Analysis of ATLAS LORHR Pressurizer Opening Test during Mid-Loop operation using SPACE code

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1. Introduction

After the Fukushima accident, the importance of accident management for the Design Extension Condition (DEC) has increased, and many studies have been conducted on the accident. The Loss of Residual Heat Removal (LORHR) accident during mid-loop operation is one of the DEC and is considered to be a relatively high-risk accident identified by probabilistic safety assessment (PSA).

Nuclear Power Plant (NPP) has a certain maintenance operation to inspect the steam generator U-tubes or to replace the reactor coolant pump seal during reactor shutdown. At this time, RCS inventory can be reduced to the mid-level of the hot leg, and the upper portion of the primary system is filled with air. Since the fuel is still loaded in the reactor, the decay heat generated in the core is removed using the Residual Heat Removal (RHR) system. This operation mode is usually called a mid-loop operation.

If the water level of RCS is lower than the mid-level of hot leg due to excessive drainage by the operator, a vortex may form at the RHR suction line, and air may be sucked into the RHR pump. A complete interruption of water supply leads to loss of function of pump. Consequently, it can result in the loss of RHR accident followed by rapid boiling in the core [1]. There are two concerns related to safety analysis for the accident. One is the maximum RCS pressure during transient to menace the integrity of RCS components such as nozzle dams, and the other is the time required for the operator to mitigate the accident such as core uncovery time [2].

An experimental investigation of the thermal-hydraulic process associated with the loss of RHR accident was conducted at the ATLAS facility. In this experiment (MLO-PRO-02), it was assumed that the pressurizer manway was opened, and the water on the secondary side of the steam generator was empty during the test [3].

In this paper, the code analysis for the MLO-PRO-02 test was performed by using the SPACE code to assess the code prediction capability. The calculated results are compared with the experimental data.

2. Modeling Information

Fig. 1. presents the SPACE nodalization of ATLAS MLO PRO-02 test. In order to establish the mid-loop condition under an atmospheric pressure, the water level in the RCS was set to mid-level of hot leg, and the upper part of the RCS was modeled to be filled with non-condensable air.

The perpendicular junctions between the core and hot leg, and between the down-comer and cold leg were modeled by crossflow junctions. The upward offtake option was adopted at the junction between the hot leg and pressurizer surge line, so that the discharge flow to the pressurizer could be properly estimated. The pressurizer manway was modeled using a pressure boundary condition on the top of the pressurizer. The flow area of the pressurizer manway was set to 765.2 mm^2, and the form loss was adjusted to match the experimental data. During the steady calculation, RHR flow of 1.4 kg/s was discharged from hot leg and injected into downcomer. The core power was kept at 97.1 kW throughout the steady and transient calculation. The initial experimental condition and steady-state calculation results are summarized in Table I.

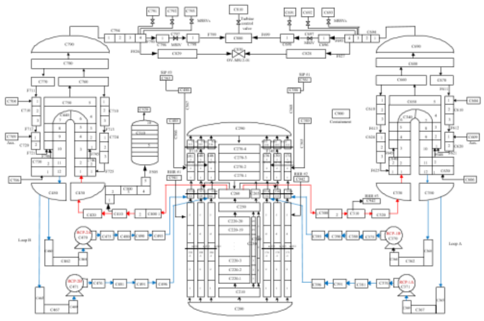

Fig. 1. SPACE Nodalization of the ATLAS MLO-PRO-02 Test

Table I: Steady State Calculation Results

Parameter	**Exp.**	**Cal.**	**Error (%)**
Primary System			
Core Power (kW)	97.1	97.1	0.0
PZR Pressure (kPa)	104.0	101.3	2.60
Core Inlet Temp. (K)	322	324.0	0.64
Core Outlet Temp. (K)	339	338.6	0.10
RHR Flow Rate (kg/s)	1.4	1.4	0.0
Hot leg Level	Mid loop	0.48	-
Cold leg Level	Mid loop	0.47	-
Secondary System			
Steam Pressure (kPa)	101.3	101.3	0.0
Steam Generator Level (m)	Empty	0	0.0

3. Simulation Results

After steady-state calculation, the transient was initiated by reducing the RHR flow rate to zero.

Fig. 2. shows the primary system pressure behavior during the transient. As the loss of RHR accident occurs, the core decay heat causes the temperature on the core to rise and the water in the reactor pressure vessel to boil. After boiling started in the core, the primary system pressure continued to increase until the safety injection water was injected. The calculated rate of pressure increase is underestimated in the early phase (t < 0.4), indicating the collapsed water level in the core decreased more than the experiment as a relatively large amount of core water flowed into the hot legs as shown in Fig. 3.

Fig. 4. shows the collapsed water level in the pressurizer. After steam generated in the core, the water in the core migrated to the pressurizer via the hot leg and pressurizer surge line. Before the pressurizer level increase, the steam velocity was not sufficient to carry the liquid up to the pressurizer, and the water was accumulated in the surge line. The primary system pressure continued to increase due to the increased interfacial drag at the pressurizer surge line. When the primary system pressure was high enough to overcome the flow resistance at the surge line, the collapsed water level in the pressurizer started to increase. The sufficient steam velocity hold up the water in the pressurizer, and then the significant discharging flow through the pressurizer manway was established, as shown in Fig. 5. The SPACE code accurately predicts the pressurizer level behavior and discharging flow rate compared to the experimental data.

Fig. 6. shows the collapsed water level in the core and downcomer. The continuous discharge flow through the pressurizer manway affects the collapsed water level in the RPV to decrease. As the collapsed water level in the core was reduced below the top of the active core, eventually, core heat-up was initiated. When the cladding temperature rises above the set point of actuation of the safety injection pump, the safety injection water was injected into RCS, and cladding temperature decreased rapidly, as shown in Fig. 7.

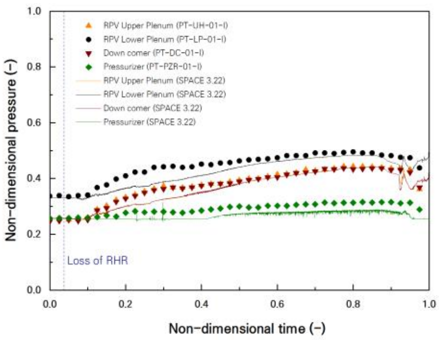

Fig. 2. Comparison of the system pressure

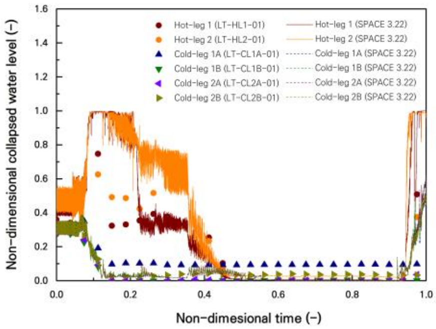

Fig. 3. Comparison of the collapsed water level in the hot and cold legs

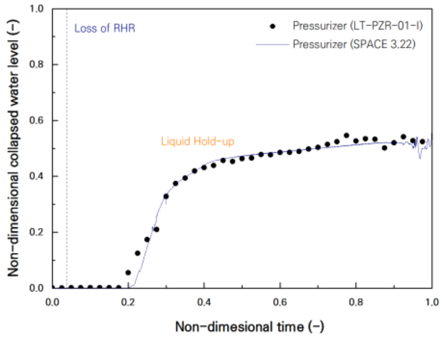

Fig. 4. Comparison of the collapsed water level in the pressurizer

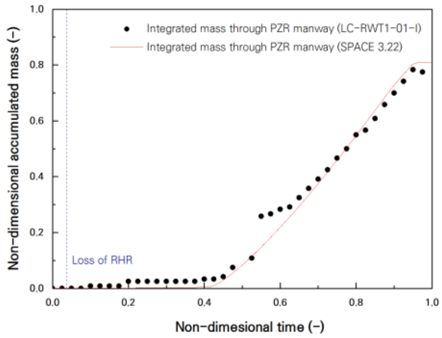

Fig. 5. Comparison of discharged mass through the pressurizer manway

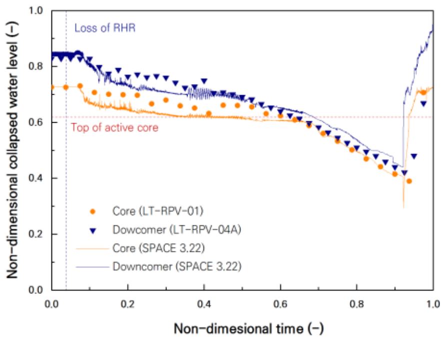

Fig. 6. Comparison of collapsed water level in the RPV

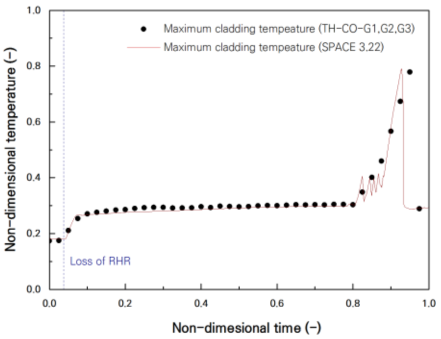

Fig. 7. Comparison of maximum cladding temperature

4. Conclusions

The ATLAS MLO-PRO-02 test was simulated using the SPACE 3.22 code to assess the code prediction capability in the loss of RHR accident during mid-loop operation. It has some discrepancies with the system pressure and collapsed water level in the early phase of the transient. However, based on the experimental and simulation comparisons, the SPACE code predicted well the overall system behavior of the transient and timing of the main events. So the SPACE code has sufficient capability to simulate the accident.

ACKNOWLEDGMENT

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