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An Investigation of Loop Seal Clearings in ATLAS SBLOCA Tests

Yeon-Sik Kim*, Seok Cho, Kyoung-Ho Kang, Hyun-Sik Park, Kyeong-Ho Min, Nam-Hyeon Choi, Jong-Gook Park, Bok-Deuk Kim, and Ki-Yong Choi

Thermal Hydraulics Safety Research Division,
Korea Atomic Energy Research Institute, Daejeon, Korea
*Corresponding author:yskim3@kaeri.re.kr

1. Introduction

KAERI (Korea Atomic Energy Research Institute) has been operating an integral effect test facility, ATLAS (Advanced Thermal-Hydraulic Test Loop for Accident Simulation), for accident simulations pertaining to an OPR1000 (Optimized Power Reactor, 1000MWe) and APR1400 (Advanced Power Reactor, 1400MWe), which are in operation and under construction in Korea, respectively [1,2].

In general, a typical sequence of events (SOEs) of the small-break loss-of-coolant accidents (SBLOCAs) in pressurized water reactors (PWRs) consists of five phases: a blowdown, natural circulation or pressure plateau, loop seal clearance, boil-off, and core recovery [3]. The duration of each phase depends on the break size and performance of the emergency core cooling system (ECCS). Among the five phases, the loop seal clearing in SBLOCAs is an important phenomenon that governs the whole thermal-hydraulic behavior of the primary system.

In the APR1400 design, four intermediate legs (ILs) or cross over legs (COLs) exist between the two SGs and four RCPs. Various kinds of SBLOCAs at the direct vessel injection (DVI) line or cold leg (CL) line breaks were performed. Generally, in early phases in most of the SBLOCA cases, the pressure of the upper-head region will increase mainly owing to the accumulated steam and water inventory in the upper-plenum. This build-up pressure acts as a suppression force to the core water level, and resultantly the core water level will decrease possibly up to and/or below the top of the active core region. Simultaneously, the downcomer water level will increase owing to the evacuated water inventory from the lower part of the core region. This unbalanced hydro-static pressure between the core and downcomer region acts as a potential pushing force to the reactor coolant pump (RCP) side intermediate leg. The potential pushing force will be increased with time to overcome the hydro-static head in the upflow intermediate leg. The unbalanced hydro-static pressure can finally be dissolved with the occurrence of the loop seal clearing. A minimum core collapsed water level, located below the elevation of the loop seal bottom leg in the ATLAS tests, is taken at this time. Since the loop seal bottom leg is located below the core top for typical PWR plants such as an APR1400, the water level depression may uncover the core upper regions until the core water level recovers with the progress of the clearing of the loop seal upflow leg. At this moment, the core temperature may increase to a peak cladding temperature (PCT) owing to an excessive core uncovery by the minimum core collapsed water level. Therefore, the loop seal clearing phenomenon is very important with respect to the PCT occurrence, which is one of the most important parameters to insure the safety of the reactor system.

The loop seal clearing behavior seems to be closely related to the break location and break size. Usually, a loop seal in the break loop is cleared first, and the number of loop seal clearings is dependent on the break size. The larger the break size, the more the loop seals that are cleared.

2. Results

2.1 Overview of the SBLOCA Tests

Various kinds of SBLOCA tests were conducted with the ATLAS test facility, e.g., DVI line breaks and CL breaks. Most of the tests show the typical SOEs of the SBLOCAs: a blowdown, pressure plateau, loop seal clearing, boil-off, and core recovery, as shown in Fig. 1, which represents the PZR pressure of a 50% DVI line break test. As shown in Fig. 1, LSC has a duration time from beginning to end, e.g., 190s and 197s in the 50% DVI line break, respectively. In most tests, each LSC had its own duration time of 7-10 seconds and there was no difference between the DVI line and CL breaks. The core level reached a minimum level at around the beginning of the loop seal clearing, whose level was about 0.53m below the bottom of the COL. At this moment, a PCT occurred. After the loop seal clearing, the core level recovered above the bottom of the COL with an abrupt level drop in the downcomer (DC) region. After the SIT injection, the DC water level started to increase apparently, and the core recovery was very slow.

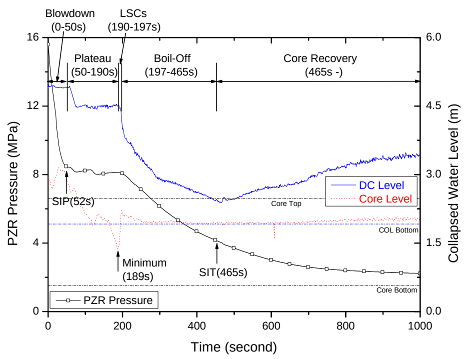

Fig. 1 SOE of 50% DVI line break (SB-DVI-09)

2.2 Summary of LSCs in the SBLOCA Tests

As mentioned above, the loop seal clearing behavior was supposed to be closely related to the break location and the break size. From the various kinds of SBLOCA tests including DVI line breaks and CL breaks with the DVI injection for the emergency core cooling water, a loop seal in the broken loop was cleared first, and the number of loop seal clearings was dependent on the break size. The larger the break size was, the more the loop seals were cleared. A summary of LSCs in the ATLAS SBLOCA tests is shown in Table 1.

Table 1. Summary of LSCs in the SBLOCA Tests

Test ID	Break Size[a]	Location of LSC	Remark
SB-DVI-06	5%(3.41mm)	IL-1B/-1B	LS Refill
SB-DVI-05	25%(7.63mm)	IL-1B/-1A/-2B	
SB-DVI-09	50%(10.8mm)	IL-1B/-1A/-2B	ISP-50
SB-DVI-08	100%(15.13mm)	IL-1B/-1A/-2B/-2A	DSP-01
SB-DVI-07	50%(10.8mm)	IL-1B/-1A/-2B	DVI-09 Repeat
SB-CL-07	2”(3.56mm)	NO	
SB-CL-05	4”(7.12mm)	IL-1A/-2B	
SB-CL-09	6”(10.68mm)	IL-1A/-2B	DSP-02
SB-CL-04	8.5”(15.13mm)	IL-1A/-2B/-2A	
SB-CL-08	6”(10.68mm)	IL-2B/-2A/-1A	CLI
SB-CL-02	6”(10.68mm)	IL-1A/-2A/-2B	No Bypass
SB-CL-01	4”(7.12mm)	IL-1A	CL-05 Repeat
SB-CL-06	6”(10.68mm)	IL-1A/-2B	50% DVI CPT

Note, a: APR1400 break size (ATLAS break nozzle)

From the view point of the location of LSCs, the test results showed a consistent behavior. Although the number of LSCs was depent upon the break size, the sequence of LSC locations in the DVI line and CL breaks showed sequent orders, as shown in Figs. 2 and 3.

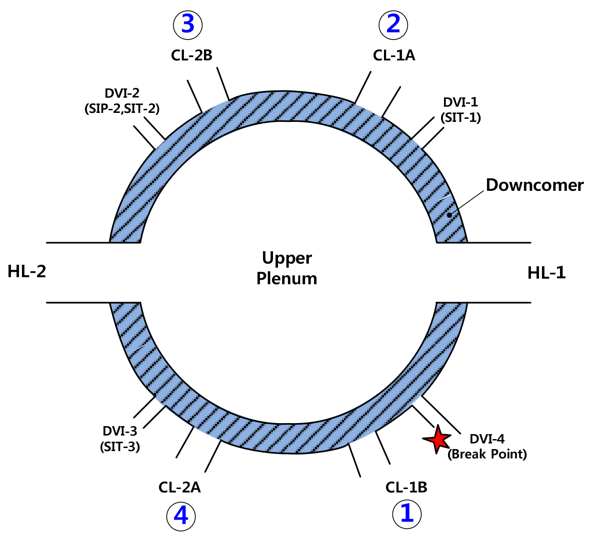

Fig. 2 Sequence of LSC in DVI Line SBLOCAs

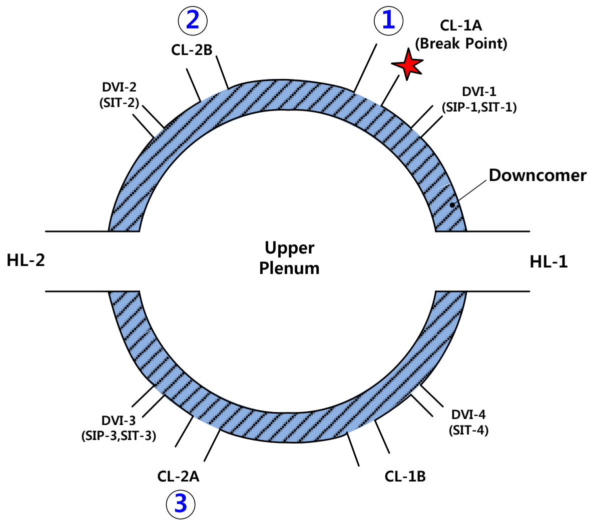

Fig. 3 Sequence of LSC in CL Break SBLOCAs

It is notewrothy here that a loop seal refilling occurred only in the SB-DVI-06 test, whose break size is very small compared to the others, e.g., a 5% DVI line break. Also, there was no LSC in SB-CL-07, whose break size is equivalent to that of SB-DVI-06.

2.3 CCFL Evautions

In a physical sense, the loop seal clearing can be interpreted using a counter current flooding limit (CCFL) suggested by Wallis [4]. A separate calculation for a dimenstionless diameter (D^*) and Kutateladze number (Ku) at the LSCs in the ATLAS SBLOCA tests showed 32-44 and 1.7-7.1, respectively. Although there were some cases not satisfing the Kutateladze criteria for flooding, LSCs occurred and sustained their clearances in all tests.

3. Conclusions

An investigation of LSC in the SBLOCA for DVI line and CL breaks were performed. The loop seal clearing behavior appeared to be closely related to the break location and break size. In general, a loop seal in the break loop is cleared first, and the number of loop seal clearings is dependent on the break size. The larger the break size is, the more the loop seals are cleared. Finally, a separate evaluation was performed for the CCFL condition.

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