Experimental and Analytical Sensitivity Study for DVI Line Break LOCA in APR1400

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1. Introduction

The APR1400 (Advanced Power Reactor 1400 MWe), a next generation nuclear reactor in Korea, has adopted a DVI (Direct Vessel Injection) system as an advanced feature of its ECCS (Emergency Core Cooling System). Therefore, the DVI system requires an additional safety assessment for a DVI line break LOCA (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 differential pressure between the core and the downcomer and to make the fuel recoverable by the liquid coolant. Thus, an integral effect test and analysis, with the same working fluid, are necessary to validate the performance of the DVI system. Moreover, it is necessary to precisely estimate the sensitivity according to the break area and L/D ratio of a broken pipe. Hence, this study focused on integral steam-water experiments involving sensitivity analyses to investigate the phenomena in a DVI line break LOCA.

2. The Test Facility and Test Conditions

2.1 The SNUF Facility

The SNUF (Seoul National University Facility) test facility [1] is a RHRP integral loop test facility designed to simulate the APR1400 pressurized water reactor. The scaling factors of length and area in the primary system are 1/6.4 and 1/178 with respect to the prototype. The geometrical configuration of the SNUF is equivalent to that of the APR1400. The maximum total operation power of the heaters is 200 kW and the maximum operation pressure is 0.8 MPa. The three intact DVI lines can supply the SI (Safety Injection) water into the upper downcomer. The one broken DVI line is connected to the discharge tank.

2.2 The determination of the Test Conditions

To determine the test conditions, it was necessary to obtain the transient results of the thermal-hydraulic phenomena in a prototype for simulating those phenomena in a small scale facility. MARS, a thermal hydraulic system analysis code, was utilized in this study for analyzing the DVI line break LOCA in the APR1400 reactor [2]. A Guillotine-break of the DVI line was postulated for the most severe case of the DVI line break LOCA.

For simulating the accident scenario reasonably in the facility, an appropriate scaling method should be applied. Thus, an energy scaling method was proposed to determine the test conditions [3]. According to the energy scaling method, the detailed test conditions were determined from scaling down the thermal-hydraulic conditions of the prototype analysis as summarized in Table 1. The experiment according to these test conditions is called as the base case in this study.

Table 1. The test conditions of the base case

Parameter	Test conditions
Test time	30 s after break
Initial primary pressure	0.6 MPa
Initial secondary temperature	158 ^oC
Initial coolant temperature	158 ^oC
Thermal power	110 kW (0 ~ 60 s) 70 kW (60 ~ 300 s) 60 kW (300 ~ 500 s)
HPSI flow rate	0.13 kg/s
SIT flow rate	0.11 kg/s
SI Temperature	27.4 ^oC
Broken DVI area	0.000177 m^2
L/D of broken DVI	5.9

2.3 The Sensitivity Test Case

The transient of the coolant inventory during the DVI line break LOCA is governed by the discharge of the coolant for the primary system through the broken DVI line. The discharged flow rate is strongly related to the area of the break. Therefore we selected the case of the reduced break area (B1) as a sensitivity case. Considering that a Guillotine break of the DVI line was simulated in the base case, the B1 case was for simulating a partial break of the DVI line. In this case, the break area was reduced by the installation of an orifice. It was 44 % of the area of the base case. The position of the break was also an important parameter for the accident. The discharged flow during the accident reaches the critical flow, so that the effect of the L/D ratio of a broken pipe can influence the discharged flow rate [4]. Therefore, the case of the extended break position (B2) was performed with 3 times the L/D ratio as compared with the base case.

3. The Experimental Results

The base case was performed with SNUF to simulate the DVI-line break accident. As shown in Fig. 1, the primary system pressure started to decrease after 15 s since the coolant of the primary system was continually discharged into the broken DVI line. However, the decreasing rates of the primary system pressure before and after 70 s were different. After that time, the downcomer collapsed water level decreased rapidly as shown in Fig. 2. This rapid decrease meant that the liquid coolant in the upper downcomer was cleared by steam flow incoming from the cold legs; then, the upper downcomer was filled with steam. That phenomenon was the downcomer seal clearing. After the occurrence of the phenomenon, the steam, generated in the core, could be effectively discharged to the broken DVI line Thus, the differential pressure between the core and the downcomer was reduced meaning that the core collapsed water level could be recovered after 70 s as shown in Fig. 3. Also, the system pressure of the core could be decreased rapidly after 70.

The break area of case B1 was smaller than that of the base case, so we expected that the discharged flow rate to the broken DVI line was also decreased. Therefore, the primary system pressure of case B1 was also decreased slowly as compared with the base case as shown in Fig. 1. Figure 2 shows that the downcomer collapsed water level of case B1 was not decreased rapidly around 70 s unlike the base case. In other words, the downcomer collapsed water level decreased slowly from 70 s to 150 s. This trends of the downcomer collapsed water level in case B1 meant that the coolant in the upper downcomer obviously was not cleared. It is because the water in the downcomer could not be discharged enough in case B1 due to the small break area. By the reason, the decreasing rate of the primary system pressure was not changed around 70 s as compared and as shown in Fig. 1. On the other hand, the core collapsed water level showed higher values as compared with the base case before 100 s as illustrated in Fig. 3. This was because the total coolant inventory was not decreased as in the base case due to the small break area.

The L/D ratio was about 5.9 in the base case; it was about 18 in case B2. Therefore, the discharged flow rate to the broken DVI line of case B2 was lower than that of the base case. From the view point of the reduction of the discharged flow rate, cases B1 and B2 encouraged very similar effects in the coolant inventory. The trends of the thermal hydraulic phenomenon also showed similar results as illustrated in Figs. 1-3. The primary system pressure and the coolant temperature were decreased slowly, and the core and the downcomer collapsed water level were higher than those of the base case.

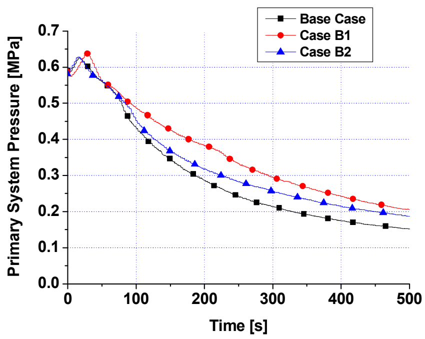

Figure 1. Primary System Pressure

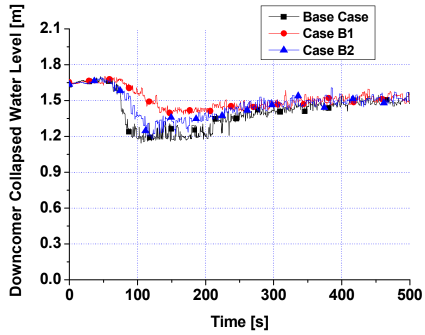

Figure 2. Downcomer Collapsed Water Level

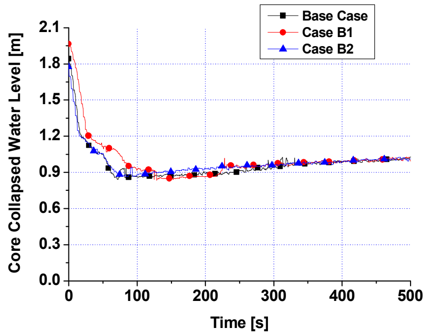

Figure 3. Core Collapsed Water Level

4. Conclusion

In order to understand the thermal hydraulic phenomena in the DVI line break LOCA of the APR1400 reactor, an experimental study was performed with the SNUF. From the results of the experiments, we concluded that the downcomer seal clearing did not clearly occur when reducing the break area or extending the break position when the discharged flow rate through the broken DVI line became low. 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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