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Performance Tests of Three Flow Distributors Using SMART-ITL with 1-Train CMT

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1. Introduction

Passive safety systems (PSSs) are under study in the nuclear field after the Fukushima accidents. Chang *et. al*. [1] focused on three issues of decay heat removal without AC power, severe accident mitigations, and the necessity of the additional passive safety systems. Passive safety systems are key tools to remove the heat from the core or containment. Safety improvements for SMART have been studied since the Standard Design Approval (SDA) for SMART was certificated in 2012. [2] Active safety systems such as safety injection pumps are replaced by a passive system [3], which is a kind of the gravity injection system with core makeup tanks (CMT) and safety injection tanks (SIT). All tanks for the passive safety systems are located higher than a pressurized reactor vessel, whose injection nozzles are located around the reactor coolant pumps (RCP).

An Integral Test Loop for the SMART design (SMART-ITL) [4] has been constructed and its commissioning tests finished in 2012. SMART-ITL is scaled down by the volume scaling methodology. Its height is conserved and its volume scale ratio is 1/49. The SMART-ITL has all fluid systems of SMART together with a break system and instruments.

Recently, a test program to validate the performance of SMART Passive Safety System (PSS) was launched. A scaled-down test facility for SMART PSS was additionally installed at the existing SMART-ITL facility [5, 6] and a set of validation tests were performed. In this paper, the performance tests of the flow distributors using SMART-ITL with 1-train CMT will be discussed.

2. Methods and Results

2.1 Overview of SMART-ITL

SMART is a 330 MW thermal power reactor, and its core exit temperature and PZR pressure are 323℃ and 15 MPa during normal working conditions, respectively. The maximum power of the core heater in 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 conditions of SMART.

The reactor coolant pump (RCP) was designed geometrically by the volume scale law, which was applied to the diameter of suction and discharge, and the liquid volume. The scale ratio of the flow rate was in proportion to the related power ratio of the core heater. Four reactor coolant pumps were installed in the upper annulus side of the pressure vessel at an angle of 90 ^{o}.

Four once-through steam generators with a helical coil were installed at the same azimuth as the RCP outside the reactor pressure vessel of SMART-ITL. The steam generator consists of primary and secondary sides. The primary function of the SG is to remove the heat of the RCS. The heat of the primary side is transferred to the secondary side in the steam generator, while the hot reactor coolant is floating through the cell side and the feed water is traveling through the tube side. To simulate the characteristics of the heat transfer, it was designed such that the surface area of the tube was properly scaled down with the scale ratio.

The secondary system consists of a feed water supply system, steam supply system, and condensation and cooling system. It is important to supply the feed water with a constant temperature and to generate the super-heated steam as the boundary values.

The passive residual heat removal system (PRHRS) plays a role in removing the residual heat of the core when an accident that decreases the pressure of the RCS, for example an SBLOCA, occurs. It has four trains. Each train has an emergency coolant tank and heat exchanger for the condensation of the steam. One makeup tank per train was installed for the pressure compensation. Individual components were scaled down by the volume scale ratio, and the pipes were designed for conserving the similarity of the pressure drop.

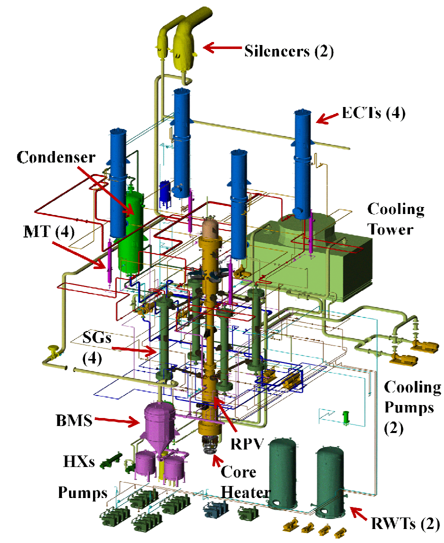

Fig. 1. Schematics of the SMART-ITL.

2.2 Passive Safety System

The passive safety system includes the core makeup tank (CMT) and safety injection tank (SIT). 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 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 gravity force caused by the height difference because all tanks are higher than the injection nozzle around the reactor coolant pumps (RCP).

Fig. 2 shows schematics of one train for the passive safety system of SMART-ITL. Each pipe has an isolation valve and flow meter. Deferential pressure and temperature can be measured for every pipe and tank. A level and pressure transmitter is installed in each tank.

The phenomena of flashing and direct contact condensation are expected to occur in the CMT, SIT, and pipes at 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.

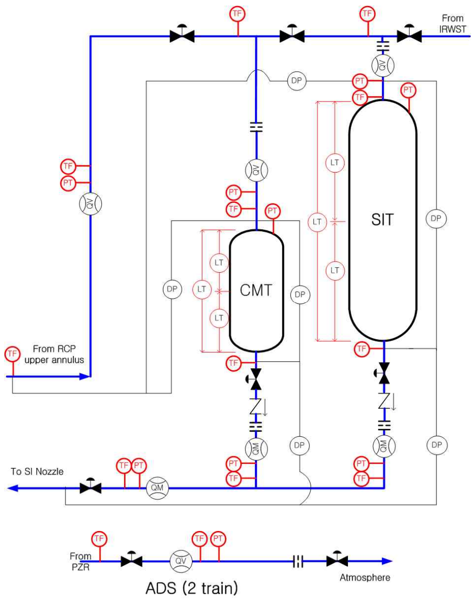

Fig. 2 Schematics of the test facility for SMART passive safety system

2.3 Scaling Methodology

CMT and SIT is designed by the volume scale law of 1/49. Their heights are conserved. The diameter is scaled down to 1/7, and the area of the tank cross-section is scaled to 1/49. The primary scale variables are listed in table I.

To maintain the characteristics of pressure drop in the pipes between a proto-plant and a facility, local phenomena scaling method was applied. The local scale variables are listed in Table II. First, a scale factor, k, for the diameter to satisfy the volume ratio of pipes was assumed. A length ratio was derived by substituting the factor into the volume scale ratio. Using these two ratios, a temporary k_1 can be selected to satisfy the Friction Number and Orifice Number. Second, another k_2 was selected to satisfy the ratio of the pressure drop, flow rate, and so on. Finally, through the best estimation, a specific k was determined to avoid the distortion of the real phenomena.

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^2_{0R}	1/49
Volume, V_{0R}	$d^2_{0R}\, l_{0R}$	1/49
Time scale	$l^{1/2}_{0R}$	1/1
Velocity	$l^{1/2}_{0R}$	1/1
Flow rate	$a_{0R}\, l^{1/2}_{0R}$	1/49
Pressure drop	l_{0R}	1/1

Table II: Local scale variables

Parameters	Scale Ratio	Value
Length, l_L	l_L	V_{OR} / k^2
Diameter, d_L	d_L	k
Area, a_L	d^2_L	k^2
Volume, V_L	V_L	V_{OR}
Time scale	$l^{1/2}_L$	$(V_{OR})^{1/2} / k$
Velocity	$l^{1/2}_L$	$(V_{OR})^{1/2} / k$
Flow rate	$a_{0R}\, l^{1/2}_{0R}$	$k * (V_{OR})^{1/2}$
Pressure drop	l_L	V_{OR} / k^2

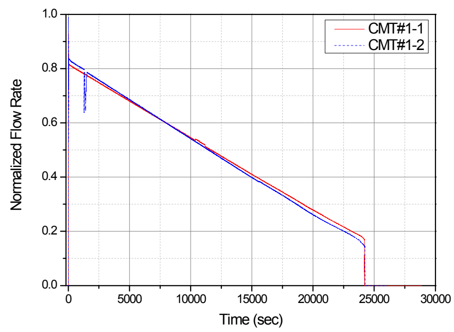

Fig. 3. Injection flow rate of 1-train CMT.

2.4 Cold State Tests: Flow Resistance Coefficient in Injection Line

The flow rate under a gravity injection condition depends on the differential pressure in the injection line. By adjusting the orifice size, the differential pressure can be controlled. Differential pressure tests were performed to determine an orifice size in the injection line of a core makeup tank (CMT). The tests were carried out in two steps for two different CMTs, which were a full-height CMT of #1-1 with a 1/49 volume compared with SMART, and a half-height CMT of #1-2 with the same scaled volume. As a first step, a basic differential pressure was measured without each orifice. The diameter of the orifice was determined by the estimation of the flow resistance coefficient to satisfy the design value in the injection line. As a second step, the differential pressure through the orifice was measured. Injection flow rate curves for the CMTs with two different heights are well matched for the slope and end time of the injection.

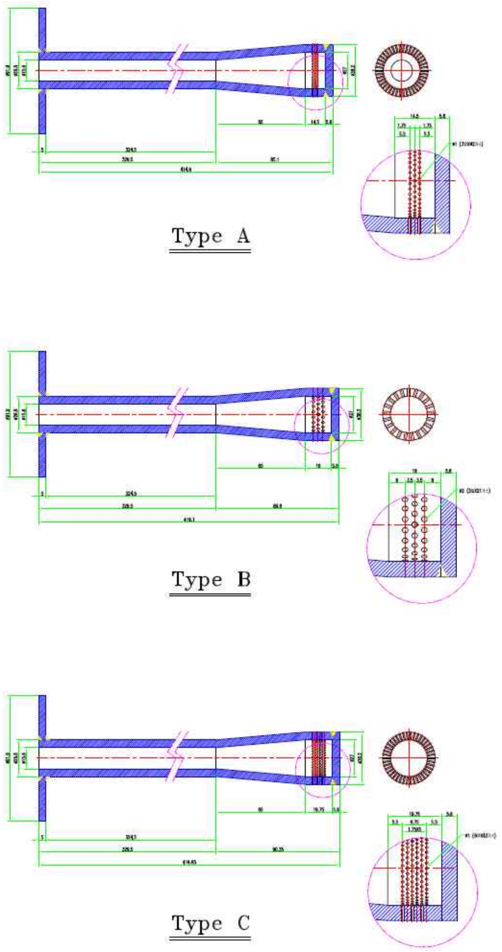

Fig. 4. Diagrams of 3-different flow distributors

2.5 Performance of Flow Distributors during a Simplified SBLOCA Scenario

Flow distributors have been announced to reduce sudden thermo-hydraulic phenomena such as a direct contact condensation in a pool or tank. Three kinds of flow distributors were designed with different sizes and numbers of holes, as shown in Fig. 4. In order to estimate the effect of flow distributors connected with an upper nozzle of CMT #1-2, a simplified SBLOCA scenario was simulated by skipping the decay power and PRHRS actuation, as shown in Table III.

Fig. 5 shows the pressure distributions with repeatable and reproducible behaviors during a simplified SBLOCA simulation. This means that each test was performed under reliable boundary conditions.

Fig. 6 shows the flow rate. During the initial stage of the CMT injection, the water is injected efficiently from the start even though a direct condensation of steam occurs at the upper header of the CMT. After 10,000 seconds, the flow rate slopes of the hot test are similar with that of the cold test.

Fig. 7 shows the differential pressure distribution. Similar trends were identified except for the case of Type C with a concave shape in the early stage. These phenomena appear in the flow rate as well. This can be explained by a dependence on the flow rate for the differential pressure.

Fig. 8 shows the level of CMT #1-2. As the flow rate and differential pressure decrease, the CMT level also decreases. In the case of type C, the decreasing slope is delayed rather than the others. This is also caused by less flow rate in the early stage.

Fig. 9 shows the temperature results. During the initial stage of the CMT injection, the fluid temperature measured in CMT#1-2 shows good stratification phenomena. As the surface level is decreased, the surface temperature is also decreased along the saturation temperature and a lower water temperature is gradually increased. It is estimated that the upper-side CMT#1-2 is filled with super-heated steam.

Finally, an additional test without a flow distributor is performed as well. In this case, all of the trends are almost the same as the others with flow distributors.

Table III Sequence of a simplified SBLOCA test

Event	Trip signal and Set-point
Break	-
LPP set-point	PZR Press = P_{LPP}
LPP reactor trip signal - Pump coastdown - CMTAS triggering	LPP+1.1 s
Control rod insert	LPP+1.6 s
CMT injection start	LPP+2.2 s
FW stop FIV/MSIV close	LPP+25.2 s
Test end	-

3. Conclusions

A 1-train passive safety system including a CMT and SIT, which is operated only by gravity force, was additionally installed in the SMART-ITL to replace the active safety system for the SMART design. Several performance tests for the flow distributors were carried out to estimate a designed flow rate.

1. The peak flow rate in a hot test does not reach the value in a cold test, and the approaching time to peak is also delayed during the early stage of gravity injection.
2. It is verified that the flow rate from a gravity injection depends on the differential pressure in the injection pipe line including a friction and form drag, which can be adjusted by controlling the resistance coefficient.

All of the behaviors are reasonable even though the results from a flow distributor of type C such as a flow rate and differential pressure are a little different from others during the early stage. The gravity injection performances according a different type of flow distributors including the case without a flow distributor in the hot tests are in good agreement with the cold test except the early stage. All amounts of injection flow rates are estimated to be almost the same for all cases.

ACKNOWLEDGEMENT

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REFERENCES

[1] S. H. Chang, S. H. Kim, and J. Y. Choi, Design of integrated Passive Safety System (IPSS) for Ultimate Passive Safety of Nuclear Power Plants, Nuclear Engineering and Design, Vol.260, p.104, 2013.
[2] Y. M. Bae, Report of Passive Safety System, SER-410-FS403-SD, 2012.
[3] Kim, K. K. et al., 2014. SMART: The First Licensed Advanced Integral Reactor, *Journal of Energy and Power Engineering*, 8, 94-102.
[4] Park, H.S., Yi, S.J., Song, C.H., 2013, SMR Accident Simulation in Experimental Test Loop, *Nuclear Engineering International*, November 2013, 12-15.
[5] H. Bae, D. E. Kim, S. J. Yi, and H. S. Park, Test Facility Design for the Validation of SMART Passive Safety System, *Transactions of the Korean Nuclear Society Spring Meeting*, Gwangju, Korea, May 30-31, 2013.
[6] D. E. Kim, H. Bae, S. J. Yi, and H. S. Park, Experimental Facility Design for Assessment of SMART Passive Safety System Concept, *Transactions of the Korean Nuclear Society Spring Meeting*, Gwangju, Korea, May 30-31, 2013.

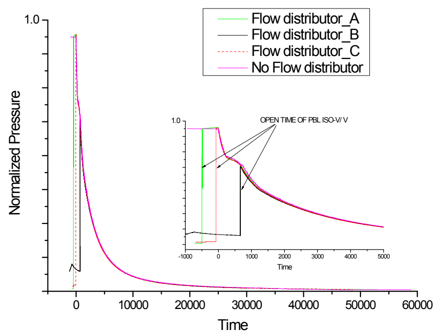

Fig. 5. Pressure distributions for flow distributors

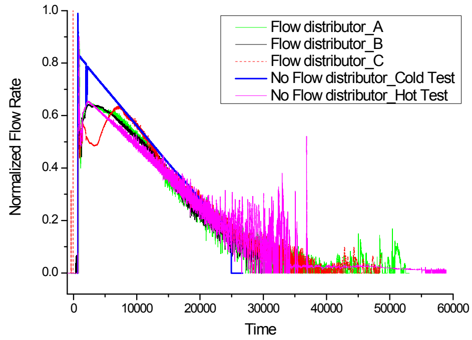

Fig. 6. Flow rate curves for flow distributors

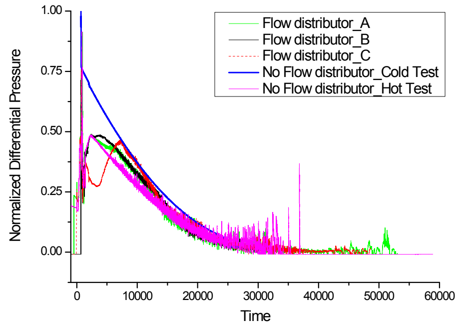

Fig. 7. Differential pressure distribution for flow distributors

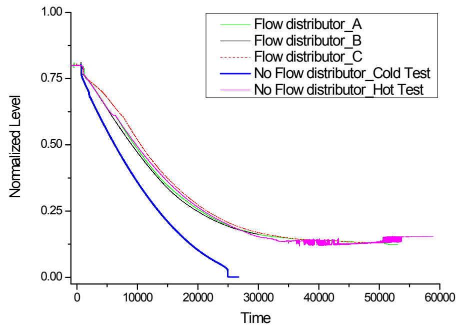

Fig.8. Level of CMT #1-2 for flow distributors

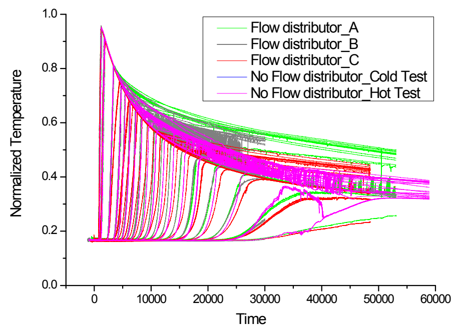

Fig. 9. Temperature distributions for flow distributors