BSG compared to the scenario without the PAFS. Furthermore, when the PAFS on ISG is considered, the cooling of the RCS by ISG further delays the steam release and prolongs the depletion of BSG.

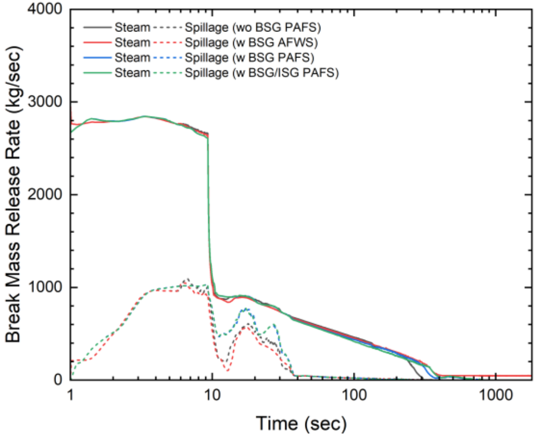

Fig. 2 Break mass release rates for four PAFS scenarios during the postulated MSLB accident in APR1000

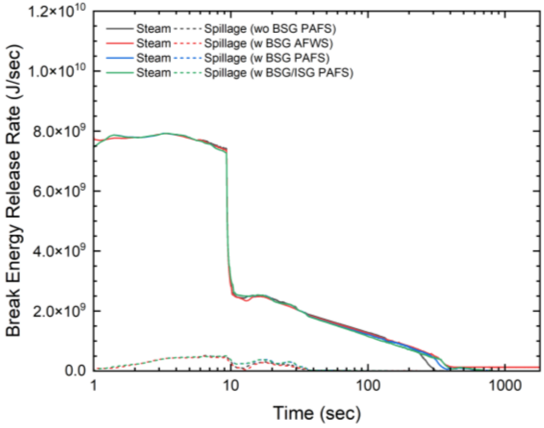

Fig. 3 Break energy release rates for four PAFS scenarios during the postulated MSLB accident in APR1000

3.2 Containment Pressure and Temperature Analysis

Figure 4 and 5 shows the containment P/T behavior for four PAFS scenarios during the MSLB accident in APR1000. The results of minimum B/P conditions represent the containment P/T behavior during the M/E release calculation using the SPACE-ME code. The containment P/T calculation of the stand-alone CAP 3.1 code within the previously calculated M/E release rates are noted as maximum P/T conditions.

The containment pressure for all scenarios reach the maximum value at the first peak which occurs at about 131 seconds when the containment spray system is actuated. Shortly after the activation of the spray, the containment pressure rises again due to the continuous M/E release. Ultimately, the containment pressure decreases from the point when the BSG is depleted. Therefore, the scenarios with greater inventory, such as with the PAFS or AFWS, exhibit higher second peak of containment pressure. Similar to the pressure, the containment peak temperature for all scenarios also occurs around 131 seconds, coinciding with the initiation of containment spray system. The reduction in the containment temperature due to the spray actuation is substantially greater compared to the pressure drop.

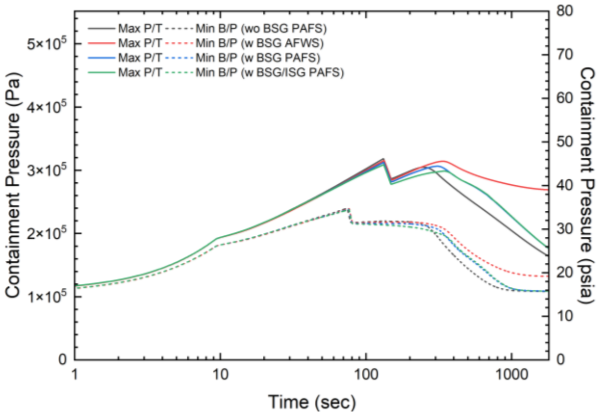

Fig. 4 Containment pressure for four PAFS scenarios during the postulated MSLB accident in APR1000

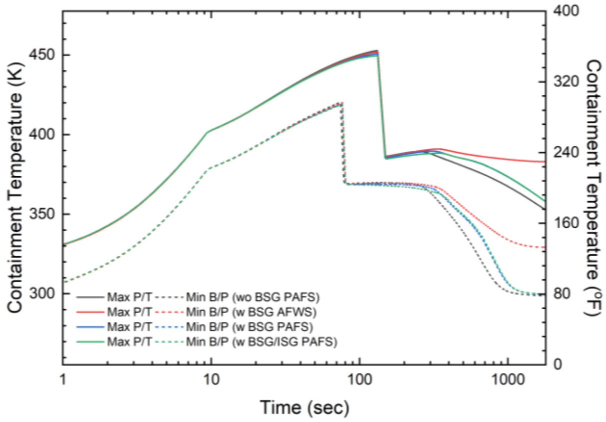

Fig. 5 Containment temperature for four PAFS scenarios during the postulated MSLB accident in APR1000

Table III summarizes the highest containment peak P/T for four PAFS scenarios during the postulated MSLB accident in APR1000. The highest containment P/T are shown at 318,383 Pa (46.18 psia) and 452.82 K (355.40 °F) in the MSLB accident without BSG PAFS. This is because the cooling of the BSG by the PAFS or AFWS reduces the steam M/E release rates. On the other hands, the second peak of containment pressure, which is closely associated with the timing of BSG depletion, was observed to be higher in the PAFS or AFWS on BSG scenarios than in the scenarios without PAFS. If the timing of second pressure peak is delayed and it exceeds the first pressure peak, the PAFS or AFWS scenario can be more conservative.

Table III. Summary of the containment peak P/T for four PAFS scenarios during the postulated MSLB accident in APR1000

Scenario	Peak Pressure, Pa (psia)		Peak Temperature, K (°F)
	First	Second	
wo BSG PAFS	318,383 (46.18)	304,831 (44.21)	452.82 (355.40)
w BSG AFWS	315,468 (45.75)	314,226 (45.57)	451.98 (353.90)
w BSG PAFS	312,567 (45.33)	306,449 (44.45)	450.86 (351.88)
w BSG/ISG PAFS	308,967 (44.81)	298,780 (43.33)	449.61 (349.63)

4. Conclusion

This study presents the M/E release analysis for the postulated MSLB accident in APR1000 using SPACE-ME methodology to compare the various PAFS scenarios: without the PAFS on BSG, with the OPR 1000 AFWS, with the PAFS on BSG, with the PAFS on both BSG and ISG. The containment response analysis for maximum containment P/T is also conducted by the stand-alone CAP 3.1 code. The highest containment P/T of MSLB accident without PAFS on BSG appears at 318,383 Pa (46.18 psia) and 452.82 K (355.40°F). The highest containment P/T for scenarios with PAFS or AFWS show lower than those of scenario without PAFS. However, the second containment peak pressure of scenario with the PAFS or AFWS on BSG is observed as higher than those of scenario without the PAFS, and with PAFS on both BSG and ISG. Therefore, the consideration of PAFS could be more conservative if the second peak of containment pressure exceeds the first peak.

This paper will serve as a preliminary study on the M/E release analysis during the postulated MSLB accident for APR 1000. Based on the research finding, further studies are required to consider the effect of PAFS inventory in the analysis to ensure conservative results.

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