Thermal-Hydraulic Validation Tests for SMART Pre-Project Engineering

Hyun-Sik Park [a*], Hwang Bae [a], Sung-Uk Ryu[a], Byong-Guk Jeon[a], Jin-Hwa Yang[a], Eun-Koo Yun[a], Jun-Young Kang[a], Nam-Hyun Choi[a], Yong-Cheol Shin[a], Kyoung-Ho Min[a], Yoon-Gon Bang[a], Chan-Jong Seo[a], Yeon-Sik Kim[a], Sung-Jae Yi [a]
[a]*Korea Atomic Energy Research Institute, 989-111 Daedeokdaero, Yuseong, Daejeon, 34057, Korea*
[*]*Corresponding author: hspark@kaeri.re.kr*

1. Introduction

Saudi Arabia and Korea started conducting a three-year project of Pre-Project Engineering (PPE) from December 2015 to prepare a Preliminary Safety Analysis Report (PSAR) and to review the feasibility of constructing SMART reactors [1] in Saudi Arabia.

The Standard Design Approval (SDA) for SMART was certificated in 2012 at the Korea Atomic Energy Research Institute (KAERI), which was only equipped with passive residual heat removal system (PRHRS). To satisfy the domestic and international needs for nuclear safety improvement after the Fukushima accident, a couple of passive safety systems (PSSs) of passive safety injection system (PSIS) and automatic depressurization system (ADS) were newly developed. [2] The SMART also adopts a new PCCS (Passive Containment Cooling System) concept of CPRSS (Containment Pressure and Radioactivity Suppression System). In addition the thermal power of SMART increased from 330 to 365 MWt and some geometrical changes were given during the SMART PPE project. Therefore, there are strong needs both to understand the thermal-hydraulic phenomena expected to occur during the operation, transient and accident scenarios and to validate its performance for the SMART design.

In this paper, the validation test activities will be summarized. They include integral effect tests of DBA (Design Basis Accident), SP (System Performance) and OP (Operation and Maintenance) using the SMART-ITL facility, which is an Integral Test Loop for the SMART design (SMART-ITL, or FESTA) [3]. Also the separate effect test facility of SISTA were commissioned to investigate the thermal-hydraulic phenomena in the SMART CPRSS (Containment Pressure and Radioactivity Suppression System).

2. Test Facilities

2.1 SMART Integral Test Loop (SMART-ITL)

SMART-ITL is scaled down using the volume scaling methodology and has all the fluid systems of SMART together with the break system and instruments, as shown in Fig. 1. The height of the individual components is conserved between SMART and SMART-ITL. The flow area and volume are scaled down to 1/49. The ratio of the hydraulic diameter is 1/7. The scaling ratios adopted in SMART-ITL with respect to SMART are summarized in Table 1.

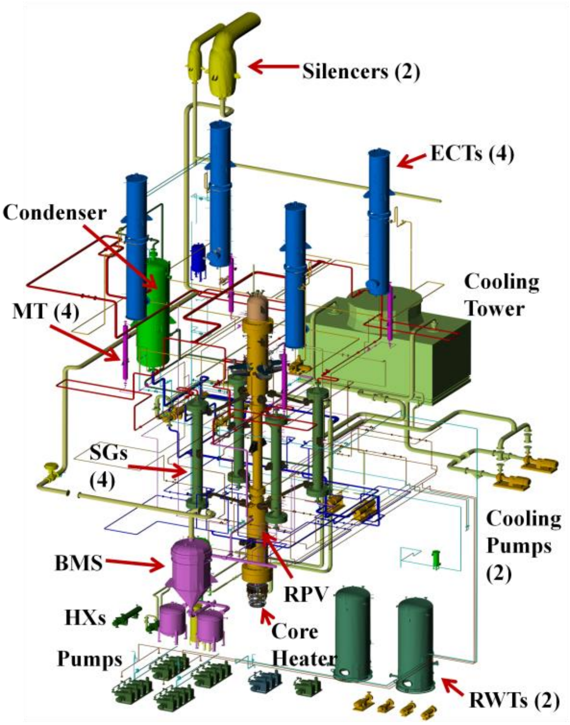

Figure 1. Schematics of SMART-ITL.

Table 1. Major Scaling Parameters of SMART-ITL.

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

All primary components except for steam generators are equipped in a reactor pressure vessel. However, as the space of the annulus used to locate the steam generator is too narrow to install itself inside the SMART-ITL, the steam generator was connected to the hot-leg and cold-leg outside the pressure vessel where the instruments are installed.

SMART is a 365 MW thermal power reactor, and its core exit temperature and pressurizer (PZR) pressure are 323℃ and 15 MPa during normal working conditions, respectively. The maximum power of the core heater in the SMART-ITL is 30% for the ratio of the volume scale. The reactor coolant system of SMART-ITL was designed to operate under the same condition as SMART.

The SMART PSS design is composed of four Core Makeup Tanks (CMTs), four Safety Injection Tanks

(SITs), and two-stage Automatic Depressurization Systems (ADSs) [2]. Individual tanks are connected with pressure-balanced pipes at the top and injection pipes at the bottom. This system is operated when a small break loss of coolant accident (SBLOCA) or a steam line break (SLB) occurs. There are no active pumps in the pipe lines to supply the coolant. This system is only actuated by the passive means of gravity force caused by the height difference because all of the tanks are higher than the injection nozzle around the reactor coolant pumps (RCPs).

The CMT and SIT were designed based on the volume scale methodology, which is the same methodology used for SMART-ITL. Their heights are conserved, their diameters are scaled down to 1/7, and the area of the tank cross-section is scaled down to 1/49. The detailed scaled values are shown in Table 1.

SMART-ITL is equipped with four trains of the PSIS, two stages of the ADS, and four trains of the PRHRS. Each pipe has an isolation valve and a flow meter. The pressure, differential pressure, and temperature can be measured at every pipe and tank. Level and pressure transmitters are installed in each tank.

After commissioned in 2012, a set of Design Basis Accident (DBA) scenarios have been simulated using SMART-ITL without PSIS and ADS. [4] Recently, a test program to validate the performance of the SMART PSS was launched and its scaled-down test facility was additionally installed at the existing SMART-ITL facility. Thereafter various kinds of validation tests on SMART PSS have been performed during 2014-2016. [5]

2.2 A Separate Effect Test Facility for CPRSS (SISTA)

The SISTA is a scaled down test facility to validate the concept of SMART CPRSS. The SMART CPRSS suppresses the increase of pressure and temperature in the containment, and limits the release of the radioactivity into the containment atmosphere by condensing the steam and isolating the radioactive material in an In-containment Refueling Water Storage Tank (IRWST) as shown in the Figure 2. The cooling capacity of IRWST in the SMART should be evaluated. The SISTA will produce experimental data for evaluating thermal-hydraulic behavior in the major components of CPRSS such as drywell, IRWST and containment for the SMART design.

The SISTA consists of steam injection systems, dry well, IRWST and containment which is illustrated in Figure 2. The steam injection systems are composed of Steam Supply System (SSS) of SMART-ITL and pressurizer (PZR) of HSIT (Hybrid Safety Injection Tank) for low and high pressure steam injection, respectively. The IRWST plays as a heat sink in the system and it is equipped with a sparger which induces thermal mixing in the water tank. The containment is a pressure boundary which is connected to the top of the IRWST water tank.

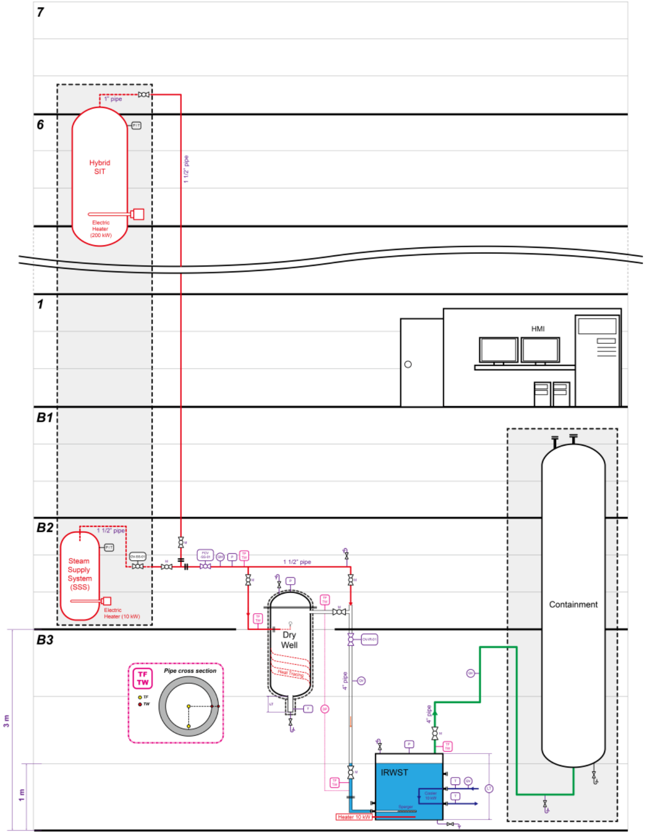

Figure 2. Schematics of SISTA.

3. Validation Tests for SMART PPE

Validation test program for SMART PPE includes several integral effect tests (DBA, SP, and OP) and SG performance tests using SMART-ITL, and concept verification tests for the SMART CPRSS using SISTA.

3.1 DBA Tests

There are various safety-related accident scenarios. Among them seven kinds of scenarios such as feedwater line break (FLB), complete loss of reactor coolant system (RCS) flowrate (CLOF), uncontrolled control rod assembly (CRA) withdrawal, small-break loss-of-coolant-accident (SBLOCA), steam generator tube rupture (SGTR), total loss of secondary heat removal (TLOSHR), and natural circulation (NC) could be validated through the DBA tests.

The feed line break (FLB) accident is initiated by partial or total rupture of a feedwater line located inside or outside a reactor building.

A complete loss of primary flow rate (CLOF) is a non-LOCA scenario without flow rate by RCPs. When a CLOF event occurs, the forced convection of the coolant is not sustained and the reactor coolant flow rate rapidly decreases since all RCPs fail simultaneously.

The uncontrolled control rod assembly (CRA) withdrawal at power condition is an event that can occur by the failure of the control rod driving mechanism

(CRDM) control system or the operator error during a power operation.

The SBLOCA is initiated by the break of safety injection system (SIS) or pressurizer safety valve (PSV) lines and the RCS inventory is discharged through the break.

The steam generator tube rupture (SGTR) is a postulated accident, where one tube inside a steam generator (SG) is ruptured. The helical tubes inside SG isolate the secondary system form the reactor coolant system, preventing leakage of radioactive materials toward the environment. The rupture of pressure boundary between the primary and the secondary system is an important accident in view of the radioactive material release.

A total loss of secondary heat removal (TLOSHR) accident is a beyond design basis accident (BDBA) resulting from a hypothetical loss of main feedwater and emergency feedwater to steam generators (SGs).

To investigate thermal hydraulic phenomena under natural circulation conditions considering the SMART specific characteristics, single phase and two phase natural circulation test are performed using the SMART-ITL facility. The first case is a stepwise reduction of the core power to decay heat level in the test facility while maintaining at constant primary coolant inventory. The objective is to examine the effect of power effect on natural circulation. The second case involves a stepwise reduction in primary mass inventory in the test facility while operating at decay power. The objective is to examine the effect of inventory reduction on natural circulation and mass distribution in the reactor coolant system.

3.2 SP Tests

There are various performance-related accident scenarios. Among them the system performance (SP) of passive safety injection system (PSIS) and passive residual heat removal system (PRHRS) will be validated through the SP tests. The PSIS performance could be investigated by reducing the number of PSIS trains used during the CLOF scenario. Similarly, the PRHRS performance could be investigated by reducing the number of PRHRS trains used during the CLOF scenario.

3.3 OM Tests

SMART operation procedure includes startup operation, power operation, and shutdown operation and their separate procedures were analyzed. Among them startup operation and shutdown operation could be validated through the operation and maintenance (OM) tests.

The startup operation is composed of auxiliary heatup operation, core critical operation and reactor startup operation. The power operation is to increase the power level from 20% to 100%. And the shutdown operation is a series of processes which is divided into isolation of power conversion system, reactor trip, RCS cooling by feedwater, connection of LTOP valve and RCS cooling by SCS.

3.4 SG Performance Tests

Four scaled down SGs are installed in SMART-ITL and they have 1/49-volume compared with SMART. One of them will be used to test its performance during the scaled full power and flowrate condition.

3.5 CPRSS Concept Verification Tests

The SMART CPRSS is a newly adopted PCCS concepts and its concept should be verified for further design. First of all, the cooling capacity of IRWST in the SMART will be evaluated. Next the thermal-hydraulic behaviors are investigated in the major components of CPRSS such as drywell, IRWST and containment for the SMART design.

4. Discussion and Conclusions

In this paper, the validation test activities for the SMART PPE are summarized. They include integral effect tests of DBA (Design Basis Accident), SP (System Performance) and OP (Operation and Maintenance) and performance tests of SG using the SMART-ITL facility. Also the SISTA facility is used to investigate the thermal-hydraulic phenomena in the SMART CPRSS (Containment Pressure and Radioactivity Suppression System).

After finishing the SMART PPE project successfully, the SMART FOAK (First-Of-A-Kind) plant is planned to be built in Saudi Arabia. To get a construction license, more validation tests to resolve licensing issues and SA (Severe Accident) and PSA (Probabilistic Safety Assessment) related tests seem to be necessary.

REFERENCES

[1] Kim, K. K. et al., 2014. SMART: The First Licensed Advanced Integral Reactor, *Journal of Energy and Power Engineering*, 8, 94-102.

[2] Y. M. Bae, Report of Passive Safety System, SER-410-FS403-SD, KAERI Internal Report, 2012.

[3] Park, H.S., Yi, S.J., Song, C.H., 2013, SMR Accident Simulation in Experimental Test Loop, *Nuclear Engineering Int.*, November 2013, 12-15.

[4] Hwang Bae, et al., “Comparison of three SBLOCA tests with different break locations using the SMART-ITL facility to estimate the safety of the SMART design," *Nuclear Engineering and Technology*, Vol. 49, pp. 968-978, 2017.

[5] Byong-Guk Jeon, et al., “Code Validation on a Passive Safety System Test with the SMART-ITL Facility," *Journal of Nuclear Science and Technology*, Vol. 54, No.3, pp. 322-329, 2017.