PRHRS Performance Test on Safety Injection System Line Break with VISTA ITL for the SMART Design

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1. Introduction

The purpose of this paper is to investigate the thermal hydraulic characteristics and behavior of the primary and secondary system including the PRHRS when the SIS line break using VISTA-ITL, a small-scale integral effect test loop for SMART design. The VISTA-ITL [1] 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 used to investigate various thermal-hydraulic phenomena during the SBLOCA. The break flow rate, safety injection flow rate, and thermal-hydraulic behaviors of major components are measured for a typical break size and break locations. The acquired data will be used to validate the related thermal-hydraulic models of the safety analysis code, TASS/SMR [2], which can assess the capability of SMART to cope with the SBLOCA scenario.

2. Description of the VISTA-ITL

Fig. 1 shows the schematic diagram of the VISTA-ITL facility. 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 during the VISTA-ITL program. The major scale ratios are as follows.

- Reference plant: SMART-330
- Scaling methodology: three level scaling
- Length scale ratio: 1/2.77
- Area scale ratio: 1/472.9
- Volume scale ratio: 1/1310

3. Discussion and Results

3.1 Steady state

Table 1 shows the major parameters at a steady state condition. During the SB-SIS test the primary and secondary system flow rates in the normal status of 100% core power are 2.63 kg/s and 0.146 kg/s, respectively. The primary system pressure of 100% core power condition is 15.0 MPa, the pressurizer level is about 70% and the inlet/outlet temperatures of steam generator primary side are maintained at 324.0℃ and 297.0℃, respectively

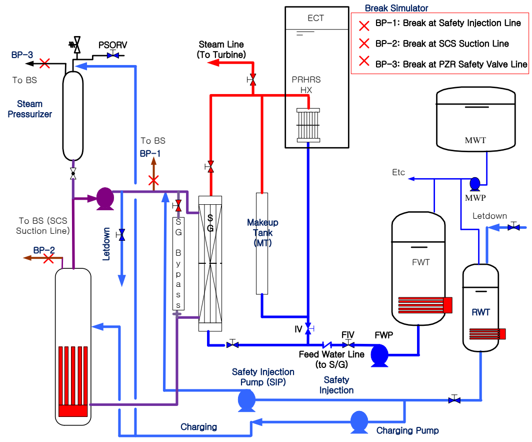


Fig. 1. Schematic diagram of the VISTA-ITL facility

Table 1. Major parameters at a steady state condition

Parameter	SMART (Design value)	VISTA-ITL (Ideal value)	VISTA-ITL (Test data)
Power (MW)	330	0.432	0.439
PZR pres.(MPa)	15.0	15	15
1st flowrate(kg/s)	2090.0	2.65	2.63
SG 1st inlet temp.(℃)	323.0	323.0	324.0
SG 1st outlet temp.(℃)	295.7	295.7	297.0
F.W. flow-rate(kg/s)	160.8	0.204	0.146
SG 2nd inlet P.(MPa)	6.0	6.0	5.95
SG 2nd outlet P.(MPa)	5.2	5.2	5.2

3.2 Transient

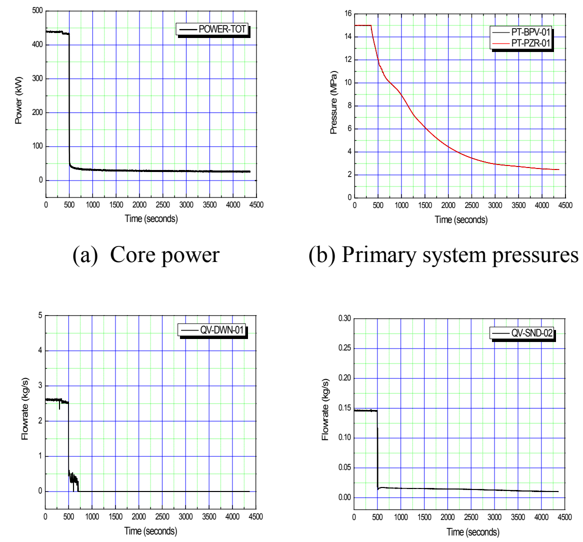
As a nozzle of SIS line is broken in the SMART design, the primary system pressure decreases with the discharge of the coolant through the break. When the primary pressure reaches the low pressurizer pressure (LPP) set-point, the reactor trip signal is generated with a 0.66 s delay. As the turbine trip and the loss of off-site power (LOOP) are assumed to occur consequently after the reactor trip, the feedwater is not supplied and the RCP begins to coast-down. With an additional 0.3 s delay, the control rod is inserted. When the PRHRS actuation signal is generated by the low feedwater flowrate 1.32 s after the LPP, the SG is isolated from the turbine by the isolation of the main steam and feedwater isolation valves and it is connected to the PRHRS. The safety injection actuation signal (SIAS) was generated when the RCS pressure reaches below the SIAS setpoint and the SI water is injected with the time delay of 18.03 s. Table 2 shows the test results of the major sequence for SBLOCA simulation test. When SIS line was broken, the RCS began to be depressurized. As the pressurizer pressure reached the LPP trip set-point (12.13 MPa) 140 s after the SIS line break. The reactor trip was generated about 1.0 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 at 143 s after the break. With the operation of PRHRS, two-phase natural circulation occurred inside the two-phase PRHRS natural circulation loop. The decay heat generated from the core reactor was transferred through the SG and eventually removed by the PRHRS heat exchanger located in a water-filled ECT. The safety injection water was injected 18 s after the Safety Injection Actuation Signal (SIAS).

Table 2. Results and major sequence of events for SB-SIS

Event	Set-point (VISTA-ITL)	DAS time(s)	Time after break (s)
Break occur	-	355	0
Reach LPP set-point	12.13 MPa	495	140
Reach LPP set-point	PZR Pres. = 12.13MPa	496	141
- FW Stop	-		
- Pump Coastdown	-		
Reactor Trip - Curve Start	LPP+0.96 s	497	142
PRHR actuation signal	LPP+1.32 s	498	143
PRHRS IV open	PRHRSAS+3.0 s	501	146
MSIV/FIV close	PRHRSAS+9.0 s	508	153
Safety injection signal	BPV Pres. = 10.0 MPa	760	405
Safety injection start	SIAS+18.03 s	778	423

Fig. 1 shows 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 decrease was slowed down during two-phase discharge period and then the pressure decreases gradually during the single-phase steam blowdown period. **Fig. 1(c)** shows the primary system flow rate. As SIS line break occurs, 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 the heat balance between the heat exchanger and SG, and the hydraulic resistance in the loop. The initial maximum value of the natural circulation flow rate is about 0.0171 kg/s and was 11.7% of the rate feed-water flow rate at maximum.



(a) Core power (b) Primary system pressures

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

Fig. 1. Test results of the major parameters

4. Conclusions

The experimental results show that 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 11.7% of nominal flow rate value in the early state of the PRHRS operation.

References

1. H. S. PARK, *et al.*, *Construction Report of the VISTA-ITL*, KAERI internal report, KAERI, Daejeon (2011).
2. Y. J. CHUNG, *et al.*, *TASS/SMR Code Topical Report for SMART Plant, Vol. I: Code Structure, System Models, and Solution Methods*, KAERI/TR-3640/2008 (2008).