A SBLOCA Test of Shutdown Cooling System for SMART with the VISTA-ITL

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1. Introduction

The VISTA-ITL [1] for a thermal-hydraulic integral effect test is a modified version of an existing VISTA facility to have the simulation capability of Small-Break Loss Of Coolant Accident (SBLOCA) for the System-integrated Modular Advanced ReacTor (SMART) design. The VISTA-ITL has been designed following the three-level scaling methodology of Ishii and Kataoka [2] which consists of integral scaling, boundary flow scaling, and local phenomena scaling. The VISTA-ITL is a 1/2.77-height, 1/1310-volume scaled test facility based on the design features of SMART. The major components of reactor pressure vessel, steam generator, PRHRS and secondary system are preserved, but some changes are given to the simulate the SBLOCA behavior of the SMART design: the steam pressurizer, the safety injection system, the steam generator bypass, the hot leg, the cold leg, the PRHRS makeup tank, the break simulator and the break measuring system were revised. In order to perform the safety analysis and performance analysis of a SMART, SBLOCA test of the Shutdown Cooling System (SCS) line break was performed by the Korea Atomic Energy Research Institute (KAERI) using the Experimental Verification of by Integral Simulation of Transients and Accidents (VISTA) Integral Test Loop (ITL). In this paper, test results of the SCS line-break have been summarized with major parameter and experimental results obtained from the SBLOCA test.

2. Sequence of SBLOCA (SB-SCS-01)

The thermal-hydraulic behavior happens 1.664 times faster in the VISTA-ITL than in the SMART design according to the time scale ratio. Table 1 shows the major sequence of event for the SBLOCA simulation test. As a shutdown cooling system line was broken in the SMART design, the primary system pressure decreases with the discharge of the coolant through the break. When the pressurizer pressure reached the low pressurizer pressure (LPP) trip set-point (12.13 MPa), the reactor tripped by the reactor trip signal which was generated with a 1.1 seconds (in VISTA-ITL: 0.66 seconds) delay. As the turbine trip and the loss of off-site power (LOOP) are assumed to occur consequently after the reactor trip, the LOOP occurs, the injection of the feed-water stopped and the RCP begins to coast-down. With an additional 0.5 seconds (in VISTA-ITL: 0.3 seconds) delay, the control rod is inserted. As the PRHRS actuation signal is generated by the low feed-water flow-rate 2.2 seconds (in VISTA-ITL: 1.32 seconds) after the LPP, the SG is isolated from the turbine by the isolation of the main steam and feed-water isolation valves and it is connected to the PRHRS. With the operation of PRHRS, two-phase natural circulation occurred inside the PRHRS. The decay heat generated from the reactor core was transferred through the SG and eventually it was removed by the PRHRS heat exchanger which is located in a water-filled ECT. The safety injection actuation signal (SIAS) was generated when the primary system pressure reaches below 10.0 MPa and the safety injection (SI) water is injected with the time delay of 30 seconds (in VISTA-ITL: 18.03 seconds).

Table 1 Major sequence of SBLOCA simulation test

Event	Trip signal and Set-point	
	SMART	VISTA-ITL
Break occur	-	-
Reach LPP set-point	PZR Press = 12.13 MPa	
LPP reactor trip signal	LPP+1.1 s	LPP+0.66s
- FW stop - Pump coastdown		
Control rod insert	LPP+1.6 s	LPP+0.96 s
PRHR actuation signal	LPP+2.2 s	LPP+1.32 s
PRHRS IV open	PRHRAS+5.0 s	PRHRAS+3.0 s
MSIV/FIV close	PRHRAS+15.0 s	PRHRAS+9.01 s
Safety injection signal	BPV Press = 10.0 MPa	
Safety injection start	SIAS+30 s	SIAS+18.03 s

3. Discussion and Results

3.1 Steady state

Table 2 shows the comparison of the major parameters between SMART design and VISTA-ITL at a steady state condition. The primary and secondary system flow rate in the normal status of core power 103% is 2.63 kg/s and 0.155 kg/s, respectively. The primary system pressure of 103% core power condition is 14.99 MPa, the pressurizer level is about 70% and the inlet/outlet temperatures of steam generator primary side are maintained at 325.5℃ and 295.3℃, respectively.

3.2 Transient

Table 3 shows the test results of the major sequence for SBLOCA (SB-SCS-01) simulation test. When a SCS line was broken, the RCS began to be depressurized. As the pressurizer pressure reached the LPP trip set-point (12.13 MPa) after the SCS line break (Das time: 511 s). The reactor trip was generated about 2.0 s after the LPP signal. Consequently with the reactor trip signal, the feed water was stopped and the reactor coolant pump started to coast-down. It was shown that the PRHRS actuation signal occurred (Das time: 514 s). The safety injection water was injected 19 s after the safety injection actuation signal (SIAS).

Table 2. Comparison of the major parameters at a steady state condition

Parameter	SMART (Design value)	VISTA-ITL (Ideal value)	VISTA-ITL (Test data)
Power (MW)	330	0.432	0.452
PZR pres.(MPa)	15.0	15	14.99
1^{st} flowrate(kg/s)	2090.0	2.65	2.63
SG 1^{st} inlet temp.(℃)	323.0	323.0	325.5
SG 1^{st} outlet temp.(℃)	295.7	295.7	295.3
F.W. flow-rate(kg/s)	160.8	0.204	0.155
SG 2^{nd} inlet P.(MPa)	6.0	6.0	6.04
SG 2^{nd} outlet P.(MPa)	5.2	5.2	5.2

Table 3 Test results of major sequence for SBLOCA

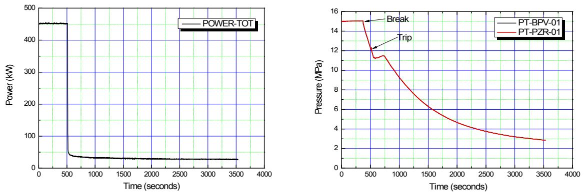
Event	Das time (seconds)	After break time (seconds)
Break occur	373	0
Reach LPP set-point	511	138
Reach LPP trip signal	512	139
- FW stop		
- Pump coastdown		
Reactor trip-curve start	513	140
PRHR actuation signal	514	141
PRHRS IV open	516	143
MSIV/FIV close	525	152
Safety injection signal	911	538
Safety injection start	930	557

Fig. 1 shows the variations of the major parameters. The decay power curve and safety injection flow rate are successfully given for the test. The core power was well simulated during the simulation, as shown in **Fig. 1(a).**

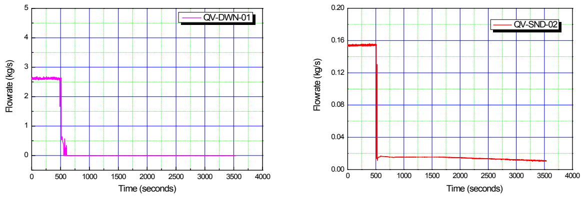
Fig. 1(b) shows the pressure behavior of the primary system. The primary pressure decreased rapidly during the single-phase blowdown period. The pressure decreases up to 11.3 MPa after the break and then increases up to 11.47 MPa again during a short period and then decreases gradually.

Fig. 1(c) shows the primary system flow rate. The flow rate was 2.68 kg/s in the steady-state. As SCS line break, the primary flow rate decreases dramatically and it was lowered to less than a measurable flow range.

Fig. 1(d) shows the secondary system flow rate. The initial flow rate is about 0.152 kg/s. As the PRHRS system operates, the feed-water flow rate shows a dramatic change at the beginning and natural circulation is achieved within a few seconds. After that, the natural circulation flow rate shows a gradual decrease at a constant rate. The flow rate under a natural circulation condition is dependent on a heat balance between the heat exchanger and the SG, and the hydraulic resistance in the loop. The initial maximum value of natural circulation flow rate is about 0.0167 kg/s and was 11.1% of the rate feed-water flow rate in maximum.



(a) Core power (b) Primary system pressures



(c) Primary system flow rate (d) PRHRS flow rate

Fig. 1. Test results of major parameters

4. Conclusions

A SBLOCA test for the shutdown cooling system line break (SB-SCS-01) has been performed. The steady-state conditions were operated to satisfy the initial test conditions presented in the test requirement and its boundary conditions were properly simulated. With the operation of PRHRS, two-phase natural circulation flow formed inside the two-phase PRHRS natural circulation loop. A natural circulation flow rate in the PRHRS loop was about 11.1% of its nominal value in the early state of the PRHRS operation.

References

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