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Analysis of Loop Seal Clearing and Reformation Phenomena During SBLOCA of the ATLAS Facility

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1. Introduction

Loop seal clearing (LSC) and reformation (LSR) are crucial phenomena for both short-term and long-term cooling in SBLOCA. Since APR1400 has deeper loop seal than other NPP types, USNRC has concerned that the deep loop seal of APR1400 could result in core uncovery and significant cladding temperature rise due to LSR during SBLOCA in the review process of Design Certificate (DC) for APR1400.

In Korea, the test simulating long-term cooling following a cold leg top slot break was conducted at ATLAS (Advanced Thermal-hydraulic Test Loop for Accident Simulation) facility by KAERI to provide an experimental evidence on that issue[1]. In this study, the analysis on LSC and LSR phenomena in top slot break condition of ATLAS using MARS-KS code was carried out under ATLAS DSP(Domestic Standard Problem)-04 program. Although the DSP-04 program was completed in 2016, the authors have attempted to understand the actual phenomena and code prediction with deviation from the test. Accordingly, additional calculation was conducted. The analysis results were compared with that of experiment to discuss the effect of LSC and LSR.

2. Modeling for Top Slot Break Experiment of ATLAS

The MARS-KS 1.4 code was used for the analysis[2]. The original steady state input deck was provided by KAERI. The nodalization of ATLAS facility for the simulation of 7.12 mm top slot break condition was presented in Fig. 1. The break size of 7.12 mm in ATLAS corresponds to 4 inch in APR1400.

The top slot break occurred at the upper part of cold leg pump discharge volume (pipe 380). The reactor coolant was discharged from pipe 380 to the vertical pipe 999 which was linked to the condensation tank 995 via break system composed of pipe 998, 997 and 996. The diameter of nozzle cell of pipe 999 was 7.12 mm. Pipe 999, 998 and 997 were assumed to be filled with the water in the same thermal-hydraulic condition of cold leg coolant. When the break occurred, motor valve 990 between pipe 997 and 996 opened.

Off-take model was used to simulate the top slot break and Henry-Fauske critical flow model was used at the junction 904 which connects pipe 996 and condensation tank 995. The default values of Henry-Fauske critical flow model (discharge coefficient of 1.0 and thermal non-equilibrium constant of 0.14) were adopted through sensitivity calculations.

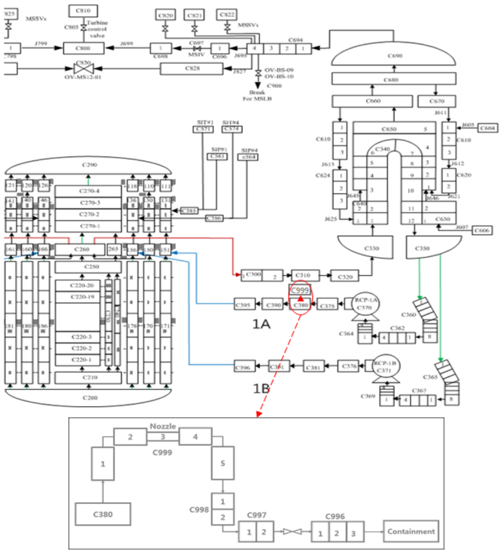

Fig. 1. Nodalization of ATLAS for Top Slot Break Experiment

3. Results and Discussion

3.1 Thermal-hydraulic Behaviors

Table 1 summarizes the sequence of event of 7.12 mm top slot break experiment.

Table 1. Sequence of Event

Event	Experiment [sec]	Calculation [sec]	Remarks
Break	300	300	
1st MSSV open	336/340	329/325	
LPP trip	332	321	PT-PZR-01 < 12.48 MPa
SIP on	381	368	PT-PZR-01 < 10.7 MPa + 28 sec delay
SIT on	1,066	875	PT-DC-01 < 4.03 MPa
LSC	733~3,687(1A) 754~3,719(2A)	640~1,019(1A) 647~3,920(2A)	2 loops/ 2 loops cleared
	4,097~4,151 (1A, 1B) 4,094~4,160(2B)	4,226~4,376(2B)	2 loops/ 1 loop cleared
	4,982~5,138(1A) 4,978~5,150(2A)	5,129~5,264(2A)	2 loops/ 1 loop cleared
	7,322~7,456(1A)	7,146~7,266(2A)	1 loop/ 1 loop cleared

The pressurizer pressure transient trend is shown in Fig. 2. The pressurizer pressure experienced a fast depressurization and then it reached a plateau value. As the experimental data of the heat loss of the steam generator was not provided, the heat loss as a function of temperature of the steam generator outside wall was roughly applied to adjust the steam generator pressure in the broken loop at 8,000 sec. The earlier depressurization after the plateau period in the calculation could result from the difference of the secondary system pressure due to different heat loss of the secondary system. Since the calculated pressurizer pressure decreased rapidly, LPP trip and actuation of SIT and SIP were initiated rapidly as shown in Table 1.

The cumulative break flow was slightly over-estimated until 1,600 sec as shown in Fig. 3 so that it could lead to the rapid depressurization at initial period. At 8,000 sec, the accumulated break flow was underpredicted by 5%.

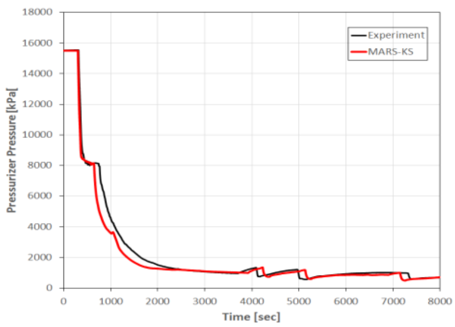

Fig. 2. Pressurizer Pressure

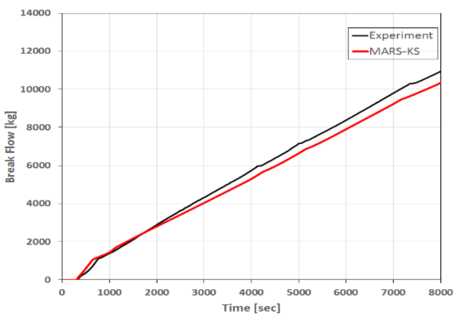

Fig. 3. Cumulative Break Flow

The trend of break flow rate is depicted in Fig. 4. Since the break flow rate after the first peak was overpredicted in the calculation, the cumulative break mass was also overestimated before the occurrence of the first LSC. After the occurrence of LSC, the break flow rate decreased significantly due to the depressurization of the primary system. After LSC, the cumulative break flow was slightly underestimated since the break flow rate was slightly underestimated in the calculation. Since the Henry-Fauske model employs only a single discharge coefficient throughout for all the discharge flow phases, overprediction of the break flow could be changed to the underprediction of that[3].

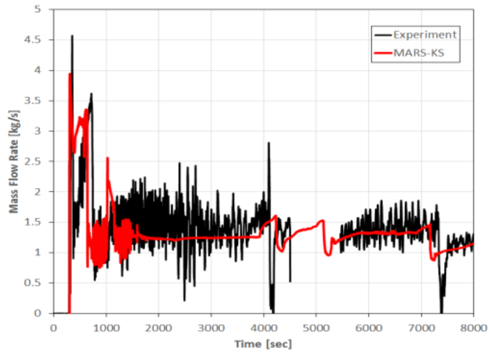

Fig. 4. Break Flow Rate

The collapsed liquid levels at four intermediate legs in RCP sides are shown in Fig. 5 and Fig. 6, respectively. In the calculation and experiment, the first LSC occurred at the same intermediate legs, 1A and 2A. However, in the calculation, the LSC at broken loop-1A did not occur obviously and LSR occurred after approximately 400 sec later only at 1A. The duration time of the first LSC at 2A was predicted well. After the first LSR, LSC occurred twice at 2A and once at 2B around 4,000, 5,000 and 7,000 sec, respectively. The beginning and duration time of LSC and LSR were predicted well except for the location of LSC occurrence.

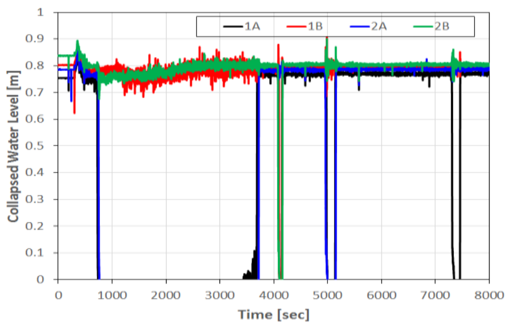

Fig. 5. Collapsed Water Level in RCP Side Intermediate Legs (Experiment)

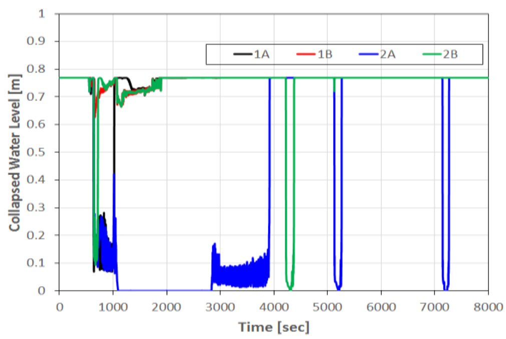

Fig. 6. Collapsed Water Level in RCP Side Intermediate Legs (Calculation)

The maximum surface temperature of the heater rod is plotted in Fig. 7. The temperature trend was similar with the primary system pressure trend as the heater rod surface temperature followed the saturated temperature. The maximum temperature was observed at the beginning of transient. Three times of small reheat induced by LSR were agreed well between calculation and experiment. However, LSC and LSR in several times did not significantly affect the core cooling capability of ATLAS at the long-term period.

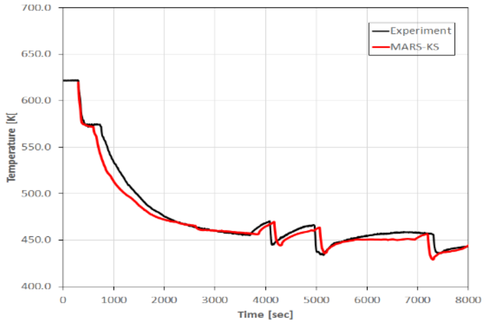

Fig. 7. Maximum Heater Rod Surface Temperature

3.2 Sensitivity Study of CCFL Model

The Counter Current Flow Limitation (CCFL) model has been generally considered at the core tie plate and the hot leg junction connecting its inclined section to the steam generator in each loop. In this study, since there was not definite prediction of loop seal clearing at the broken loop 1A, the authors have concerned if CCFL might have an influence on the prediction. Thus the CCFL model was directly applied to all the intermediate legs. The effect of the gas intercept in Wallis CCFL form on loop seal clearing at 1A was investigated and Fig. 8 shows the calculation result.

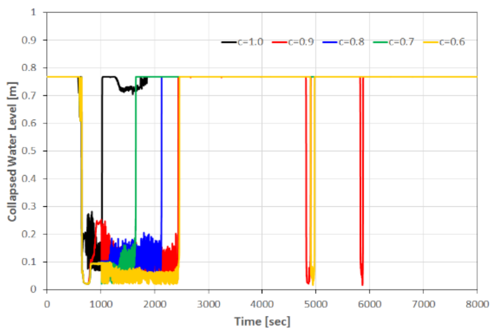

Fig. 8. Collapsed Water Level of 1A according to Gas Intercept of Wallis CCFL Form

It was found that the LSC at 1A is more definite as gas intercept gets smaller. In particular, LSC continues until 2,500 s when the gas intercept is 0.6. Although LSC at 1A did not continue for a long time like experiment, LSC at other loops contributed to continuing LSC period.

It is necessary to investigate the effect of the CCFL model implemented in the calculation to accurately predict the LSC phenomena. It is also needed to take into account the CCFL phenomena in other portion of primary system such as steam generators.

4. Conclusion

7.12 mm top slot cold leg break test of ATLAS was calculated with MARS-KS 1.4 code as the DSP-04 program. The sequence of events at initial period indicated earlier depressurization than experiment. Nevertheless, the overall trends at long-term period such as pressure, break flow rate and maximum heater surface temperature, etc. were predicted well. Except for the occurrence location of loop seal clearing, the beginning and duration time of LSC and LSR were predicted well. As a result, LSC occurred several times and LSR did not significantly affect the core cooling capability of ATLAS at the long-term period. As the next step, sensitivities on the nodalization of the loop seal and on the break flow rate and steam generator heat loss for better prediction of the primary and secondary system pressure will be conducted to identify the effect of LSC and LSR. The CCFL model was investigated as a parameter which could affect loop seal clearing at the broken loop. It was found to have a significant influence on the occurrence of LSC at broken loop. Therefore, it is needed to take into account the CCFL phenomena to accurately predict LSC in detail.

ACKNOWLEDGEMENTS

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