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Some Findings from Thermal-Hydraulic Validation Tests for SMART Passive Safety System

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1. Introduction

The Standard Design Approval (SDA) for SMART [1] was certificated in 2012 at the Korea Atomic Energy Research Institute (KAERI). To satisfy the domestic and international needs for nuclear safety improvement after the Fukushima accident, an effort to improve its safety has been studied, and a Passive Safety System (PSS) for SMART has been designed [2].

In addition, an Integral Test Loop for the SMART design (SMART-ITL, or FESTA) [3] has been constructed and it finished its commissioning tests in 2012. Consequently, a set of Design Base Accident (DBA) scenarios have been simulated using SMART-ITL. 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. [4, 5]

In this paper, some findings from the validation tests for the SMART PSS will be summarized. The acquired data will be used to validate the safety analysis code and its related models, to evaluate the performance of SMART PSS, and to provide base data during the application phase of SDA revision and construction licensing.

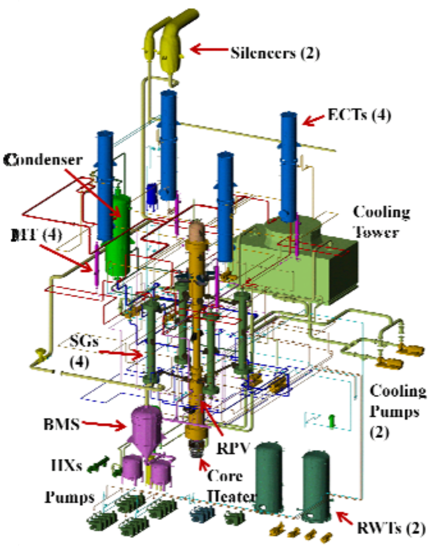


Fig. 1 Schematics of the SMART-ITL.

2. Methods and Results

2.1 SMART-ITL (FESTA)

SMART is an integral type reactor. A single pressure vessel contains all of the major components, which are the pressurizer, core, steam generator, reactor coolant pump, and so on.

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.

Table 1 Major Scaling Parameters of the FESTA Facility.

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 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 330 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 the SMART-ITL was designed to operate under the same conditions as SMART.

2.2 SMART Passive Safety System

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 the pressure-balanced pipes on the top side and injection pipes on the bottom side. This system is operated when a small break loss of coolant accident (SBLOCA) or the steam line break (SLB) occurs. There are no active pumps on 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 (RCP).

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. Detailed scaled values are shown in Table 1.

Fig. 2 shows a schematic of one train for the passive safety system of the SMART-ITL. 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.

The phenomena of flashing, condensation, and thermal stratification are expected to occur in the CMT, SIT, and pipes in the early stage. Appropriate thermocouples have to be installed in the pipes and tanks to investigate the complex thermal-hydraulic phenomena after the system is operated by opening the isolation valve in the injection line.

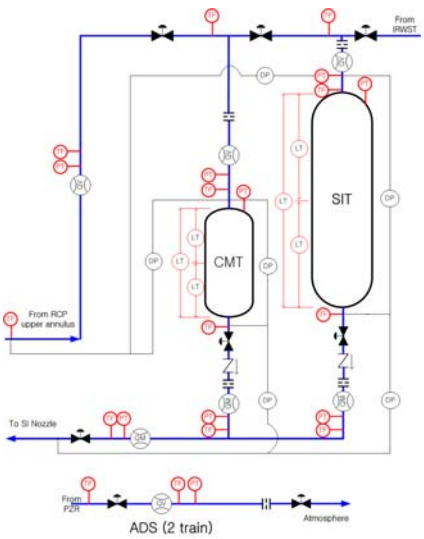


Fig. 2 Schematic of the Test Facility for SMART PSS

2.3 Validation Tests for SMART PSS

The objectives of this research are to construct a scaled-down test facility and to assess the performance of CMT and SIT for SMART and to analyze the thermal-hydraulic phenomena of flashing, wall film condensation, interfacial direct contact condensation, and thermal stratification expected to occur inside of the tank [6, 7].

An experimental facility design for validating the SMART PSS was introduced. Through the validation tests, the general thermal-hydraulic performance of the passive safety system can be understood, and the performance of the nozzle geometry of flow distributor, break size and tank geometry can be assessed. Thus, the obtained quantitative data can be applied to a real system design and safety analysis code. Furthermore, by analyzing the experimental data, the existing condensation models for wall film and interfacial condensation occurring in CMT and SIT will be assessed.

First, the SMART passive safety injection system was simulated with active safety injection systems of SIPs prior to the complete installation of four trains of SMART PSS.

Second, 1 train of the SMART passive safety injection system was simulated by attaching it to the existing FESTA facility. Appropriate orifices in the pressure balancing and injection lines were chosen and the flow distributor type was selected based on the test data. The effect of break size on the thermal-hydraulic behavior during SBLOCA scenario was also simulated. Table 2 shows the selected test matrix of 1-Train SMART PSS tests performed during 2014.

Table 2 Test Matrix of 1-Train SMART PSS Tests.

Case	Break (inch)	CMT Type	Flow Distributor	Description
S100	2	#1-2	NA	No flow distributor
S101	2	#1-1	Type C	Full-height CMT
S102	2	#1-2	Type B	Flow distributor
S103	2	#1-2	Type A	Flow distributor
S104	2	#1-2	Type C	Flow distributor
S105	2	#1-1	Type A	Full-height CMT
S106	0.4	#1-1	Type C	Different size

2.4 SBLOCA Scenario of SMART PSS

A SBLOCA scenario was simulated using the SMART-ITL facility. The break type is a guillotine break, and its break location is on the SIS line (nozzle part of the RCP discharge). The thermal-hydraulic behavior happens with the same time scale in the SMART-ITL and SMART designs as it is a full-height test facility. Table 3 shows the major sequence of events for the SBLOCA simulation test.

Table 3 Major Sequence of SBLOCA Tests

Event	Trip signal and Set-point
Break	-
LPP set-point	PZR Press = P_{LPP}
LPP reactor trip signal - FW stop, Pump Coastdown - CMTAS triggering	LPP+1.1 s
Control rod insert	LPP+1.6 s
MSHP set-point	LPP+4.1 s
PRHR actuation signal (PRHRAS)	MSHP+1.1 s (=LPP+5.2 s)
PRHRS IV open, FIV close	PRHRAS+5.0 s
MSIV close	PRHRAS+20.0 s
CMT injection start	CMTAS+300 s
SIT actuation signal (SITAS)	PZR Press = P_{SITAS}
SIT injection start	SITAS+300 s
ADS #1 open	CMT level < 35%
Test end	-

As a nozzle of the safety injection system (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 1.1 s delay. As the turbine trip and 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. In addition, a CMT actuation signal (CMTAS) was generated coincidently with a reactor trip signal. With an additional 0.5 s delay, the control rod is inserted. When the PRHRS actuation signal is generated by the trip signal of the main steam high pressure (MSHP) 4.1 s after the LPP, the SG secondary side is connected to the PRHRS with a 5 s delay and is isolated from the turbine by the isolation of the main steam and feedwater isolation valves with a 20 s delay. CMT injection starts following CMTAS with a time delay of 300 s by opening the isolation valve installed on the injection line downstream of CMT.

An SIT actuation signal (SITAS) is generated when the RCS pressure reaches below the SITAS setpoint, and the SIT tank is connected to the RPV with a 300 s delay when the isolation valve in the injection line downstream of CMT is opened. The ADS valve is opened as the CMT level falls below 35% of its full height.

The break nozzle diameter is 50.8 mm in the SMART design and the scaled-down value is 7.26 mm in the FESTA for a 2.0 inch break. A 0.4 inch break is simulated using an orifice with an inner diameter of 1.45 mm in FESTA.

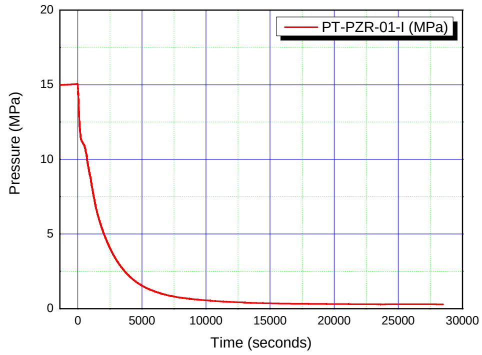
2.5 Major Findings from SMART PSS Tests

2.5.1 SMART PSS Tests using Active Pumps

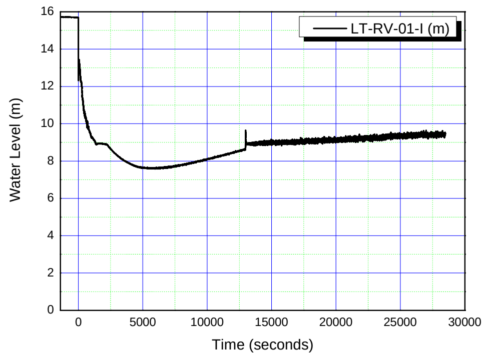
A couple of SMART PSS tests using active pumps were conducted to simulate the performance and to assess the cooling capacity of SMART PSS during SBLOCA scenarios prior to the installation of four trains of SMART PSS. During the SMART PSS tests using active pumps, the major sequence of Table 3 was a slightly changed as the active pumps are used instead of passive injection from CMT and SIT. A set of characterization tests using two SIPs were conducted to simulate the injection performance of CMT and SIP.

The major findings from SMART PSS tests using active pumps during 2013-2014 are as follows.

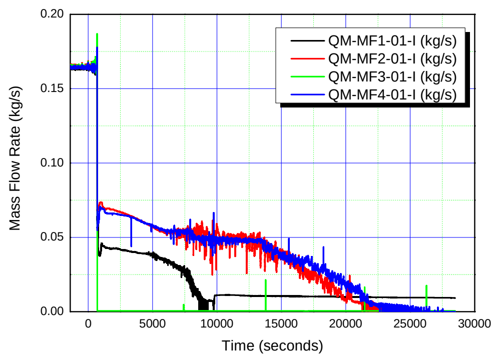
- The SBLOCA scenario for SMART PSS was simulated well using the FESTA facility with calibrated active pumps instead of CMTs and SITs.
- During the SBLOCA scenario, the reactor pressure vessel was cooled down efficiently with the operation of PSS including CMT, SIT, ADS and PRHRS, as shown in Fig 3(a).
- The RPV level was sufficiently recovered with a proper operation of safety injection systems, as shown in Fig 3(b).
- The PRHRS is actuated. Except for Train #3, only 3 of 4 trains were actuated. They show asymmetric characteristics between the four trains, as shown in Fig 3(c). While Train #1 has lower flow rate, both Trains #2 and #4 show similar trends.
- It was estimated that the PSS of SMART can function properly during a SBLOCA scenario.



(a) Primary pressure



(b) RPV water levels



(c) Secondary system flow rates

Fig. 3 Test Results of Major Parameters from SMART PSS Tests using Active Pumps

2.5.2 1-Train SMART PSS Tests

Several SMART PSS tests using 1 train, a passive CMT, were conducted to simulate the performance of the 1 train of SMART PSS during SBLOCA scenarios prior to the installation of four trains of the PSS.

During the 1-train SMART PSS tests, the major sequence of Table 3 was simplified. The decay power was not given and the PRHRS was also not actuated.

Three different kinds of tests were performed for a SBLOCA scenario: 1) the selection of flow distributor types of A, B, and C; 2) the effect of two different CMTs of #1-1 (full-height, 1/49-volume compared with SMART) and #1-2 (Half-height, same scaled volume), and 3) the effect of different break sizes of 2 and 0.4 inches. The major findings from 1-train SMART PSS tests during 2014 are as follows.

- During the initial stage of CMT injection, the fluid temperature measured in CMT#1-2 shows good stratification phenomena.
- During the initial stage of CMT injection, the water is injected efficiently from the start.
- The results show a different tendency compared with previous CMT test results [7, 8]. A more detailed analysis is required in the near future.
- The detailed thermal-hydraulic phenomena concerning the selection of the flow distributor type, effect of different CMTs, and the effect of a different break size will be discussed in a separate paper [9].

3. Conclusions

A test program to validate the performance of SMARS PSS was launched with an additional scaled-down test facility of SMART PSS, which will be installed at the existing SMART-ITL facility. In this paper, some findings from the validation tests of the SMART passive safety system during 2013-2014 were summarized. They include a couple of SMART PSS tests using active pumps and several 1-train SMART PSS tests.

From the test results it was estimated that the SMART PSS has sufficient cooling capability to deal with the SBLOCA scenario of SMART. During the SBLOCA scenario, in the CMT the water layer inventory was well stratified thermally and the safety injection water was injected efficiently into the RPV from the initial period and cools down the RCS properly.

ACKNOWLEDGEMENT

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