Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 27-28, 2016

Safety assessment of the SMART design during SBLOCA tests using the high pressure safety injection pump of the SMART-ITL facility

Hwang Bae[a*], Sung Uk Ryu[a], Byong-Guk Jeon[a], Jin-Hwa Yang[a], Eun-Koo Yoon[a], Yong-Cheol Shin[a], Kyoung-Ho Min[a], Jong-Kuk Park[a], Nam-Hyun Choi[a], Yun-Gon Bang[a], Chan-Jong Seo[a], Sung-Jae Yi[a], Hyun-Sik Park[a]
[a]*Korea Atomic Energy Research Institute, 989-111 Daedeokdaero, Yuseong, Daejeon, 305-353, Korea*
[*]*Corresponding author: hbae@kaeri.re.kr*

1. Introduction

SMART [1] is a small-sized integral pressurized light water reactor designed by the Korea Atomic Energy Research Institute (KAERI) from 1997 and received standard design approval (SDA) by the Korean regulatory body in July 2012. Single reactor pressure vessel contains all of the main components including a pressurizer (PZR), steam generators (SG) and reactor coolant pumps (RCP) without any large-size pipes.

A large-scale integral effect test facility, SMART-ITL, called FESTA (Facility for Experimental Simulation of Transients and Accidents) [2] was designed to simulate the integral thermal-hydraulic behavior of SMART. Several tests to verify a safety and performance of SMART design were carried out. This paper introduces a comparison with three SBLOCA tests. Overall thermal-hydraulic phenomena were observed and showed a traditional trend to decrease a system pressure and temperature. A collapsed water level of the hot side indicated that the safety injection system was successfully operated to recover the reactor coolant system (RCS) and protect the core uncover.

2. Methods and Results

2.1 Scaling Methodology

SMART-ITL was designed following a three-level scaling methodology of Ishii et al. [3] consisting of integral scaling, boundary flow scaling, and local phenomena scaling. Its height is preserved to the full scale, and its area and volume are scaled down to 1/49 compared with the prototype plant, SMART. The design pressure and temperature of SMART-ITL can simulate the maximum operating conditions, that is, 18.0 MPa and 350 ℃. The scaling ratios adopted in SMART-ITL with respect to SMART are summarized in Table I.

Table I: Primary scale variables

Parameters	Scale Ratio	Value
Length, l_{0R}	l_{0R}	1/1
Diameter, d_{0R}	d_{0R}	1/7
Area, a_{0R}	d_{0R}^2	1/49
Volume, V_{0R}	$d_{0R}^2\ l_{0R}$	1/49
Time scale	$l_{0R}^{1/2}$	1/1
Velocity	$l_{0R}^{1/2}$	1/1
Core Power, Flow rate	$a_{0R}\ l_{0R}^{1/2}$	1/49
Pressure drop	l_{0R}	1/1

2.2 SBLOCA scenario

The SMART-ITL has been used to investigate the thermal-hydraulic behavior for SMART during an operational transient and design basis accident (DBA). An SBLOCA as a representative DBA of the SMART is that a small-size pipe connected with the RPV is broken and the inventory of RCS then is discharged. Its break location is on the SIS line (the nozzle part of the RCP discharge), PSV line (the top side of pressurizer) or SCS suction line (the nozzle part of the RCP suction). This transient test was conducted according to the SBLOCA scenario.

2.3 Steady State Results

A steady-state condition represents an initial test conditions to maintain the normal-operation conditions of SMART. The target values of the pressure and temperature, and the core power and flow rate imply a 100 % condition of the prototypic nuclear reactor and 20 % condition of the scaled ratio, respectively. A steady-state operation was maintained over 600 seconds prior to the individual transient tests. Table II shows the normalized-major parameters of the target values and test results during a steady-state condition. All of the results are satisfied with the target values.

2.4 Transient Results

Table III shows the major sequence of the SBLOCA test as the boundary conditions. After the corresponding line was simulated to be broken, a transient test was performed according to the small-break loss-of-coolant accident (SBLOCA) scenario.

Table II: Description of the steady state condition

Parameter	Normalized state-state condition (Measurement/Target value, %)		
	SIS	SCS	PSV
Power	112	113	112
PZR pressure	100	100	100
1st flowrate	99	104	91
SG 1st inlet temp.	98	100	100
SG 1st outlet temp.	99	101	99
Feed Water flow rate	101	104	104
SG 2nd inlet temp.	104	98	100
SG 2nd outlet pressure	103	95	102

Table III: Major sequence of the transient test

Event	Time After Break (seconds)		
	SIS	SCS	PSV
Break	0	0	0
LPP set-point	134	125	58
Reactor trip signal - FW stop - Pump coastdown	135	128	61
Reactor trip-curve start			61
PRHR actuation signal	136	130	62
PRHRS IV open	141	135	67
FIV close MSIV close	149 172	134 150	67 82
Safety injection signal	481	641	541
Safety injection start	512	671	572
Stop the test	8,932	8,696	7,244

Fig. 1 shows the pressure behavior of the primary system. The primary pressure decreases rapidly during the early stage. The pressure decrease is slowed down during the middle stage, and then the pressure decreases gradually during the final stage. The depressurization in the individual tests shows a little quantitative difference even though the qualitative trends are the similar to each other.

Fig. 2 shows the collapsed water level of the RCS hot side. The collapsed water level is decreased by each break and recovered by the SI injection. The collapsed water level in the final stage is different from the SIS break to the SCS break even though the decreasing trend in the early stage is almost the same each other. It can be caused by the different break flow rate and safety injection flow rate.

Fig. 3 shows the accumulated break and SI flows. Accumulated break flow of the SIS break is the largest amount and that of the PSV break is the smallest amount. The UDC is a part of the RCP discharge region where the discharge flow can be included in the break flow and add to accelerate the break flow. The suction flow on CSB-UGS annulus can disturb the break flow through the break nozzle between the RCPs. The phase of the break flow in the SIS and SCS is sequentially changed to three steps, which are single water phase, steam-water phase, and single-water phase. On the other hand, the PSV break flow is discharged to single-steam phase only. Total amount of the break flow of the PSV is naturally smaller than that of the other cases.

3. Conclusions

An SBLOCA test simulating a guillotine break on the SIS, SCS, and PSV was performed. It was enough to keep a steady-state condition before the SBLOCA test begins. An actuation signal as the boundary condition was properly simulated during the transient test. The scenarios of the SBLOCA in the SMART design were reproduced well using the SMART-ITL facility. The safety injection is effective to protect the core uncover as well as to cool down the RCS. All of the measured parameters show reasonable behaviors.

ACKNOWLEDGEMENT

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIP). (No. 2016M2C6A1004894)

REFERENCES

[1] K. K. Kim et al., SMART: The First Licensed Advanced Integral Reactor, Journal of Energy and Power Engineering, 8, pp.94-102, 2014.
[2] H.S. Park, et al., SMR accident simulation in experimental test loop, Nuclear Engineering International, pp. 12-15, 2013.
[3] M. Ishii and I. Kataoka, Similarity Analysis and Scaling Criteria for LWR's Under Single-Phase and Two-Phase Natural Circulation, NUREG/CR-3267, ANL-83-32, U. S. NRC, Washington, D. C., 1983.

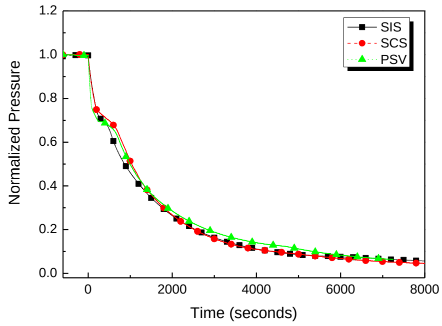

Fig. 1. Normalized pressure distribution of the RCS

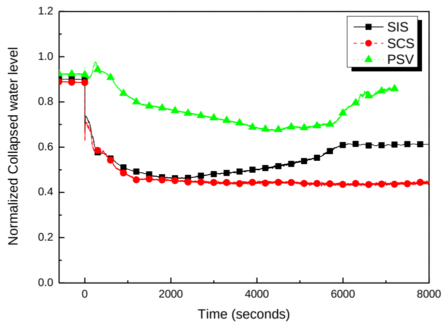

Fig. 2. Normalized collapsed water level of the RCS hot side

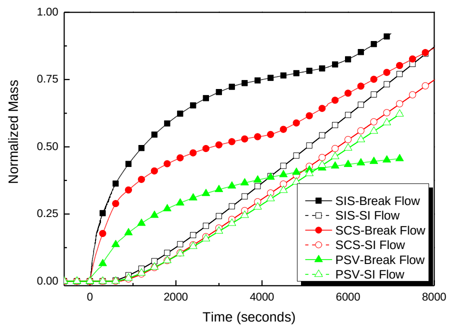

Fig. 3. Normalized accumulated break and SI flows