Experimental Study for Effect of SIP flow rate on Cold Leg 4 inch Upward Break Scenario in ATLAS Facility

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1. Introduction

The depth of the loop seal of APR1400 (Advanced Power Reactor 1400 MWe) has 0.608 m depth while the U.S.EPR has 0.030 m depth [1]. The deeper loop seal of APR1400 and its impact can be more serious than in other PWRs because the deeper loop seal necessitates longer time to clear the loop seal and partial core uncovery can occur during this time.

Therefore, an issue about loop seal and its impact on long term cooling during a postulated loss-of coolant accident (LOCA) was raised for the APR1400. In particular, a top slot break at a cold leg with a medium or small size break was concerned [2]. During this accident, a loop seal reformation after a loop seal clearing can lead a partial core uncover and core temperature excursion may occur. It is possible that the loop seal is reformed by primary steam condensation by steam generator heat transfer or safety injection water flooding (reverse flow to loop seal) after loop seal clearing. And then, pressure increase at the top core region due to the steam released from core. This pressurized steam pushes down the core level and partial core is uncovered. And core temperature excursion may occur.

An experimental investigations for the top slot break at a cold leg have been performed as a test item of the 4th ATLAS-Domestic Standard Problem (DSP) [3]. This experiment (ID: LTC-CL-04R) was performed in ATLAS, an integral effect test facility. For this experiment, the safety injection pumps operated with maximum flow rate (about 0.3 kg/sec per pump) during their operating time. This condition is more conservative condition because larger amount of safety injection water increases reverse flow rate to loop seal and loop seal reformation is easily reformed.

In the current study, an experiment (ID: LTC-CL-05) for the top slot break at a cold leg was repeated with nominal SIP flow rate to investigate SIP flow rate effect on the loop seal behaviors.

2. Description of the Test Facility

2.1 ATLAS Test Facility

ATLAS was designed to model a reduced-height primary system of APR1400 which was developed by the Korean nuclear industry. ATLAS has the 1/2-height, 1/144-area and 1/288-volume scales for APR1400 [4]. ATLAS can be used to provide the unique test data for the reactor coolant system with 2 hot legs, 4 cold legs and a direct vessel injection (DVI) of emergency core cooling (ECC). ATLAS can simulate full pressure and temperature conditions of APR1400. The total inventory of the primary system is 1.6381 m^3. The secondary system of ATLAS is simplified to be a circulating loop-type. The steam generated at two steam generators (SGs) is condensed in a direct condenser tank, and the condensed feedwater is re-circulated to the SGs. A detailed design and description of the ATLAS facility can be found in the literature [5].

2.2 Break Simulation System

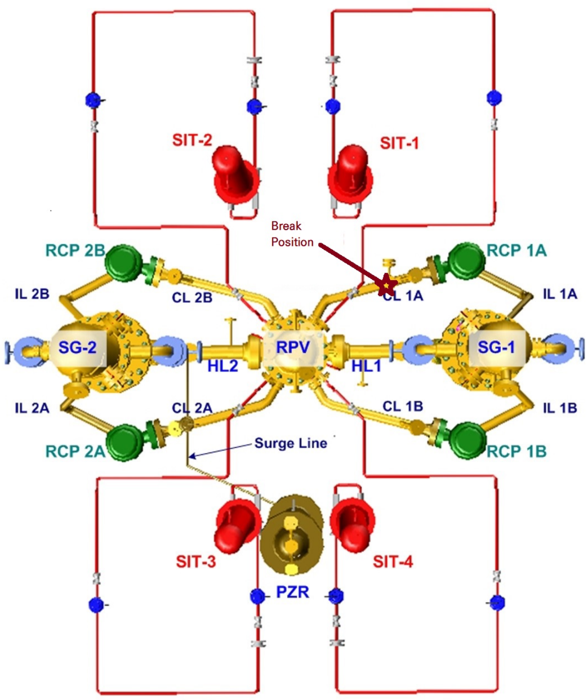

Fig. 1. Top view of ATLAS and position of break system

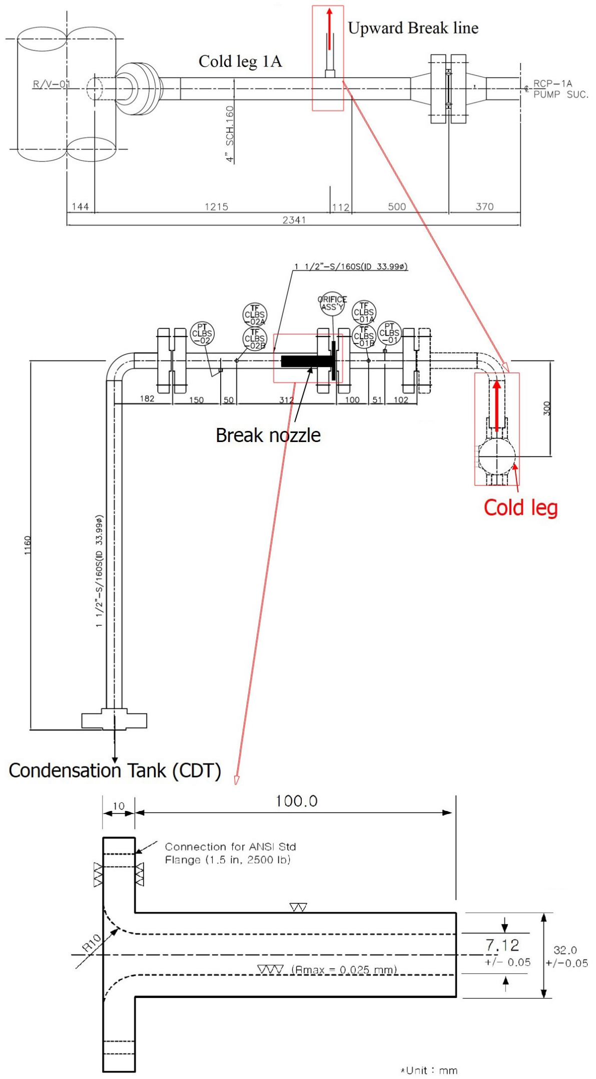

Fig. 2. Break system

Fig. 1 shows a top view of schematic diagram of ATLAS and the position where a break system was installed. Fig. 2 shows a break simulation system of ATLAS. That was installed on the top side of a cold leg (CL1A) to simulate a top slot break at a cold leg. The break nozzle, which has 7.12 mm inner diameter, was installed to simulate a 4 inch break of APR1400.

2.3 Test condition

Major conditions for experiments are summarized on Table I. A difference between the LTC-CL-04R and LTC-CL-05 was SIP flow rate as mentioned in Section 1. The SIP flow rate is controlled with flow rate curve that refers the primary pressure. The SIP flow rate for LTC-CL-04R and nominal conditions are compared on Fig. 3. In the case of current experiment, nominal SIP flow rate was applied.

In the ATLAS, bypass lines are installed at upper head-downcomer and hot leg-downcomer as Fig.4. For LTC-CL-04R and LTC-CL05, these lines were closed to induce repetition of loop seal clearing and reformation.

Table I: Major conditions for experiments

Parameter	
Core Power	102% rated power
Decay Heat	ANS73*1.2
SG cool-down operation	Not credited, but MSSVs operate & AFW is introduced
SIP	- 4 SIP with max flow rate (LTC-CL-04R) - 4 SIP with nominal flow rate (LTC-CL-05)
SIT	SIT flow credited
SI water temperature	Ambient temperature
By-pass	Down comer - 0%

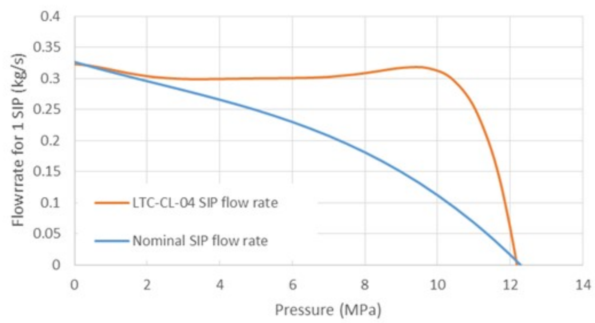

Fig. 3. SIP flow rate curved for experiments

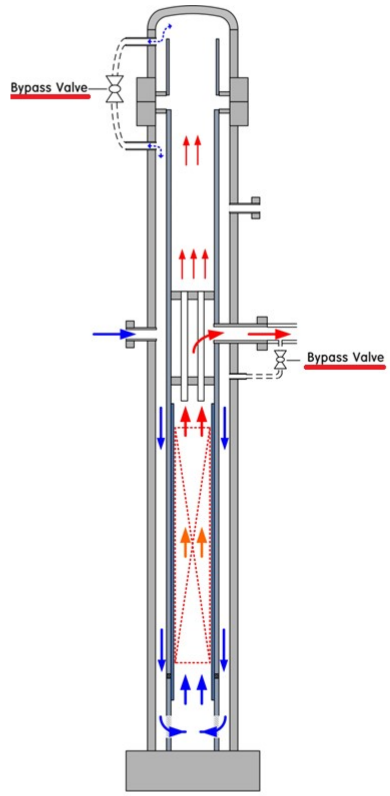

Fig. 4. Schematic diagram of RPV and by-pass valves of ATLAS

3. Test Procedure

Considering the confidential problem of test data, all of the test results in this paper were normalized by an arbitrary value including the time frame.

After break valve opening, the sequence of experiment was controlled by control logic that defined the set-value and related time for these scenarios. When the pressure of the pressurizer (sensor ID: PT-PZR-01) dropped below 0.78 normalized pressure, a low pressurizer pressure (LPP) signal was issued. After the LPP signal, the reactor, RCP, and pressurizer heater were tripped immediately. The main feed water isolation valves were closed with the LPP signal. The actuation of the SIPs was set to occur with a 0.0018 normalized time delay from the LPP signal.

The loop seal clearing and reformation were recognized with the collapsed water level of the intermediate leg. For a loop seal clearing, the water level at the vertical intermediate leg (sensor IDs: LT-ILj-03) becomes lower than the height of the horizontal intermediate leg. On the other hand, the water level at the vertical intermediate leg becomes higher than the height of the horizontal intermediate leg for the loos seal reformation.

4. Test Result

Table II summarizes the sequence of major events. Fig. 5 ~ Fig. 9 show major thermal hydraulic parameters for LTC-CL-04R and LTC-CL-05. The SIP operating time was almost same for both experiments. But, SIP flow rate for LTC-CL-05 was lower than LTC-CL-04R. Less injected safety injection water led slow core cooling. Therefore, primary pressure also decreased slowly as Fig. 6. In the case of LTC-CL-04R, loop seal clearings and reformations repeated (Table II and Fig 7). In the case of LTC-CL-05, however, the loop seal cleared at 3 loop seals. And then only two loop seals were reformed and the one kept cleared loop seal during long term phase. During the test, steam that flows through RCS loop (RPV → hot leg → SG → cold leg → downcomer) pushes up the flooding water (CCFL) at vertical intermediate leg. If the safety injection water flooding (reverse flow to loop seal) is enough to overcome the CCFL by steam, loop seal is reformed. In the case of LTC-CL-04R, SIPs flow rate was enough large to make loop seal reformation. But, SIPs flow rate was not enough for LTC-CL-05. Therefore, loop seal was cleared during long term phase.

After the loop seal reformation, steam is accumulated at the upper head of RPV and steam increases the pressure and saturated temperature in the core. And then, the core heater temperature increases due to the increased saturated temperature. This is observed for LTC-CL-04R in Fig 6. However, core heater temperature increasing is not observed for LTC-CL-05 because loop seal reformation was not happened for this test.

Table II: Sequence of event (LTC-CL-04R and LTC-CL-05)

Events	LTC-CL-04R (4.0”, 16°C SI, bypass 0%)	LTC-CL-05 (4.0”, 20°C SI, bypass 0%)
Break start	0.0200	0.0200
MSSV	0.0224/0.0227	0.0224/0.0225
LPP trip (PT-PZR-01 < 0.78)	0.0221	0.0221
SIP on (PT-PZR-01 < 0.67 + delay)	0.0254	0.0253
SIT on (PT-DC-01 < 0.25)	0.0710	0.0875
Loop seal clearing	0.0489~0.05125(1A) 0.0503~0.2480(2A)	0.0494~0.2860(1A) 0.0487~0.4470(2B) 0.0487~ (2A)
	0.2731~0.2767(1A,1B) 0.2729~0.2773(2B)	
	0.3321~0.3425(1A) 0.3319~0.3433(2A)	
	0.4881~0.4971(1A)	

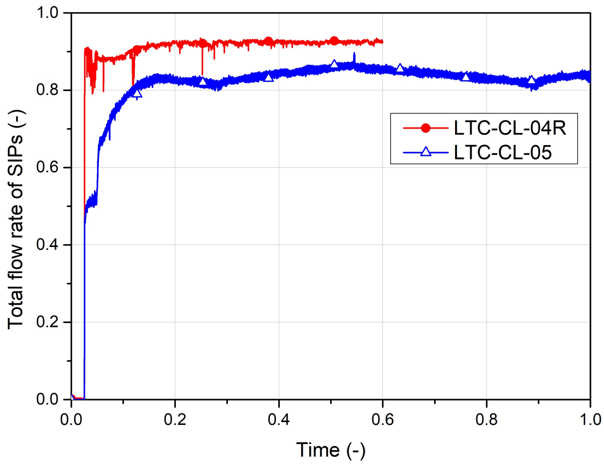

Fig. 5. Total flow rate of SIPs

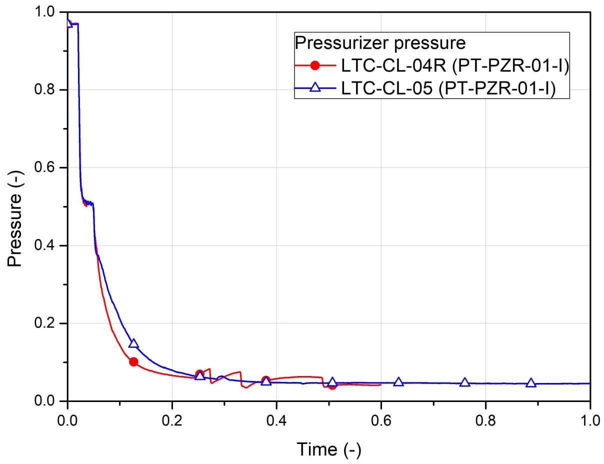

Fig. 6. Primary loop pressure

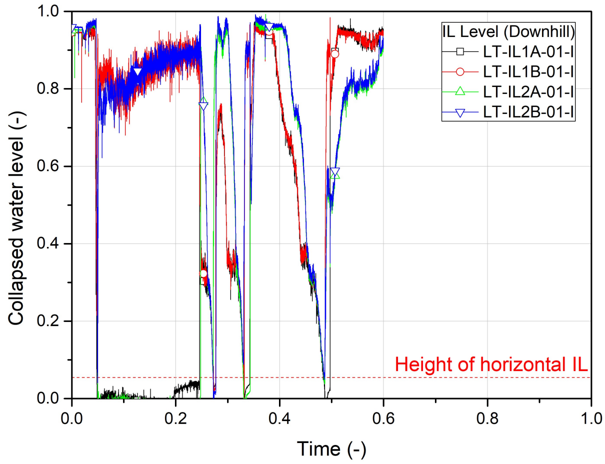

Fig. 7. Loop seal behavior (LTC-CL-04R)

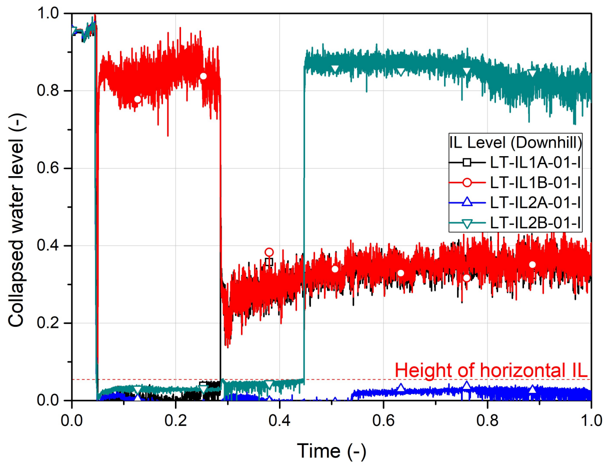

Fig. 8. Loop seal behavior (LTC-CL-05)

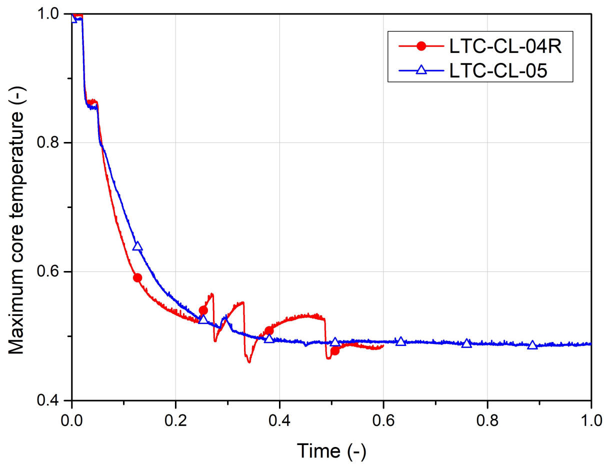

Fig. 9. Maximum core temperature

5. Conclusions

In the current study, SIP flow rate effects were experimentally analyzed for the top slot break at a cold leg. For this study, an experiment (ID: LTC-CL-05) was performed in ATLAS. Conditions for LTC-CL-05 was same as previous test (ID: LTC-CL-04R) except the SIP flow rate. In the case of LTC-CL-05, the less SIP flow rate reduced core cooling performance. And it also reduced safety injection water flooding from cold leg to intermediate leg that is important parameter to make loop seal reformation. Therefore, loop seal reformation was not observed for LTC-CL-05.

ACKNOWLEDGMENTS

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