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A Comparison of SBLOCA Tests in SMART-ITL Facility

Yeon-Sik Kim*, Hwang Bae, Byong-Guk Jeon, Yoon-Gon Bang, and Hyun-Sik Park

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

The Korea Atomic Energy Research Institute (KAERI) launched a project to develop a small modular reactor (SMR) in 1997 and developed an integral type PWR with a rated thermal power of 330MWt (electric power of 100MWe), called a SMART. For the overall philosophy of the SMART reactor development, KAERI [1] can be referenced.

The single reactor pressure vessel contains all primary components such as the reactor core, steam generators, reactor coolant pumps, and a pressurizer, as shown in Fig. 1. This integral arrangement of the reactor vessel assembly makes it possible to remove the large-sized pipe connections between major components, thus essentially preventing the occurrence of large break loss of coolant accidents (LBLOCAs). The in-vessel pressurizer was designed to control the system pressure at a nearly constant level over the entire range of performance design basis events.

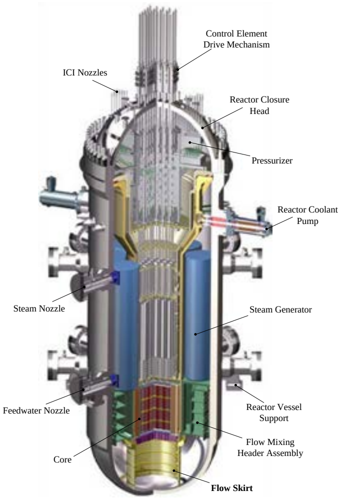


Fig. 1 Configuration of the SMART reactor

There are several safety systems simulated in SMART-ITL, as summarized in Table 1. As shown in Fig. 2, each train of the PRHRS consists of one emergency cooling tank (ECT), one ECT heat exchanger (HX), an isolation valve, and connected lines to the secondary side of each SG. In SMART, a total of four SGs were equipped in the RV and thus there are four trains in the PRHRS. For the PSIS, each train of the PSIS consists of one CMT, one SIT, and pressure balance lines (PBLs), which connect between the RV's upper down comer (UDC) and the top of the CMT or SIT. Through the PBLs, the RV pressure is transferred to the top of each tank. Normally, the CMT and SIT are full of emergency core cooling (ECC) water, and the PBL for the CMT is also full of water, but that for the SIT is half-full of water. In addition, the PBL for the CMT is normally opened, and that for the SIT is kept closed by an isolation valve in the line. Thus, the CMT is under normal pressure of the RV, but the SIT is under atmospheric pressure. The SI injection line of the CMT and SIT is isolated by one isolation valve, which is opened by the CMT actuation signal (CMTAS). The SIT discharge line is normally isolated by a check valve from the SI injection line. In the case of the SIT actuation signal (SITAS), it opens the isolation valve in the PBL to equalize the SIT pressure with the RV pressure, which facilitates the SIT injection to the RV.

Table 1. Summary of safety systems simulated in the SMART-ITL facility

System	No. of Train	Major Component's Number/Train
PRHRS	4	Emergency Cooldown Tank (ECT) 1EA
		ECT Heat Exchanger (HX) 1EA
SIS	4	Safety Injection Pump (SIP) 1EA
		Refueling Water Tank (RWT), Common
PSIS	4	Core makeup Tank (CMT) 1EA
		Safety Injection Tank (SIT) 1EA
ADS	2	ADS Valve 1EA

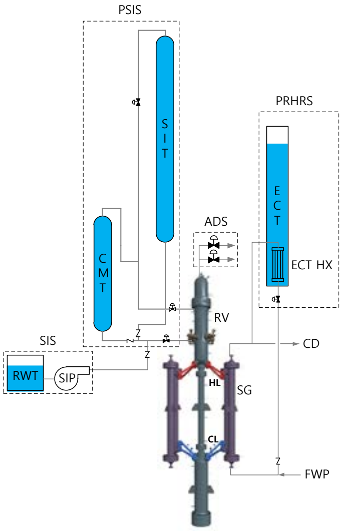


Fig. 2 Schematic diagrams of safety systems simulated in the SMART-ITL facility

It should be noted that there were no connecting pipes between the SGs and RV in the SMART plant. However, in SMART-ITL, scaling law requires separate connecting pipes between the SGs and RV. The connecting pipes between the UDC of the RV and SGs are called hot legs (HLs), and those between the LDC of the RV and SGs are called cold legs (CLs), as also shown in Fig. 2.

In SBLOCA scenarios, possible break locations in SMART plant would be a safety injection line, shutdown cooling line, automatic depressurization system line, PZR safety valve line, etc. The largest line size connected to the SMART's RV is 2 in. and thus the possible largest SBLOCA in the SMART plant is a 2 in. break. In the SMART-ITL, a break nozzle of 7.26 mm in inner diameter was used to simulate 2 in. SBLOCAs of the SMART plant. In this paper, two typical breaks, i.e., a PZR safety valve line and one of the safety injection line breaks, were selected for an investigation of the thermal hydraulic behavior in the SMART-ITL during the SBLOCA scenarios. The arrangements of the safety systems for the selected SBLOCA scenarios are summarized in Table 2.

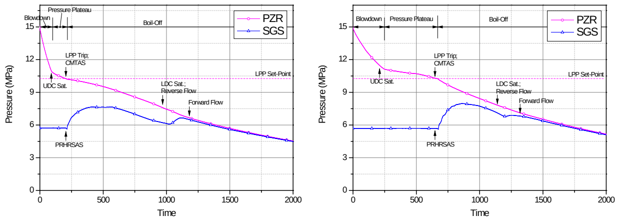
Table 2. Summary of safety system arrangements for the two selected scenarios.

Scenario	Break Location/Size	Safety System Arrangement
PSV Line Break	PSV Discharge Line/2″	- No SIS - Four-Train PSIS - Four-Train PRHRS - Two ADS Stages
SI Line Break	SI (No.4) Injection Line/2″	- No SIS - Three-Train PSIS - Four-Train PRHRS - Two ADS Stages

2. Thermal Hydraulic Behavior of SBLOCA Tests

2.1 Typical sequential phases of SBLOCA tests

A comparison of the initially sequential phases in SBLOCA tests for the PSV line and SI line breaks is shown in Fig. 3. As can be seen in the figure, the overall behavior of the PZR pressure corresponding to sequential phases appeared to be more reasonable in the case of an SI line break. In the SMART-ITL tests, there was no core uncovery for any 2" SBLOCA tests owing to a combination both effects of a relatively small break size and large amount of primary inventory. The blowdown period appeared until the point of saturation in the UDC region after a break. In addition, the pressure plateau extended to the LPP trip point, when the reactor and RCP trips and CMTAS were triggered. During the pressure plateau, although all RCPs were running, a mass transfer occurred from both the RV-Outer1 and Outer2 regions to the RV-Inner one. The boil-off period extended to a point, where the core level started to increase. After this point, the long term cooling period extended to the end of the test. During the boil-off period in the SMART-ITL test, there was a short flow reversal phenomenon from the LDC to the primary side of the SG (SGP) owing to the occurrence of vaporization in the LDC region, where its inventory becomes saturated according to the depressurization of the RV. The flow reversal period was sustained for about 200 s for both tests. As a result, sequential phases of SBLOCAs in SMART-ITL can be identified as four phases, i.e., a blowdown to the UDC saturation, a pressure plateau under forced circulation, a boil-off after an RCP trip, and core level restoration after SIT injection or long-term cooling. The core level restoration after SIT injection occurred at around 10800 s after the break in the PSV line break and at around 6000 s for the SI line break.



(a) PSV line break (b) SI line break

Fig. 3 Comparison of sequential phases between PSV and SI line breaks

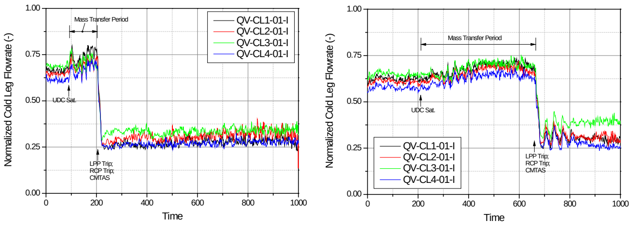
Here, a further discussion on the pressure plateau would be informative. In conventional PWRs, the PZR pressure of the pressure plateau is deeply dependent on the SG pressure and a LSC provides a trigger for a transition from the pressure plateau to the boil-off phases. However, in the SMART plant, the PZR pressure of the pressure plateau seemed deeply dependent on the UDC temperature, and an LPP trip seemed to provide a trigger for a transition between the pressure plateau and boil-off phases. In the conventional PWRs, the U-tube SG has quite a large amount of secondary inventory, and this provides a higher temperature of the heat sink in the pressure plateau phase. However, in the SMART plant, the helical-tube SG has less amount of secondary inventory, and this seemed to not provide an effective higher temperature of a heat sink. This can be also confirmed in two tests of Fig. 3, where the PZR pressure seemed independent on the secondary pressure in the pressure plateau phase.

2.2 Mass transfers among RV regions during pressure plateau

Until the LPP set-point, the primary system is under forced circulation by four RCPs, and thus the flowrates at the CLs maintained normal values. However, the measured flowrates at four CLs in the SMART-ITL showed abruptly or gradually increasing trends after the UDC saturation, as shown in Fig. 4. (Hereinafter, measured data are presented by normalized values for all the figures.) This means that an additional flow was added to the RCP flowrates. Every CL flowmeter measured the coolant flowrate from the connected SG to

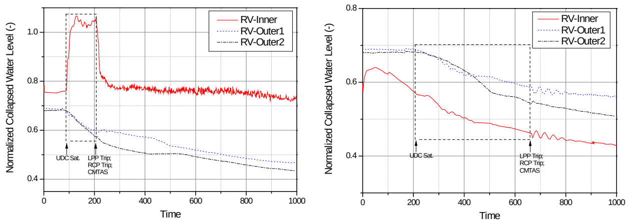
LDC, and thus the increasing flowrate at the CL means that an additional flow occurred from the RV-Outer2 to RV-Inner regions. In this respect, the trends of the CL flowrates provided evidence for a mass transfer phenomenon between the RV-Outer 2 and RV-inner regions just after the UDC saturation.

If there are mass transfers between or among RV regions, trends of collapsed water levels for three regions also showed reasonable behavior corresponding to mass transfers. Fig. 5 shows the trends of the collapsed water levels in the three RV regions for the two tests. As noted by the dashed boxes in the figure, the collapsed water level of RV-Outer1 showed a similar trend with that of RV-Outer2, which means that there is an inventory decrease in the RV-Outer1 region, as well. Actually, RCPs are still running during the mass transfer period, and thus quite a large amount of coolant was transferred from the RV-Outer1 to RV-Outer2 regions. In this respect, the measured increasing flowrates at the CLs also included mass transfers between two regions, e.g., RV-Outer1 and Outer2. As a result, there were dominant mass transfers from the RV-Outer1 and Outer2 to RV-Inner regions after the UDC saturation.



(a) PSV line break (b) SI line break

Fig. 4 Comparison of cold leg flowrates between PSV and SI line breaks



(a) PSV line break (b) SI line break

Fig. 5 Comparison of collapsed water levels in RV regions between PSV and SI line breaks

3. Summary and Conclusions

A comparison of the thermal hydraulic behavior of small break loss of coolant accident (SBLOCA) tests in an integral test loop (ITL) of a system-integrated modular advanced reactor (SMART) was performed, especially on the pressurizer safety valve (PSV) line and safety injection (SI) line breaks. Compared to typical phases of SBLOCAs in conventional pressurized water reactors (PWRs), four sequential phases were identified: a blowdown to the upper downcomer (UDC) under saturation conditions, a pressure plateau under forced circulation, boil-off after the reactor coolant pump (RCP) trip, and core level restoration after the safety injection tank (SIT) injection or long-term cooling. The pressure plateau was deeply dependent under UDC saturation conditions and there were mass transfers among the reactor vessel (RV) regions during the pressure plateau. In the boil-off phase, a short reverse flow occurred from the lower downcomer (LDC) to the primary side of steam generator (SGP) owing to the occurrence of vaporization in the LDC region. The core level restoration is mainly dependent on the SIT injections. In the secondary system, the fluid conditions on the secondary side of steam generator (SGS) outlets were changed during the tests from superheat to saturation, from saturation to subcooling, and from subcooling to superheat. In the passive safety injection system (PSIS) system, there was a short reverse flow in the pressure balance line (PBL) lines of the core makeup tanks (CMTs) just after the break, and sufficient injection flowrates of the CMTs were achieved after the partial clearing/blocking of the PBL. In the case of a SIT actuation signal, duration times for the hydraulic equilibrium conditions among the CMTs, SITs, and RV were needed.

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[1] KAERI, "South Korea thinks small," Nucl. Eng. Int. (Issue of 6 November 2010), 44-45 (2010).