Transactions of the Korean Nuclear Society Spring Meeting
PyeongChang, Korea, Oct. 30-31, 2008

Core Thermal Hydraulic Behavior during LB-CL-09 and LB-CL-15 of the ATLAS

Seok Cho*, Hyun-Sik Park, Ki-Yong Choi, Kyong-Ho Kang, Yeon-Sik Kim, Won-Pil Baek
Korea Atomic Energy Research Institute, (150-1 Deokjin-dong) 1045 Daedeokdaero, Yuseong, Daejeon, 305-353, Korea, Tel:+82-42-868-2719, Fax:+82-42-868-8362, E-mail:scho@kaeri.re.kr

1. Introduction

This paper presents experimental results of the ATLAS during a reflood phase of a LBLOCA test named as LB-CL-0 and LB-CL-15, and provides related technical descriptions from the view point of the system-core interactions on the thermal-hydraulic behavior in the core of the ATLAS. LB-CL-09 test is one of the integral-effect preformed by the ATLAS and LB-CL-15 case is the separate-effect test to investigate the thermal-hydraulic behavior during a reflood period, and to provide reliable data for validating the LBLOCA analysis methodology for the APR1400.

The initial and boundary conditions were obtained by applying scaling ratios to the MARS simulation results for the LBLOCA scenario of the APR1400. The ECC water flow rate from the safety injection tanks and the decay heat were simulated from the start of the reflood phase. This paper presents related experimental results for the ATLAS during the reflood phase of a LBLOCA test named as LB-CL-09 and LB-CL-15, and provides related technical descriptions from the view point of the system-core interactions on the thermal-hydraulic behavior in the core of the ATLAS facility.

2. Test Conditions and Procedure

Table 1 Summary of the major events for LB-CL-09 and LB-CL-15

Events	Time (LB-CL-09)	Time (LB-CL-15)	Description
Test Start	0	0	Data Recording Start
Heating End	1061	93	Core/RCP Trip, SS Isolation, Heater Power Off
Vent	1197	203	3 Vent Valves Open (RPV Top, 2 EA, PZR SDS line, 1 EA)
Drain	1534	505	P<3.0 MPa: FCV-BS-02 20% Open
	1585	563	P<2.5MPa: FCV-BS-02 40% Open
	1623	605	P<1.5MPa: FCV-BS-02 100% Open
BS Open	1677	665	P<1.5MPa: OV-BS-01 Open; OV-CL1A-01 Close; Tracing Off; Vent Valves Close
IL Drain	1700	675	Intermediate lines are emptied.
Power Restart	1855	1175	After achievement of ICs; 20s linear increase
SIT Injection	1910	NA	Max. T > 450°C (target: 456°C)
	1930	NA	SIT-High Flow (94% ~ 72%)
	2033	NA	SIT-Low Flow (72% ~ 47%)
Reflood Start	**1912**	**1245**	2.0 s after SIT Injection (for LB-CL-09), 2.0 s after SIP Injection (for LB-CL-15)
SIP Injection	1927	1243	12.7 s after Reflood Start (for LB-CL-09), 2.0 s before Reflood Start (for LB-CL-15)
Test End	2778.5	1805.5	DAS stop

Table 1 shows a sequence of events procedure for the related tests. The actual reflood phase was initiated at 1,912 and 1,245 second after the start of the data acquisition system (DAS) for LB-CL-09 and LB-CL-15, respectively. As can be observed in Table 1, the 'reflood start' event was preceded by several preparation procedures such as the 'vent' to de-pressurize the primary system and the 'drain' to evacuate the primary water inventory by an opening of the break simulating valves named as FCV-BS-01 and OV-BS-01 and the 'power restart' to heat up the cladding temperature and the 'SIT (or SIP) injection'. The water level was located at the lower plenum, which is just below the active core region, at the start of the reflood phase. In these procedures, the water level can be control by the drain valves at the RPV bottom and a fill pump. The core heater power was controlled to follow the specified decay heat, i.e.- 1.2 times of the ANS-73 and 1.02 times of the ANS-79 decay curve for LB-CL-09 and LB-CL-15, respectively.

3. Results and Discussions

A collapsed water level of the reactor core (LT-RPV-03) and the downcomer (LT-RPV-04A), and the corresponding quench front locations estimated by the quench time of the specified thermocouples embedded at the indicated elevations are shown in Figs. 1and 2 for LB-CL-09 and LB-CL-15, respectively.

With a starting of the SIT injection, for the case of LB-CL-09, the water levels of the core and the downcomer are increased rapidly. However, they are decreased with a decrease of the ECC flow rate and a spillover of the water inventory. After this level decreasing period, the water levels are increased steadily mainly due to the lowered downcomer wall temperature and a sufficient cooling capacity of the ECC water. For the case of LB-CL-15, however, the collapsed water level of the core and the downcomer are increased gradually without fluctuation due to low flow rate (about 1.2 kg/s) of the SIP injection.

The previous work of the authors [1] indicated that the dominant flow regime in a rod bundle geometry during a reflood phase can be identified by a comparison of the collapsed water level and the corresponding quench front locations as shown in Figs. 1 and 2. When the flooding rate is high (up to 0.15 m/sec), the dominant regime above the quench front is an inverted annular regime. In this regime, the rod is covered with a thin layer of vapor and the rest of the channel is filled with subcooled liquid. Therefore, in this regime, the collapsed water level is relatively higher than the quench front elevation [2] as can be seen in Fig. 1. When the inlet flow rate is lower (up to 0.0254 m/sec), the liquid reaches a saturation state quickly at or below the quench front and no subcooled inverted annular regime is observed. During the blowdown and reflood phases of the LOCA, the heat is transferred from the rod to a continuous vapor flow with dispersed droplets.

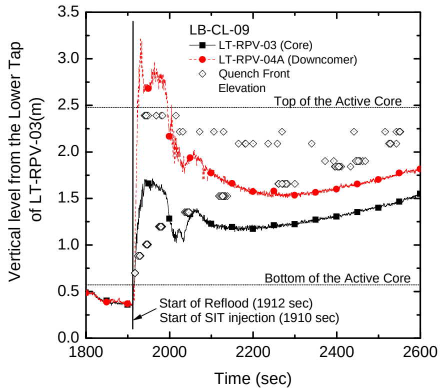

Fig. 1 Collapsed water level in the core and the downcomer with quench front behavior during LB-CL-15

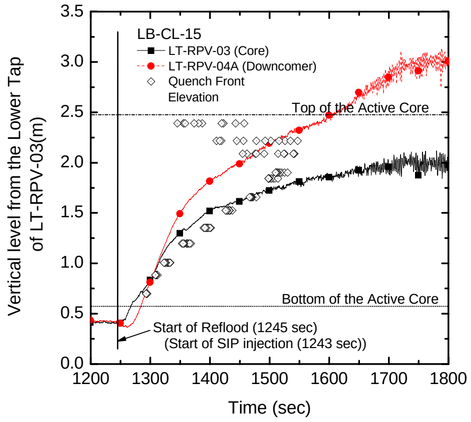

Fig. 1 Collapsed water level in the core and the downcomer with quench front behavior during LB-CL-09

From the observations of Figs. 1 and 2 and the descriptions above, the qualitative thermal-hydraulic behavior in the core during the reflood phase could be understood. As can be seen in Fig. 1 for LB-CL-09, in a lower third part of the active core, the inverted annular flow regime is dominant. In the middle third part, the quench front level is always higher than the collapsed water level. In the upper third part, a top-flooding due to a condensation of the steam and the de-entrainment of droplet is governed the quenching phenomena. For LB-CL-15 shown in Fig. 2, the inverted annular flow regime is dominant in a lower half part of the active core. In the upper half part, the quench front level is always higher than the collapsed water level, which means the two-phase-mixture level is always higher than the collapsed water level and a top-flooding due to a condensation of the steam and the de-entrainment of droplet is governed the quenching phenomena.

Figs. 3 and 4 show measured and calculated gravity head difference between the core and the downcomer. The positive differential means upper head pressure is higher than that of the downcomer. As can be observed in these figures, the differencial pressure behavior is closely related with safety injection flow rate. For large amount of SIT flow as the case of LB-CL-09, the downcomer pressure shows a sudden and faster decrease than the core pressure due to the effect of rapid condensation of steam in the downcomer caused by direct contact condensation with a large amount of safety injection water. For the case of LB-CL-15, small SI flow condition, the downcomer pressure shows a slightly larger increase than the core pressure due to the effect of evaporation of safety injection water caused by heating from a stored heat releasing of downcomer wall.

3. Conclusions

This paper presents and discusses the experimental test results of the integral-effect test (LB-CL-09) and the separated-effect test (LB-CL-15) of the ATLAS. During the reflood phase, the SI flow rate has a significant effect on the thermal hydraulic behavior at the core and the downcomer.

REFERENCES

1] S. Cho et al., “ Rewetting of a vertical hot surface of a simulated 6x6 rod bundle during a reflood phase,” NTHAS5: Fifth Korea-Japan Symposium on Nuclear Thermal Hydraulic and Safety, Jeju, Korea, Nov., 2006.

2] K.H. Sun, R.B. Duffey and C.M. Peng, “The prediction of two-phase mixture level and hydro-dynamically controlled dryout under low flow conditions,” Int. J. Multiphase Flow, 7(6), 521, 1981.

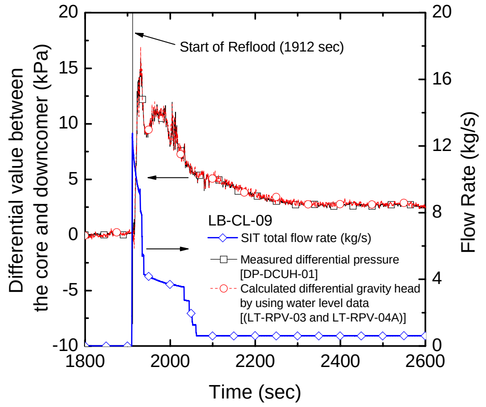

Fig. 3 Pressure difference between the core and the downcomer compared with hydrostatic head of collapsed water level during LB-CL-15

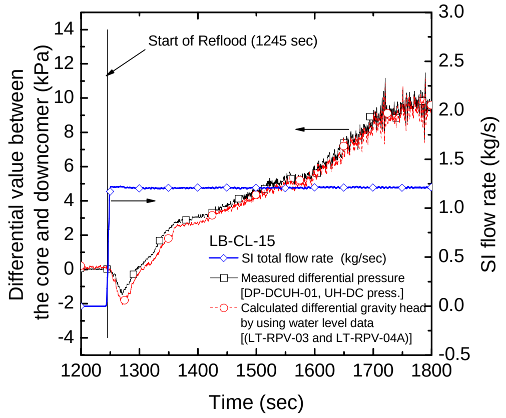

Fig. 4 Pressure difference between the core and the downcomer compared with hydrostatic head of collapsed water level during LB-CL-09