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Simulation of ATLAS CRDM-SIP-03 Test using MARS-KS Code

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1. Introduction

The Domestic Standard Problem (DSP) program has been operated by KAERI in collaboration with KINS since 2008. The DSP aims at an effective utilization of an integral effect database obtained from the ATLAS (Advanced Thermal-hydraulic Test Loop for Accident Simulation) tests and improvement of a safety analysis methodology for the pressurizer water reactors.

The sixth DSP (DSP-06) program was launched in 2020. In the framework of DSP-06 program, KAERI performed the CRDM-SIP-03 test using the ATLAS facility to address the safety issue related to the degradation of the upper head penetration nozzles of the reactor pressure vessel (RPV) [1].

In this study, we assess the predictable capability of MARS-KS 1.6 [2] for the main thermal-hydraulic behaviors observed in the CRDM-SIP-03 test.

2. Description of ATLAS CRDM-SIP-03 Test

The target scenario of the CRDM-SIP-03 test is a small break loss-of-coolant accident (SBLOCA) at two control rod drive mechanism (CRDM) nozzles with a failure of all safety injection pumps (SIP).

The break unit consisted of a quick opening valve, a break nozzle, the piping and related instruments as shown in Fig. 1. The accident management (AM) of 50% opening of the atmospheric dump valves (ADVs) was taken to mitigate an accident consequence when the maximum heater rod surface temperature (or maximum cladding temperature; MCT) reaches the pre-set value.

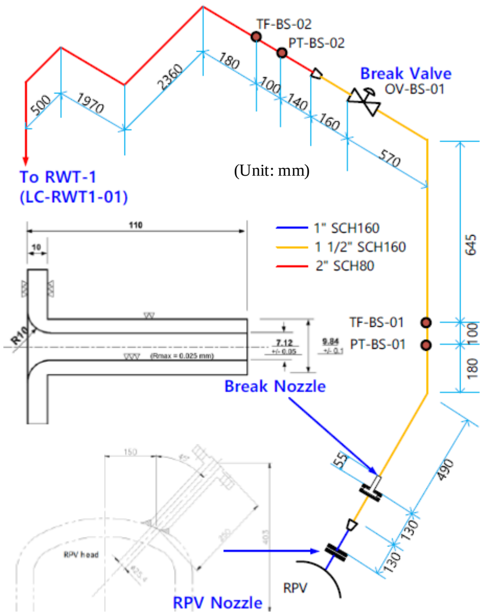

Fig. 1. Schematic diagram of the break unit [1].

The SIPs were not available. The safety injection from the four safety injection tanks (SIT) was supplied through the direct vessel injection (DVI) nozzles. The fluidic device of SIT was simulated by the flow control valve. The SIT flowrate was changed from the high flowrate to the low flowrate when the collapsed water level in the SIT reached the set-point. The auxiliary feedwater (AFW) was injected at 25% of the steam generator (SG) water level and stopped at 40% of the SG water level.

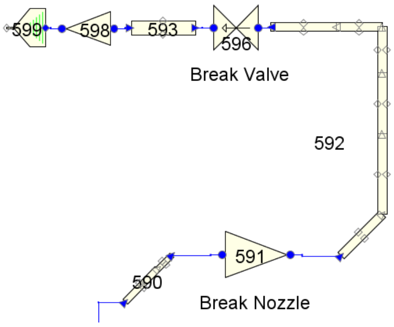

Fig. 2. MARS-KS model of the break unit.

3. Description of MARS-KS Input Model

The MARS-KS input model for the CRDM-SIP-03 test was developed by modifying the existing input model for the analysis of natural circulation characteristic test [3].

Figure 2 depicts the break unit model. The break nozzle was modeled using the single junction (SNGLJUN-591). The Henry-Fauske critical flow model was applied to the break nozzle, main steam safety valves (MSSV), and ADVs.

The SIT was modeled using the PIPE component with seven axial nodes. The heat loss from the primary and secondary systems to atmosphere was modeled. The total heat loss from the primary system was assumed to occur only on the outer surface of the reactor vessel.

4. Results and Discussion

The main results of MARS-KS code are compared with the experimental data. The results are plotted with the dimensionless values.

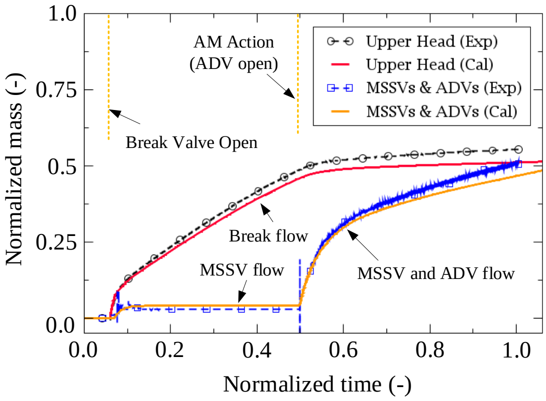

Fig. 3. Cumulative discharge mass.

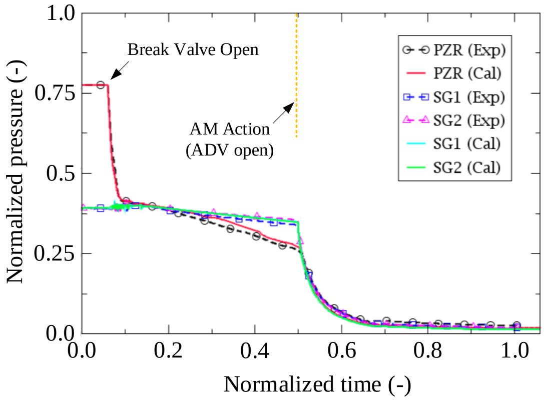

Fig. 4. Primary and secondary system pressures.

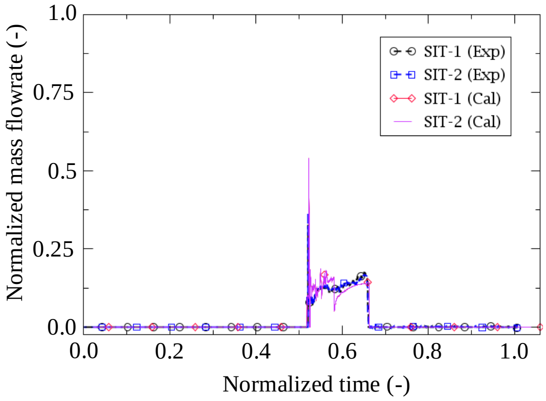

Fig. 5. Injected mass flowrates of SIT-1 and SIT-2.

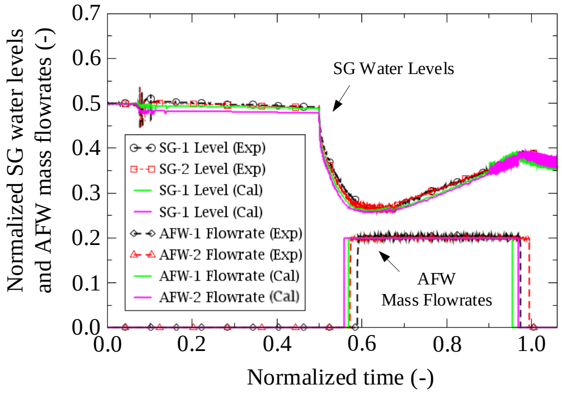

Fig. 6. SG water levels and AFW mass flowrates.

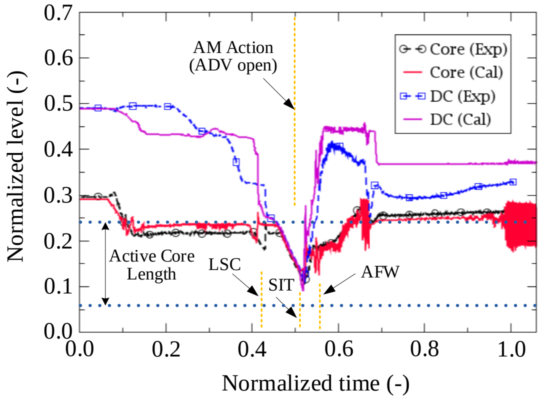

Fig. 7. Collapsed water levels of core and downcomer.

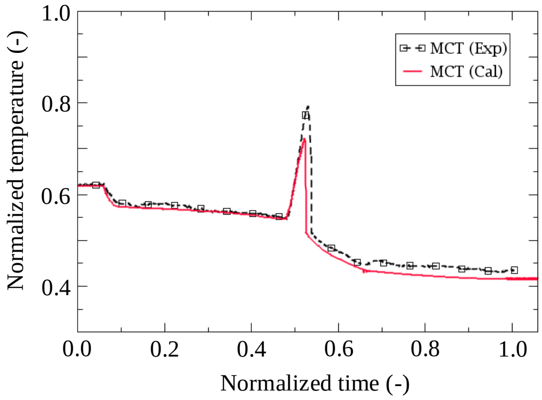

Fig. 8. Maximum cladding temperatures.

In the test, the transient started by the opening the break valve. The decrease in the core water level causes the heater rod surface temperature to increase, which results in the start of AM action. By opening of the ADVs, the pressure and water level of SG secondary side drastically decreased. The primary pressure also decreased enough for SIT injection to start. The decrease in water level of SG caused AFW to be injected. The injection of SIT and AFW restore the RPV and SG inventories. The natural circulation is formed in the primary loop. The test was terminated when the heater rods were sufficiently cooled down [1].

Figure 3 shows the results of cumulative discharge mass from the primary and secondary systems. The calculated cumulative mass of break flow was slightly smaller than the measure data. The break flowrate was determined by the sensitivity analysis so that the start time of the core heat-up was similar between the calculation and the experiment. The duration of the operation of the MSSVs was quite well predicted. The cumulative mass of discharge flow from the MSSVs and ADVs after the ADVs opened was also slightly smaller in the calculation than in the experiment.

Figures 4 compares the predicted pressures of the primary and secondary systems with experimental data. The MARS-KS prediction is in very good agreement with the measured data.

Figure 5 shows the results of injected mass flow rates from the SIT-1 and SIT-2. The code reproduced well the duration time of the SIT injection and the mass flow rates. The calculated results showed a sudden decrease in the mass flow rates while transitioning from the high flow condition to low flow condition, which was not observed in the experiment.

Figure 6 shows the collapsed water levels of the secondary side of SGs and AFW flowrates, respectively. The code results were generally satisfactory. The decrease in water levels occurred relatively faster in the calculation than in the experiment. This resulted in relatively earlier AFW injection in the calculation.

Figure 7 shows the results of collapsed water levels in the core and the downcomer (DC). The predicted core level shows good agreement with the data. The code captured well the recovery of core water level by the loop seal clearing (LSC). The code also predicted well the minimum core water level when the core heat-up started. While a relatively large discrepancy was observed in the DC water level, the code predicted well the general trend of the DC water level.

Figure 8 shows the result of the maximum cladding temperature. The start time of the core heat-up and the core rewetting time were well predicted by the code. However, the code underestimated the maximum rod surface temperature.

5. Conclusions

We assessed the predictable capability of MARS-KS 1.6 using ATLAS CRDM-SIP-03 test in the DSP-06 program. It was found that the MARS-KS code is able to predict adequately the main thermal-hydraulic phenomena during the SBLOCA at RPV upper head with a failure of SIPs.

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