Post -calculation for C2.1 of OECD-ATLAS3 program

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Keywords : ATLAS, PECCS, SBLOCA, OECD-ATLAS3 program

1. Introduction

C2.1 integral effect test was performed as one of the major experiment in the frame of OECD-ATLAS3 international cooperation program using ATLAS test facility of KAERI. Major objectives of the C2.1 are to investigate thermal hydraulic transient behavior in a reactor coolant system (RCS) during a small break loss of coolant accident (SBLOCA) scenario and to evaluate the effectiveness of PECCS. A SBLOCA was induced from an open of two 2 inch break simulation valves installed at a top and bottom heads of reactor pressure vessel (RPV). With a simultaneous open of two break simulation valves, primary system pressures showed a rapid decrease to an injection triggering point of the HPSITs. Safety injection flows from the HPSIT were not effectively injected to the primary system during a pressure plateau period. Only after the opening of the ADVs, cooling water from the HPSITs was practically injected to the downcomer, resulted in a decreased of maximum clad temperature. In the present paper, post-test calculation results using MARS-KS 1.4 code will be compared with corresponding results of the C2.1 test.

2. Facility configuration for the C2.1

C2.1 was performed using the ATLAS integral effect test facility of KAERI in December 7, 2022. To allow for the simulation of high-pressure scenarios, the loop was designed to operate at up to 18.7 MPa. The primary system includes a reactor pressure vessel (RPV), two hot legs, four cold legs, a pressurizer, four reactor coolant pumps (RCPs), and two steam generators (SGs). The total inventory is 1.6381 m^3, which was validated by actual inventory measurement. In ATLAS, four SITs are installed, which have the same design specifications. The design pressure and temperature of the SITs are the same with those of the primary components. However, to perform the present test related with the PECCS, two of the SITs, such as SIT-1 and SIT-3, were used as HPSIT-1 and HPSIT-3, respectively. Two PECCS lines connect the HPSIT-1 and HPSIT-3 to CL-1A and CL-2A, respectively, as presented in Fig. 2, which show the test configuration for the present test.

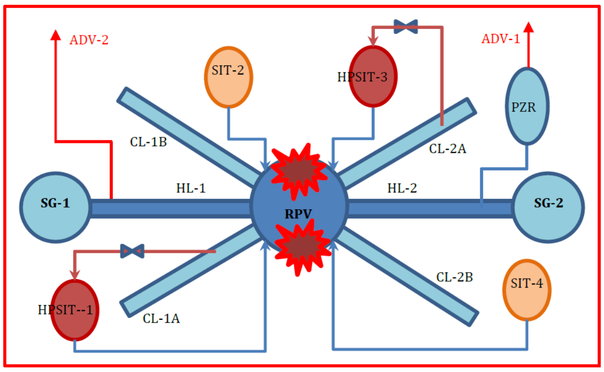

Fig. 1. Schematics of test configuration for the C2.1

Table I: Sequence of events observed in the test and post-calculation

Event	Time (in non-dimensional unit)		Description for Test
	Experiment	Post-test Calculation	
Test start (Break @ RPV top & Bottom)	0.108	0.108	2 inch x 2 EA RPV SBLOCA (Discharged to RWT1)
Pressurizer heater power termination	0.124	-	By water level interlock (LT-PZR-01 ≤ $WL_{minimum\_allowable}$)
Reaching saturated temperature condition of the primary system	0.130	0.130	Based on TF-UP-01 (refer to Fig. 7)
LPP signal	0.146	0.157	$P_{PZR} \leq 0.535$
SG 2nd system isolation	0.146	0.159	Main steam and feed valve closed
1st open of MSSV of SGs	0.148	0.162	Same set-point condition with APR1400
Core Power decay start	0.150	0.161	Start with scaled time delay
HPSIT-1 and HPSIT-3 open	0.156	0.178	$P_{PZR} \leq 0.500$
Loop seal clearing	0.571	Not observed	Occurred at IL-1B and IL-2B in C2.1
Start of 1st excursion of max. clad temperature	0.649	0.642	-
ADV1 open	0.670	0.671	$T_{max\_clad} \geq 0.543$
ADV2 open	0.675	0.693	$T_{max\_clad} \geq 0.589$ (Discharge to CDT)
SIT-2 and SIT-4 open	0.685	0.699	$P_{PZR} \leq 0.210$
SIT-2 and SIT-4 close	0.776	0.810	LT-SIT2/4-01 ≤ $WL_{minimum\_allowable}$
HPSIT-1 and HPSIT-3 close	0.830	0.795	LT-SIT1/3-01 ≤ $WL_{minimum\_allowable}$
Start of 2nd excursion of Clad temperature	0.901	0.880	-
Actuation of LTC injection	0.970	0.906	$P_{PZR} \leq 0.018$
Termination of test	0.991	-	TH-CO-G1/G2/G3-MAX ≥ $T_{max\_allowable\_clad}$

2.1 Test sequence

Transient of the C2.1 was initiated at 0.108 (hereafter all values mentioned in this paper is in non-dimensional form) as shown in Table I. Low pressurizer pressure (LPP) signal was issued at 0.146 by the lower pressure than 0.535 of pressurizer. The secondary system was isolated by LPP signal with the closing of valves including the feed water isolation valves and the main steam isolation valves. Due to the continuous heat transfer from the U-tubes, pressures of the secondary side of SGs gradually increased up to the opening set-point of the main steam safety valves (MSSVs).

The HPSIT-1 and HPSIT-3 were activated at 0.156 with opening of the injection line valves and the PECCS line valves. In this initial stage, actually no safety injections from the HPSITs were injected to the primary system due to a relatively small driving force between the HPSITs to the downcomer of RPV.The ADV1 was controlled to open with this set-point of the maximum clad temperature, and it opened at 0.670. The opening of the ADV1, however, seemed not enough for a steep depressurization of the primary system pressure. Increasing of the clad temperature was maintained up to 0.589 that actuated the opening of the ADV2.

With the opening of the ADV1 and ADV2, the safety injection flows from the HPSITs increased and finally resulted in a steep decrease of the primary pressure below 0.21, which is the actuation set-point of the two SITs. The actuation of the SIT-2 and SIT-4 was triggered at 0.685 by the condition of the lower pressurizer pressure than 0.21. After the termination of all safety injections, the maximum clad temperature increased again from 0.901. In the present test, the core power was controlled to terminate when the clad temperatures reached an allowable maximum clad temperature of 0.857. During the process of continuous depressurization of the primary system, LTCI was initiated when the pressurizer pressure decreased below than an equal to 0.018.

2.2 Post-calculation

A series of post-test calculations were performed using MARS-KS 1.4 code. In the calculations, core power was corrected to make an agreement with the actual applied core power during the C2.1 test. For the break valves installed at the upper and lower part of the RPV, discharging coefficients for the Henry-Fauske critical flow model were changed to investigate an effect of the discharging coefficient. Final selected discharging coefficient are 0.82 and 0.68 for the upper and lower break valves, respectively, even though the discharging coefficients used in the pre-test calculations were 0.62 for both break valves. Table I compares the sequence of event timing during the test and the post-test calculation.

3. Result comparisons between the test and post-calculation

Pressure trends of the primary and secondary system are compared in Fig. 2. The primary system pressure of the post-test calculation shows a slight delay in decreasing trend around 0.55. This delay is the main reason of the delayed issuing of the low pressurizer pressure (LPP) signal in the calculation. Water levels in the RPV are compared in Fig. 3. Even though, the core water level of the post-test calculation showed a slight recovery at around 0.586, loop seal clearance was not observed in the calculation. On the other hand, in the test, the loop seal clearance occurred in the intermediate leg (IL)-1B and IL-2B at around 0.571 as presented in the Table I and Fig. 4.

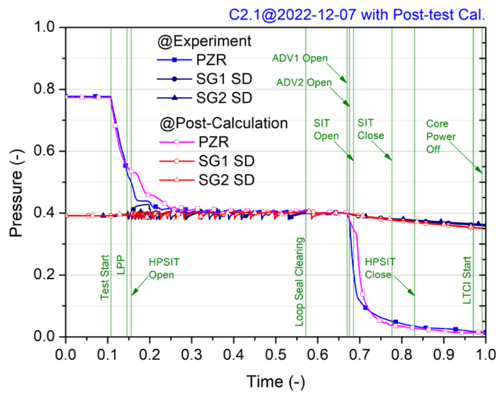

Fig. 2. Comparison of system pressure trends

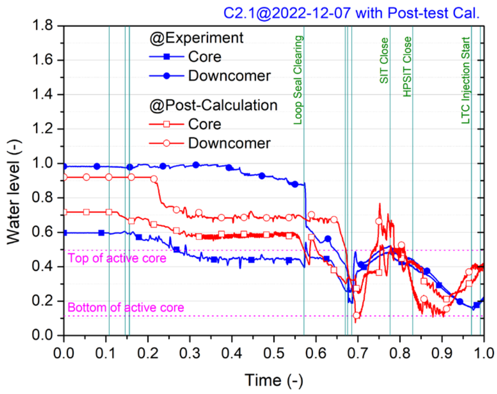

Fig. 3. Comparison of water levels in RPV

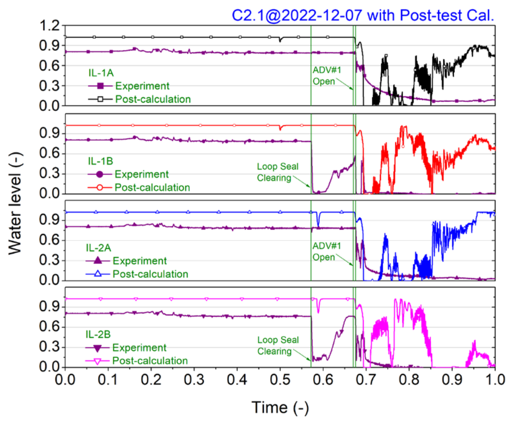

Fig. 4. Comparison of loop seal behavior in the intermediate legs

Injection flow rates from the HPSITs and SITs are presented in Fig. 5 and Fig. 6, respectively. Calculated flow rates and injection timings from these tanks showed a different trend from those of the test. As mentioned, the triggering point of the injection from HPSITs and SITs are closely related to the open timing of the ADV#1 and ADV#2. Flow rates of the long-term cooling injections can be observed in Fig. 7.

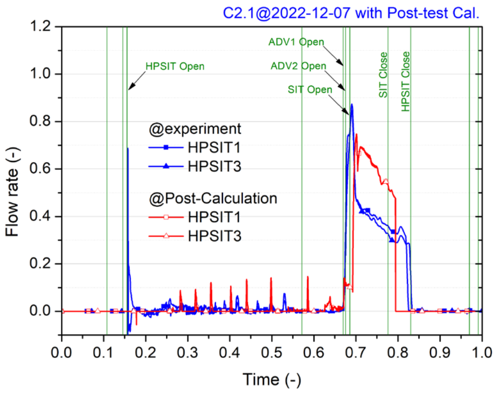

Fig. 5. Comparison of injection flow rate from HPSITs

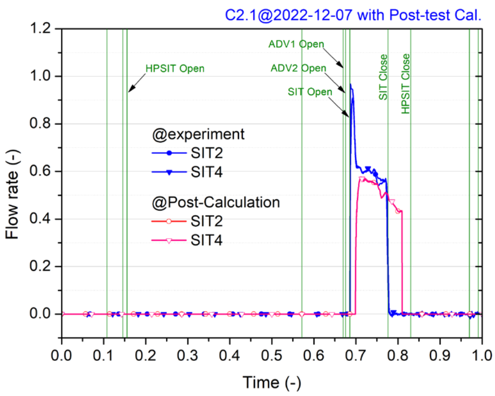

Fig. 6. Comparison of injection flow rate from SITs

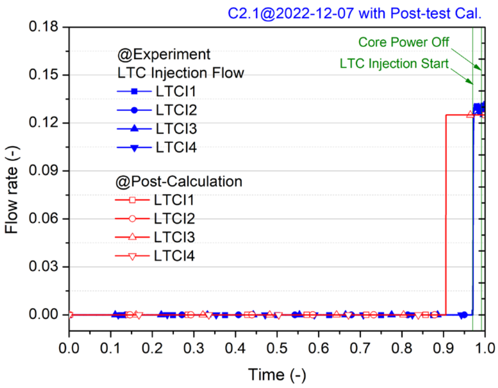

Fig. 7. Comparison of actuation timing and flow rate of LTCI

Finally, clad temperature behaviors were presented in Fig. 8. In the calculation, notwithstanding the test, increasing rate of the clad temperature slightly decreased after the opening of the ADV#1 at 0.671. Additionally, after the termination of the safety injection from HPSITs and SITs at 0.795 and 0.810, respectively, the core water level decreased suddenly below the top of active core level as indicated in Fig. 3. This relatively steeper decrease of the core water level in the calculation induced the relatively earlier clad temperature increase along with the earlier actuation of the LTCI.

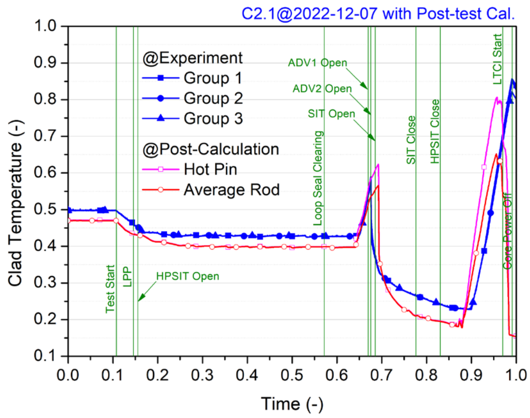

Fig. 8. Comparison of clad temperature trends

4. Conclusions

The post-test calculations were performed using MARS-KS 1.4 code. In the MARS code calculations, core power was corrected to make an agreement with the actual applied core power during the C2.1, and discharging coefficients of the Henry-Fauske critical flow model were changed.

In summary, the calculation results show a relatively nice agreement with those of the test. However, the injection durations of the HPSITs and SITs for the calculation are shorter than those of the test, which is one of the main reasons of the earlier clad temperature increase than that of the test. As presented in Table I, starting times of the 2nd excursion of clad temperatures in the test and post-test calculation are 0.901 and 0.880, respectively.

Acknowledgements

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Ministry of Science and ICT, Korea government (Grant No. RS-2022-00144111). In addition, the authors are grateful to all the participants for their support and contribution in the OECD-ATLAS3 international cooperation projects.

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[1] S. Cho, et al., "RPV Top and Bottom break SBLOCA with passive emergency core cooling system using ATLAS test facility," NURETH-20, 40704, American Nuclear Society (2023).