Summary of LBLOCA Reflood Tests by using the ATLAS

Hyun-Sik Park*, Ki-Yong Choi, Seok Cho, Kyoung-Ho Kang, Nam-Hyun Choi, Yeon-Sik Kim and Won-Pil Baek
Korea Atomic Energy Research Institute, 1045 Daedeokdaero, Yuseong, Daejeon, 305-600, Korea
**Corresponding author: hspark@kaeri.re.kr*

1. Introduction

The APR1400 has been developed by Korean industry. The most important safety issue of the APR1400 to obtain its license from the Korean regulatory organization is the thermal-hydraulics occurring in the downcomer region during the late reflood phase for a LBLOCA (Large-Break Loss of Coolant Accident). In particular, the downcomer boiling will degrade the core cooling capability and the direct ECC bypass can affect the core cooling behavior significantly. Therefore, the LBLOCA reflood tests were performed intensively in the first phase of the ATLAS program to resolve these issues.

2. ATLAS LBLOCA Reflood Tests

A set of LBLOCA reflood tests was performed and their main objectives were to identify the major thermal-hydraulic characteristics during the reflood phase of a LBLOCA for APR1400 by providing qualified data and to help validate the LBLOCA analysis methodology for APR1400 licensing.

The ATLAS LBLOCA reflood tests [1] could be divided into two phases (Phase-1 and Phase-2) according to the target period to be simulated. The Phase-1 tests were parametric effect tests for downcomer boiling in the late reflood phase of LBLOCA and the Phase-2 tests were integral effect tests for the entire reflood phase of LBLOCA. The experimental results from both Phase-1 and Phase-2 tests reproduced typical thermal-hydraulic trends expected to occur during the APR1400 LBLOCA scenario. A separate effect test was also performed under a low reflooding rate condition and its experimental results showed a gradual reflooding in the core and a cooling of the core heater rods and the reactor pressure vessel downcomer. Table I summarizes the test conditions for the major LBLOCA reflood tests by using the ATLAS.

During the LB-CL-05 test (Phase-1) the maximum surface temperature of 309^{o}C was observed and it was much lower than that predicted by the MARS code (792^{o}C). As shown in Fig. 1, the LB-CL-09 test showed the most conservative results and the LB-CL-14 test showed highly best-estimated results because it considered a radial power distribution and varying system pressure more realistically. Their rewetting velocities were 0.3, 0.87 and 1.11 cm/s for LB-CL-09, LB-CL-11, and LB-CL-14, respectively. During the LB-CL-15 test (SET) the maximum surface temperature of 584^{o}C was observed and the entire rewetting process was finished by about 306 s after the reflood start time.

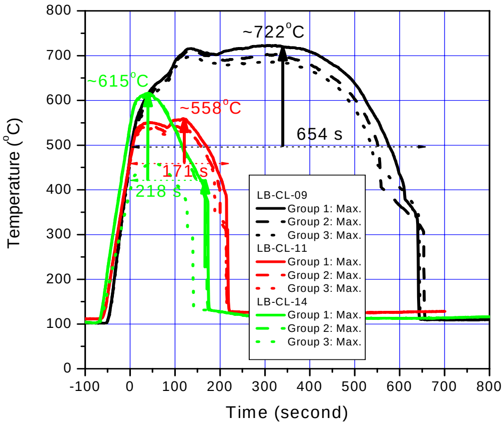

Fig. 1. Comparison of the maximum rod surface temperature between major Phase-2 tests

3. Major Thermal-Hydraulic Phenomena Found during the LBLOCA Reflood Tests

Four important thermal-hydraulic phenomena of downcomer boiling, steam binding, ECC bypass and core quenching were identified during a LBLOCA reflood test by using ATLAS [2]. Major finding are as follows.

It was shown from the scaling analysis that the present reflood test was performed in a condition that the scaled heat flux from the RPV wall of the ATLAS was higher than that for the APR1400 even though the initial value was matched. The downcomer boiling phenomena was observed in the lower part of downcomer, but its void fraction was smaller when compared with the RELAP5 simulation results. The direct ECC bypass was the dominant ECC bypass mechanism during the LB-CL-11 test, for example. The ECC bypass fractions fluctuated very much during the initial period, during which the sweep-out phenomena could be witnessed also. It was between 0.2 and 0.6 only by the direct ECC bypass during the later period of the LB-CL-11 test. Even though some characteristics of the steam binding phenomena were observed, its effects on the core cooling behavior were very little. Both bottom quenching and top quenching was observed for a radially uniform power profile during the LB-CL-11 test. Bottom quenching and top quenching occurred in homogeneous and inhomogeneous manners, respectively. The top quenching phenomena occurred more quickly in the center and middle regions than in the outer region in a radial direction due to the effects of accumulated water inventory in the upper plenum and core top.

Table I: Summary of the test conditions for the major LBLOCA reflood tests

Test ID	Part	LB-CL-05	LB-CL-09	LB-CL-11	LB-CL-14	LB-CL-15
Power (kW)	Core	715	1065	830.9	801.4	466.6
Pressure (MPa)	RPV DC	0.2~0.23	0.1	0.15~0.25	0.12~0.26	0.1
	SG steam	4.6~5.0	4.6~5.0	4.4~5.0	4.2~4.9	4.3~4.7
	CS	0.19~0.21	0.1~0.13	0.15~0.21	0.11~0.21	0.10~0.12
	SIT (init/reflood)	1.5/NA	4.3/2.4	4.3/2.35	4.3/2.6	Not used
ECC flow rate (kg/s)	SIT-High flow	2.94~3.58	2.94~3.58	2.41~3.53	2.60~3.76	0
	SIT-Low flow	0.81~1.04	0.81~1.04	0.79~1.13	0.66~1.09	0
	SIPs (100% & 80%)	0.30/0.34 (0.24/0.28)	0.32/0.30	0.30/0.31	0.33/0.32	0.29/0.31/ 0.30/0.31
Temperature (^{o}C)	RV DC wall	207 (160)	204	209	212	190
	SIT / RWT	80/53	53/53	50/50	55/55	Not used/50
	Heater rod surface	NA	465 (max.)	459 (max.)	546 (max.)	300 (max.)
level (m)	RPV-Initial	2.91	0.53	0.41	0.43	0.50

As shown in Fig. 2, the water levels both in the downcomer and the core increased abruptly and the subcooling degrees of the water inventory increased in the lower part of the downcomer and lower plenum as a result because the ECC injected from the SIT has a relatively high flow rate in the early stage of the reflood. However, with a decreasing SIT flow and the effect of a structural stored energy release, the subcooling degrees of the liquid decreased continuously and the void fraction near the cold leg increased. When the mixture level reaches the level within the critical void height, the sweep-out occurs and thus the break flow rate increases and the ECC bypass fraction increases very rapidly. When the fluid temperature in downcomer reaches a saturated condition due to the heat from downcomer wall, the collapsed water level decreases drastically around 1530s due to the significant sweep-out and increased direct ECC bypass. As shown in Fig. 2, the mixture water level is detected around cold leg elevation (LT-DC-05) until 1620s, and thus it was considered that the sweep-out occurs due to the higher mixture level. The effect of sweep-out could be excluded after that time. As the vessel wall was cooled down steadily and the core was fully quenched around 1650s, the sub-sectional collapsed levels increased steadily with some fluctuation after that. The measured void fraction in the lower downcomer region was relatively smaller than that estimated from RELAP5, which predicted an unrealistically higher void generation and magnified the downcomer boiling effect.

4. Conclusion

The ATLAS facility had provided the unique data peculiar to APR1400. The ATLAS reflood test program could be divided into two phases (Phase-1 and Phase-2) according to the target period to be simulated and a separate effect test was performed under a low reflooding rate condition. Four major phenomena of downcomer boiling, direct ECC bypass, steam binding and inhomogeneous top quenching were identified during the ATLAS LBLOCA reflood tests. As a future work, the ATLAS reflood tests could be analyzed by using a best-estimate system analysis codes to assess their reflood models and the assessed or revised codes could be used to help validate the LBLOCA licensing methodology.

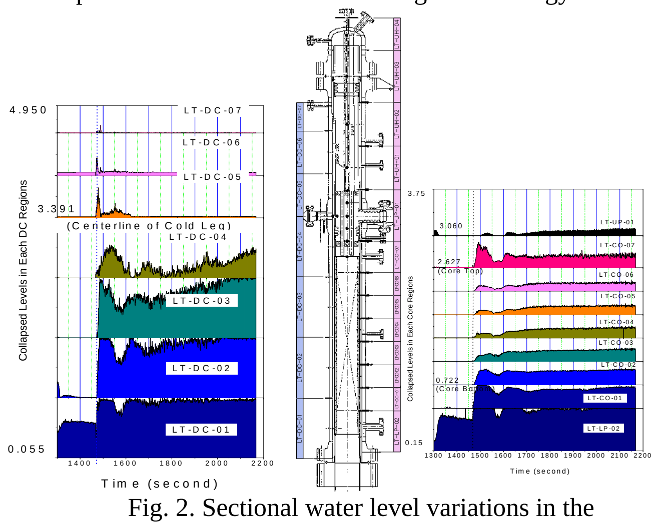

Fig. 2. Sectional water level variations in the downcomer and core regions during LB-CL-11

REFERENCES

[1] Park, H.S., et al., "Overview of the KAERI LBLOCA Reflood Test Program Using the ATLAS Facility," Proceedings of NUTHOS-7, Seoul, Korea, October 5-9 (2008).

[2] Park, H.S., et al., "Experimental Investigation on the Major Thermal-Hydraulic Phenomena during LBLOCA Reflood Phase for an Advanced Pressurized Water Reactor APR1400," Proceedings of NURETH-13, Kanazawa, Japan (2009).