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Integral Experiment and MARS Analysis for DVI Line Break SBLOCA in APR1400

K. H. Lee, B.U. Bae, G.C. Park
Department of Nuclear Engineering, Seoul National University, Seoul, 151-742, Korea, snulkh99@snu.ac.kr

1. Introduction

APR1400 (Advanced Power Rector 1400 MWe) adopted DVI (Direct Vessel Injection) systems as the advanced feature of ECCS (Emergency Core Cooling System), which have four trains equipped to the upper downcomer of reactor vessel. Since the conventional ECCS is based on CLI (Cold Leg Injection), the additional safety analysis requires for DVI line break SBLOCA (Small Break Loss of Coolant Accident). Especially, the thermal-hydraulic phenomena in the upper downcomer are important to safety in this accident, because the steam generated in core should pass through the upper downcomer to decrease the primary system pressure. Previous studies with the one-dimensional system code analysis or air-water experiment were not sufficient to exactly show phenomena inside the upper in such accident. Therefore, this study conducted on the integral steam-water experiment and the analysis that are required to investigate the phenomena in DVI line break SBLOCA exactly. Especially, this experiment is focused on the phenomenon in upper downcomer with the visualization of upper downcomer.

2. Test Facility and Test Conditions

2.1 SNUF Facility

The SNUF(Seoul National University Facility) test facility is a RHRP (Reduced-Height and Reduced Pressure) integral system facility designed to simulate the APR1400 pressurized water reactor [1]. The schematic of the SNUF is shown in Figure 1.

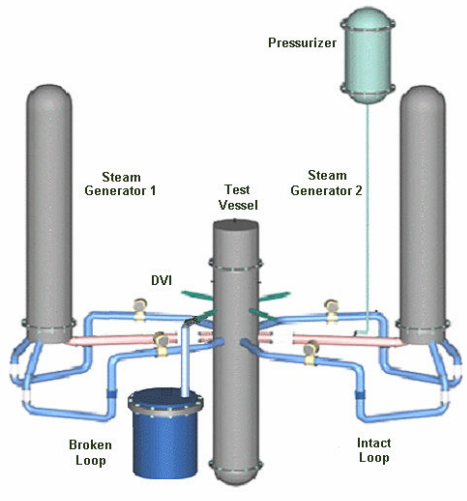

Figure 1. Schematic of the SNUF facility.

The scaling factors of length and area in the primary system are 1/6.4 and 1/178, respectively. The geometrical configuration of SNUF is almost equivalent to that of APR1400. The test vessel contains 260 heaters to simulate the core decay heat. And the steam generator in each loop contains 16 U-tubes. The three intact DVI lines can supply the SI (Safety Injection) coolant into the upper downcomer and the one broken DVI line is connected to the discharge tank.

2.2 Test Conditions

It is necessary to get the information of thermal-hydraulic phenomena in prototype for simulating that in a small scale facility. MARS, the system analysis code, was utilized in this study for analyzing the DVI line break accident in APR1400 [2]. For conservative conditions, it is assumed that core power has 102 % of normal power and 120 % of decay heat according to the ANS73 model. Also the Guillotine-break of DVI line was postulated for the most severe case.

Considering that SNUF is a kind of the RHRP facility, an appropriate scaling methodology should be applied in order to simulate the accident scenario in the prototype. In this study, the energy scaling methodology [3] was suggested as scaling the coolant mass inventory and thermal power for the reduced-pressure condition.

According to the energy scaling method, the test conditions of SNUF test was determined by scaling down the results of MARS analysis in the prototype. For not simulating the normal power of prototype, the test simulates the transient from 30s after break. In the other hand, it is impossible to exactly simulate the power curve in the actual facility, so that the integrated power is supplied. The integrated power is composed of three steps. SI flow rate is also applied as integrated value during the transient. Considering the test capability of SNUF, the reduced primary system pressure at initiation was determined as 8 bar. And the temperature of coolant and SI water is determined according to the energy scaling method. The area of broken DVI is determined considering critical flow rate. The test conditions are listed in Table 1.

Table 1. Test conditions of SNUF

Parameter	Test Condition
Test Time	30 s after break
Initial Primary Pressure	6 bar
Initial Secondary Temperature	150 ^{o}C
Initial Coolant Temperature	150 ~ 160 ^{o}C
Thermal Power	110 kW (0 ~ 60 s) 70 kW (60 ~ 300 s) 60 kW (300 ~ 500 s)

HPSI Flow Rate	0.042 kg/s
SIT Flow Rate	0.035 kg/s
SI Temperature	27.5 ^{o}C
Break Area	227 mm^2

3. Experimental Results and MARS Analysis

The experiment was performed with SNUF to simulate the DVI-line break accident. And the experiment was simulated with MARS code according to the test condition,

The experiment data was compared with the analysis data that is from simulating real experiment with MARS code. As shown in Figure 2, the change rate of primary system pressure of experiment was simulated well with MARS code. However, there is difference between experiment data and analysis data after 250 s. For simulating the broken DVI-line exactly, sudden contraction is considered in incompressible flow, so that the discharge coefficient is applied according to the contraction ratio. However, the ratio is inappropriate for predicting the phenomenon that steam is discharged after downcomer seal is cleared. Thus, the pressure of primary system is not predicted well during the later period of transient. But the downcomer seal clearing phenomenon is occurred before 100 s, so that this difference is not the main part of this study.

As shown in Figure 3, the downcomer collapsed water level is simulated well with MARS code. The phenomenon of decrease of downcomer collapsed level means that downcomer seal clearing is occurred. Thus, it can be concluded that downcomer seal clearing phenomenon is simulated well with SNUF experiment and MARS code.

The core collapsed water level is also simulated reasonably with MARS code as shows in Figure 4. Especially, the minimum core collapsed level and the timing of the event is predicted appropriately by MARS code. And this figure shows the core level is started to be discovered after downcomre seal clearing phenomenon is occurred at about 70 s.

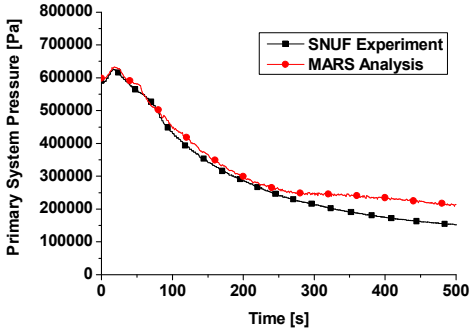

Figure 2. Primary System Pressure

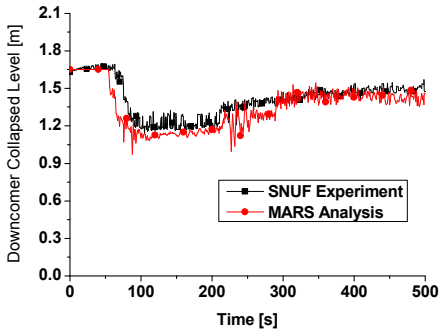

Figure 3. Downcomer Collapsed Water Level

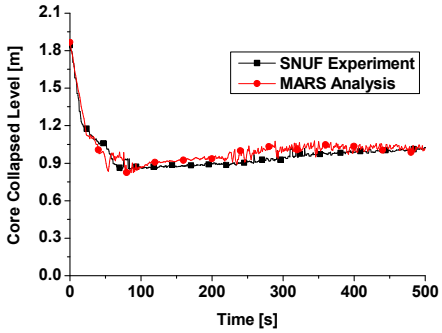

Figure 4. Core Collapsed Water Level

4. Conclusion

In order to study the thermal hydraulic phenomena in DVI line break SBLOCA, experimental study in SNUF was performed. The results showed a good agreement with the transient behavior in DVI line break SBLOCA of APR1400. And the capability of MARS code for predicting the downcomer seal clearing was verified with the results of experiment. In evaluating the scale-up capability of MARS code, the results in this study will be valuable as the counter-part test data of ATLAS (Advanced Thermal-hydraulic Test Loop for Accident Simulation) facility.

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