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A Review of Loop Seal Clearing in ATLAS Facility

Yeon-Sik Kim* and Kyoung-Ho Kang

Thermal Hydraulics Safety Research Division, Korea Atomic Energy Research Institute
111, Daedeok-Daero 989 Beon-Gil, Yuseong-Gu, Daejeon, 34057, Korea
**Corresponding author: yskim3@kaeri.re.kr*

1. Introduction

Loop seal clearing (LSC) behavior was investigated for small-break loss-of-coolant accident (SBLOCA) and station blackout (SBO)-related tests in the Advanced Thermal-Hydraulic Test Loop for Accident Simulation (ATLAS) facility. Major characteristics of LSC behavior between two scenarios were identified and summarized. In SBLOCA tests, the first LSC provided an instant event connecting the pressure plateau phase to the boil-off phase, and tended to induce a resultant peak cladding temperature (PCT) for larger break sizes. Every LSC induced an intermittent inventory redistribution between the downcomer (DC) and the core. In SBO-related tests, most LSCs occurred under a nearly stagnant or even reverse loop flow condition, especially in the hot legs, and showed little effect on PCT occurrence. After LSC, water level changes in the core and loop seals showed synchronizing trends but opposite directions. LSC also induced mass transfer between the DC and core. And a visual observation on the sequence of an LSC was discussed.

2. Overview of the ATLAS facility

2.1. The loop seal arrangement/clearing in previous ATLAS tests

ATLAS is a large-scale thermal-hydraulic integral effect test facility for advanced PWRs such as APR1400 and OPR1000. It can simulate a wide range of accident and transient conditions including a station blackout. The scaling ratios of some major geometrical and thermal-hydraulic parameters between the ATLAS and APR1400 are summarized in Table 1, and a more detailed discussion of the ATLAS scaling principles can be found in Kim et al. [1].

Fig. 1 shows a conceptual arrangement for one of four loop seals around the downcomer and active core of the ATLAS facility. As shown in the figure, a loop seal consists of a downward pipe from the SG, a horizontal part, and an upward pipe to the reactor coolant pump. (Here, the direction of a pipe is defined in accordance with normal flow direction.) A typical clearing sequence of LSC starts from the clearance of the downward pipe, moving to the horizontal part, and then to the upward pipe. It is well known that LSC tends to affect core water level, such as by compressing the core mixture level, to compensate for the concurrent manometric liquid level differences between the loop seal and the core. Thus, core mixture level is hardly affected by the clearance of the first two regions, that is, the downward pipe and the horizontal part, and it is mainly affected by the clearance of the upward pipe. In this respect, the horizontal part in a loop seal provides a reference point for manometric level differences of the loop seal and core. (It is understood that an occurrence of LSC is hardly related to a counter-current flow limit (CCFL) condition, but a CCFL condition should be satisfied at the upward pipe for its sustenance after the LSC. However, in this study, occurrence behavior of LSC was mainly focused upon.) From a previous study by one of the authors of this paper (Kim and Cho, 2014), every LSC seemed to occur with a duration time, which was obtained by a manipulation of each collapsed water level in loop seals. In most SBLOCA tests for cold leg (CL) pipe and direct vessel injection (DVI) line breaks, every LSC had a duration time of 6-11 s, and there was no difference between two kinds of SBLOCA tests.

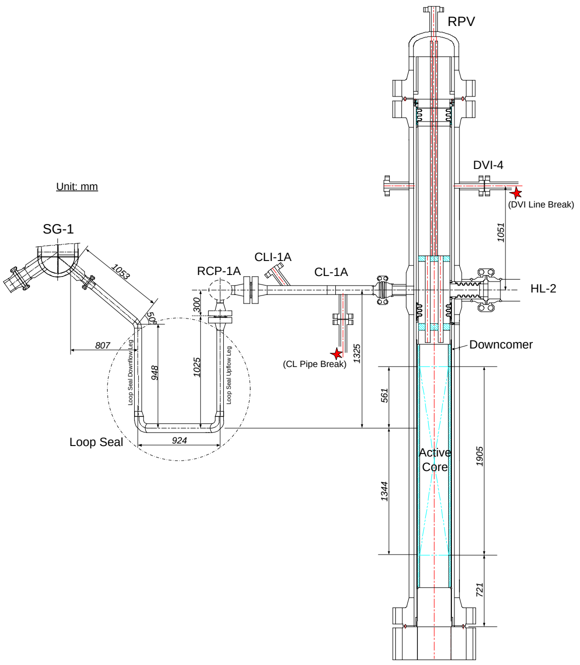

Fig. 1 Schematic arrangement of loop seal in ATLAS facility

2.2 Overview of the SBLOCA and SBO-related tests

Various kinds of SBLOCA tests were performed in ATLAS, including CL pipe break, DVI line break, pressurizer (PZR) surge line break, and RPV-top break, among others, as shown in Fig. 2. Intermediate-break LOCA (IBLOCA) tests have also recently been performed to address safety issues of the IBLOCA (Kang et al., 2018). In ATLAS tests, there are two options for emergency core cooling water (ECCW) injection (CL injection and DVI), but most of the SBLOCA and IBLOCA tests adopted DVI, which is the ECCW injection concept of the APR1400. It is noteworthy that all excursions of heater rod temperature or PCTs in larger SBLOCA and IBLOCA tests occurred during the duration time of the first LSC. This can be understood as the core mixture level being pushed downward faster to compensate for a manometric force between the loop seal and the core, and that this seemed to induce such excursions of PCT.

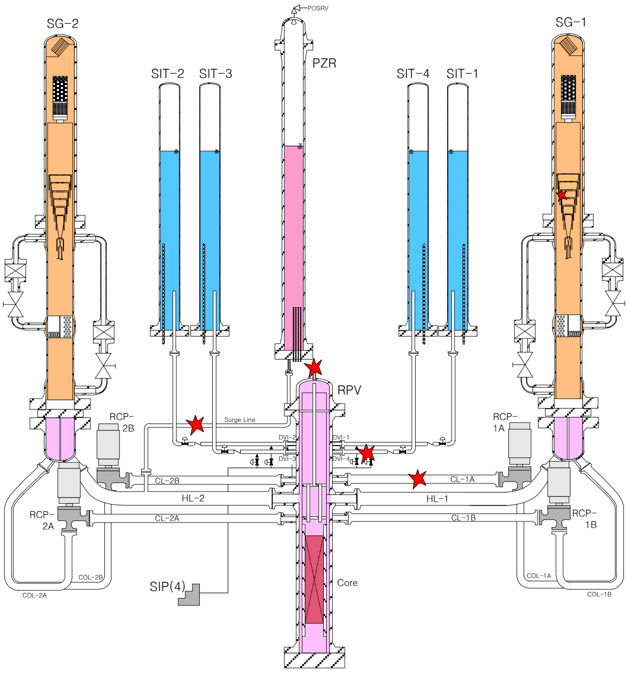

Fig. 2 Break locations for SBLOCA and SBO-related tests in ATLAS facility

For SBO-related tests, we considered a conventional SBO test, an SBO concurrent with steam generator tube rupture (SGTR) (SBO+SGTR), and an SBO with hybrid safety injection tanks (HSITs) (SBO+HSIT). The tests commenced with the assumption that the loss of on-site and off-site power occurred simultaneously with the failure of the emergency diesel generators and the auxiliary feedwater system including turbine-driven pumps. It is noted that an HSIT has dual functions, one for the core makeup tank (CMT) and the other for the accumulator. In the SBO+HSIT test, a passive core makeup function with the HSITs during an SBO test was performed (Kang et al., 2018). In SBO-related tests, there seemed to be little relation between occurrences of LSCs and excursions of PCT.

3. Overview of LSC behavior

3.1 LSC behavior in SBLOCA and IBLOCA tests

From SBLOCA tests, each LSC is triggered by a differential pressure (DP) between the core and the DC, which tends to be dependent on the manometric force between the bottom of the loop seal (or cross-over-leg (COL)) and the core or DC water level. In Fig. 3, a comparison of DP between upper head (UH) and DC to the core water level difference with respect to the loop seal bottom is depicted, and in Fig. 4, to the DC water level difference, respectively. (Figures with percentage and inch for all open symbols in Figs. 3 and 4 represent equivalent percentages of the DVI line break or break sizes of the CL pipe break of the APR1400.) From a manometric point of view, there was a negative proportion between the DP values and core water level, but a positive proportion between the DP values and DC water level, as shown in the figures. Most PCTs occurred at larger break sizes, which induce higher DP values, lower core water levels, and higher DC levels, as represented by dotted ellipsoids in the figures.

As noted in a previous study [2], there appeared respective consistencies in the locational sequence of LSCs for CL pipe and DVI line SBLOCAs, as shown in Fig. 5. Similar consistencies were also found for IBLOCA tests. It is noted that a different sequence appeared in RPV-Top and PZR-SL break tests, e.g., 1st LSC at COL-1A and 2nd one at COL-2A for the two scenarios.

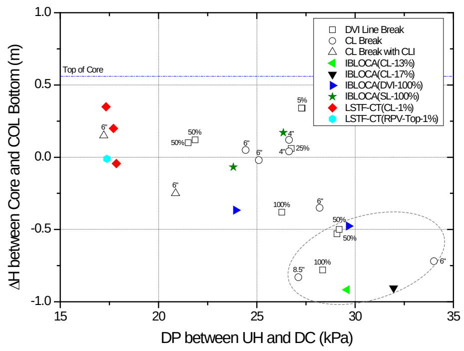

Fig. 3 Comparison of pressure difference (UH-DC) vs. water level difference (Core-COL)

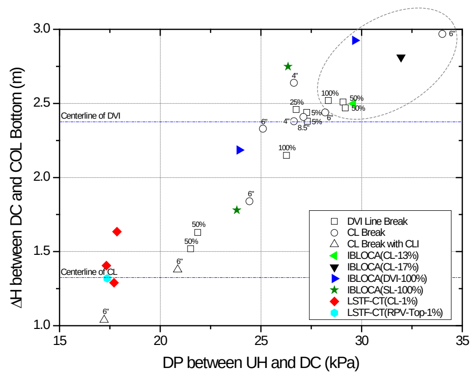

Fig. 4 Comparison of pressure difference (UH-DC) vs. water level difference (DC-COL)

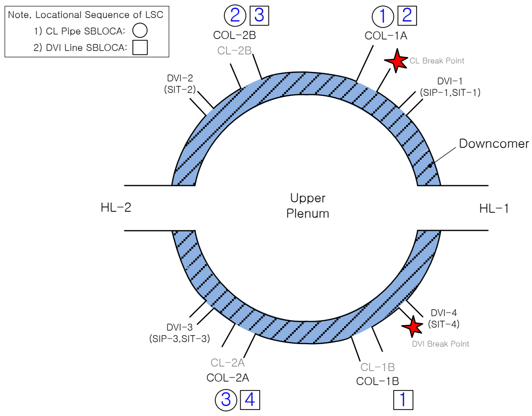

Fig. 5 Sequence of LSCs in CL pipe and DVI line SBLOCAs

3. Conclusions

LSC behavior in SBLOCA and SBO-related tests was examined. In SBLOCA tests, the first LSC provided an instant event connecting the pressure plateau phase to the boil-off phase. Every LSC induced respective inventory redistribution between the DC and core in an RPV. A maximum DP value appeared at the start of the first LSC and pushed the core water level down to the minimum, which induced a resultant PCT, especially for larger break sizes. From a manometric point of view, DC water level is proportional to the DP values between the core and the DC, but core water level is inversely proportional to the DP Values. In SBO-related tests, most LSCs occurred under a nearly stagnant or even reverse loop flow condition, especially in hot legs, and showed little effect on PCT occurrence. As a result, LSC also induced mass transfer between the DC and the core in an RPV. From a manometric aspect, similar trends were found, but DC water levels maintained higher values compared to SBLOCA tests. After an LSC occurrence, water level changes of the core and loop seals showed synchronizing trends but opposite directions.

From a comparison of loop seal behavior between the SBLOCA and SBO-related tests, a noticeable finding was a different behavior in DC water levels. In SBO-related test, there were little loop flows and thus, the pressure difference between the core and DC was totally exerted to the level difference between the core and DC and as a result, higher DC water levels appeared compared to the SBLOCA cases.

Finally, from a visual observations, a sequence of an LSC looks alike a combination of vertical upward and horizontal flow pattern changes. Two times of flow pattern changes occurred in the horizontal pipe, e.g., stratified flow → wavy flow → annular flow, and three times of changes, in the vertical pipe, e.g., bubbly flow → slug flow → churn flow → annular flow.

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