Sensitivity Analysis of Heat Loss through Secondary System for MSGTR with PAFS operation

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1. Introduction

The multiple steam generator tube rupture (MSGTR) accident is one of the most important beyond design basis accidents having a significant impact on safety, which can result in fission product release bypassing the containment boundary. The 5th Domestic Standard Problem (DSP-05) utilizing ATLAS facility was launched in 2018, and MSGTR accident with the passive auxiliary feed-water system (PAFS) operation (SGTR-PAFS-02) was selected as the DSP exercise [1]. The experiment has shown that during an MSGTR accident, the PAFS was properly operated and had sufficient cooling capacity to remove the decay heat of the core.

As the DSP activity was carried out, there was an issue about the effect of heat loss in evaluating the prediction capability of the system code. Many efforts have been made to simulate the experiment. However, some discrepancies between the experiment and calculation results have not been resolved because the heat loss effect could not be properly modeled in the simulation.

This paper presents the results of the sensitivity analysis with a range of heat loss value to identify how much the simulation results are affected by the assumed heat loss through the secondary system. Additionally, the comparison of the condensation model was conducted to evaluate PAFS cooling performance. For the sensitivity analysis, the SPACE code, which is a best-estimate thermal-hydraulic analysis code, was used.

2. Modeling Information

ATLAS facility is a scaled-down integral effect test facility designed to be used in safety study related to thermal-hydraulics of pressurized water reactor. It has a scaling ratio of 1/2 in height and 1/288 in volume with respect to the reference plant of APR 1400 (Advanced Power Reactor 1400) [2]. The scaled flow area can reduce the electrical heating power and component size, but generates potential distortions in heat loss from primary and secondary loop boundary.

Fig. 1. presents the SPACE nodalization of the ATLAS facility. The nodalization has been utilized and developed with the DSP-05 exercise. The break simulation piping from the hot side of the lower plenum to the upper location of the steam generator was included in the nodalization. The break flow rate is one of the important factors affecting the progression of the MSGTR accident. Detailed geometry of the break line was modeled, including the break orifice and the break simulation valves. The form loss coefficients along the break line were adjusted to match the break flow rate in the experiment.

As shown in Fig. 2., the PAFS was modeled in the steam line of the intact loop, so that the asymmetric cooling could be performed during the transient. Heat loss is implemented by applying a constant external temperature and heat transfer coefficient on the outer wall surfaces of the reactor coolant system piping, steam generator, and reactor vessel structures. The heat transfer coefficient was determined by calculating the heat loss of the entire primary system and compared to the experimental data in the steady state condition. The results of the steady-state calculation were summarized in Table I. All design parameters agree well with the experiment results.

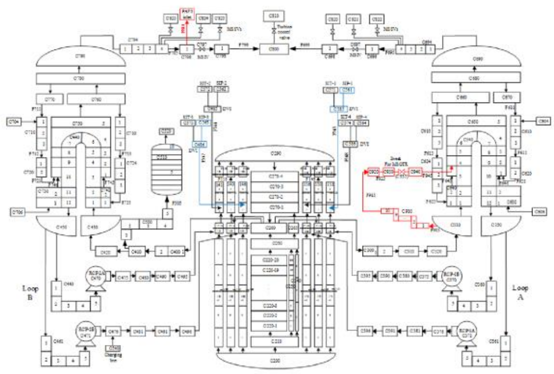

Fig. 1. SPACE Nodalization of the ATLAS facility

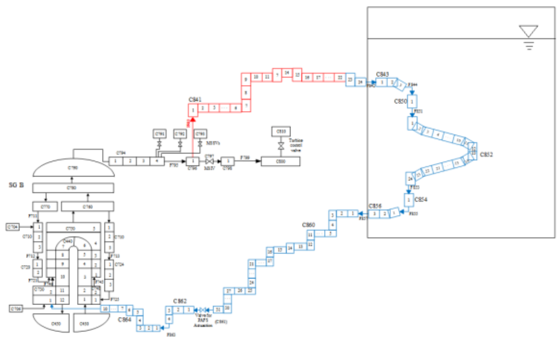

Fig. 2. SPACE Nodalization of the PAFS

Table I: Steady State Calculation Results

Parameter	Exp.	Cal.	Error (%)
Primary System			
Core Power (MW)	1.627	1.627	0.0
Heat Loss (kW)	97.1	97.1	0.0
PZR Pressure (MPa)	15.52	15.50	0.13
Core Inlet Temp. (°C)	292.0	289.0	1.01
Core Outlet Temp. (°C)	327.5	324.9	0.79
Cold leg Flow Rate (kg/s)	1.9728	1.9400	1.66
PZR Level (m)	3.71	3.71	0.0
Secondary System			
Steam Flow Rate (kg/s)	0.4019	0.4155	3.38
Feed Water Flow Rate (kg/s)	0.4209	0.4195	0.33
Steam Pressure (MPa)	7.83	7.88	0.64
Steam Generator Level (m)	4.97	4.97	0.0
PAFS			
Initial PCCT Level (m)	3.80	3.80	0.0
Initial PCCT Temp. (°C)	28.8	28.8	0.0

3. Simulation Results

In the transient, a multiple steam generator tube rupture was simulated by opening the break simulation valve. With the initiation of the break, the reactor coolant was discharged to the secondary side, and the collapsed water level on affected steam generator was continuously increased during the transient. According to the scenario, main feedwater was isolated and the steam on the secondary system could be discharged through the main steam isolation valves (MSSV), so that the collapsed water level on the intact steam generator was continuously decreased due to the continued heat transfer. When the collapsed water level on the intact steam generator is decreased below 25%, the PAFS was automatically operated by opening the PAFS initiating valve.

3.1 Heat Loss through the Secondary System

The main issue in the DSP exercise is the PAFS operation time and related heat loss. Figure 3 shows the comparison of the PAFS operation time according to heat loss through the secondary system. The heat loss which includes the steam generator, secondary steam line, PAFS steam supply (SS) line and return water (RW) line was modeled by assuming a constant external temperature and changing the heat transfer coefficient. The range of heat loss for sensitivity analysis was within about 0.7% of normal power. Despite the relatively small range of heat loss, it has a significant difference with the PAFS operation time. The difference in PAFS operating time in the most restrictive case was about 2.5 times. Moreover, when the heat loss exceeds the certain points, the PAFS did not operate. It means that the steam release through MSSVs and heat loss through the secondary boundary was sufficient to allow the water level to be maintained almost constant. So the collapsed water level on the intact steam generator did not reach the set point of PAFS operation.

Figure 4 presents the transient behavior of the collapsed water level on the intact steam generator with 3 cases. Case 1 describes a situation where the PAFS operated faster than the experiment. In Case 2, PAFS was operated at a time close to the experiment. In Case 3, PAFS did not operate during the transients. The transient results explain how heat loss affects the decreasing rate of water level. In the early stage after the accident, the water level behavior among each case is almost the same. However, as time goes by, decay heat generated in the core decreased along the decay curve, and the water level behavior showed the difference. It can be seen that the effect of heat loss in the system behavior was dominant as the decay heat was low enough.

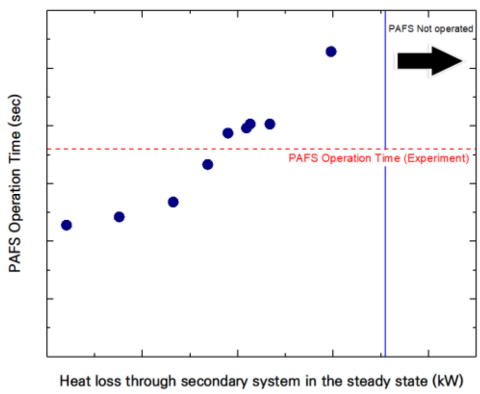

Fig. 3. Comparison of PAFS operation time according to heat loss through the secondary system

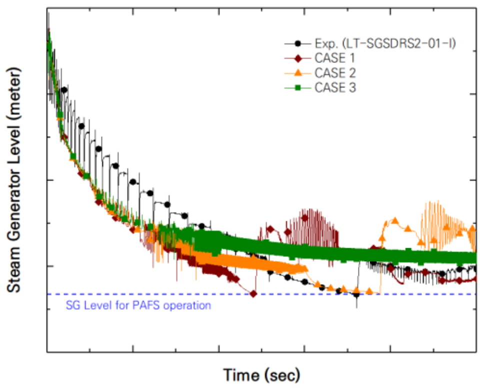

Fig. 4. Comparison of Steam Generator Level with 3 Cases

3.2 Wall Condensation Model in the PCHX

For the calculation of wall condensation heat transfer, the default option of SPACE code, which modeled by Nusselt (1916), Chato (1962), Shah (1979) correlation in the pure steam condition can be selected. Also, PAFS model was implemented in the SPACE code to improve the prediction capability for the condensation heat transfer in the PCHX (Passive Condensation Heat Exchanger) [3, 4]. The simulation results using two options were compared to the experiment.

Fig. 5 shows the fluid temperature after PAFS operation. Even though both options underestimate cooling performance, the calculation results using PAFS model more accurately estimated than the default option.

Fig. 6 shows the distribution of temperature inside PCHX at 300s after PAFS operation. It is remarkable that the PAFS model has a larger temperature difference inside the PCHX than the default option, which means the steam is more condensate in case of PAFS model

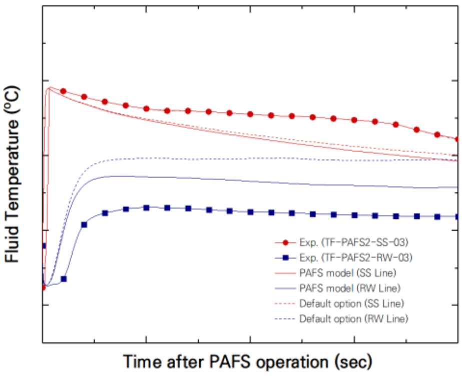

Fig. 5. Fluid temperature at SS line and RW line after PAFS operation

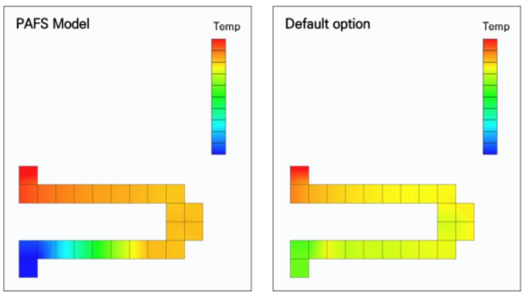

Fig. 6. Distribution of fluid temperature inside PCHX at 300 sec after PAFS operation

4. Conclusions

The sensitivity analysis with SPACE code was performed to assess the heat loss effect through the secondary system in the SGTR-PAFS-02 experiment. The results showed that despite the relatively small variation of heat loss, it could give significant difference in the system behavior. From these results, the detailed modeling of heat loss through the secondary system is required for code simulation to the integral effect test facility. Also, the calculation results applied PAFS model as the wall condensation model in PCHX showed better agreement with the experimental data than the default option of SPACE code

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