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Passive Cooling Test using a Full-Height Test Facility for SMART CPRSS

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1. Introduction

A newly developed passive containment cooling system (PCCS) of system-integrated modular advanced reactor (SMART) [1] is containment pressure and radioactivity suppression system (CPRSS) [2]. Recently, an integral system test apparatus for SMART CPRSS (SISTA2) was constructed to investigate the full-height integral effect for the validation of SMART CPRSS. There was a previous study on pressure and temperature distribution during 10,000 seconds after SBLOCA [3].

In this study, we introduced the SISTA2 and integral effect test results during 3 days after SBLOCA occurred.

2. Experimental Facility

The SISTA2 was designed and constructed according to the volume scaling ratio of 1/750 with design values of SMART CPRSS. Detailed descriptions about scaling and components of SISTA2 were presented in previous paper [3]. Figure 1 presents a schematic diagram of SISTA2.

The lower containment area (LCA) is divided into four sections in the SISTA2; LCA reactor vessel (LCA_RV), LCA lid cover (LCA_Lid), LCA core makeup tank (LCA_CMT), and LCA safety injection tank (LCA_SIT). These tanks simulate free volume of each section, the volumes of internal structures (RV, pressurizer, CMT and SIT) were excluded.

The emergency cool-down tank (ECT) and CPRSS heat exchanger (CHX) are heat sink for LCA pressure and temperature reduction. The CHX is composed of heat exchanger tubes and it is immersed inside ECT. The in-containment refueling water storage tank (IRWST) reduces pressure and temperature of LCA in the beginning of transients of break accidents. Two types of spargers are in the IRWST.

The radioactive material removal tank (RRT) is to remove radioactive materials from IRWST by chemical reaction. However, it is a water tank without chemical material in the SISTA2. The upper containment area (UCA) was simulated as half of scaled-down volume with one main tank and four sub-tanks. The steam supply tank (SST) generates saturated steam and injects it to the LCA_RV for break simulation.

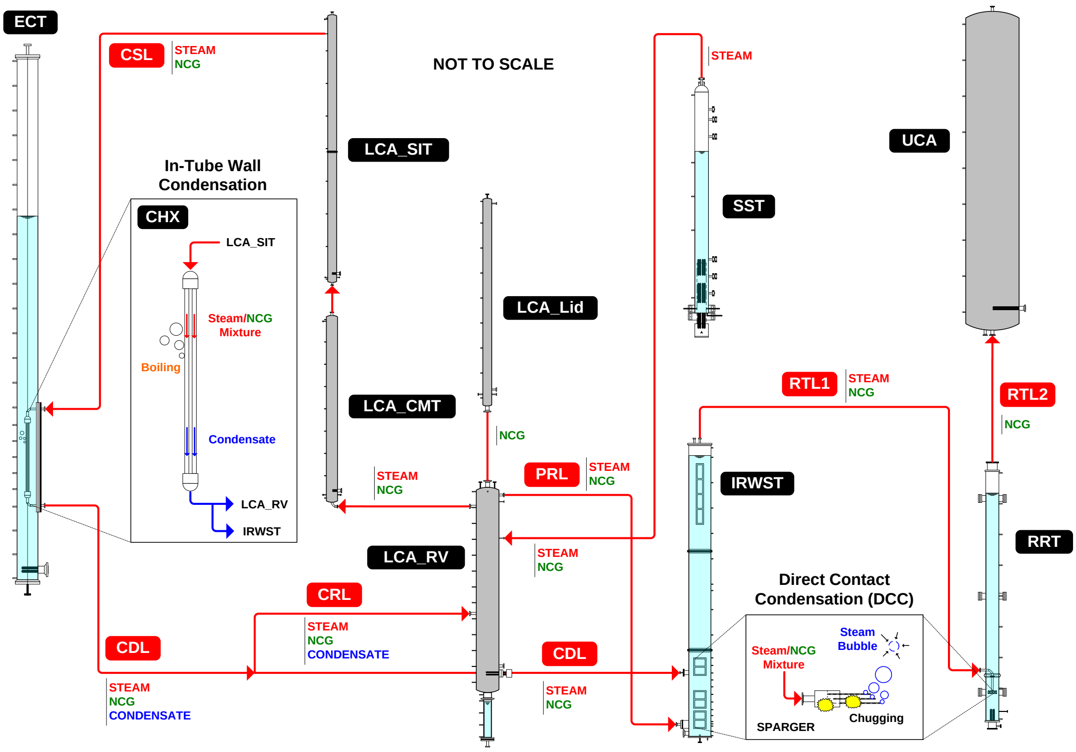

Fig. 1. Schematic diagram of SISTA2

3. Experimental Results

The passive cooling test was carried out to simulate an integral system effect of passive cooling behavior on SMART CPRSS during 3 days after SBLOCA using SISTA2. Initial conditions of each component were adjusted to meet design values and compensate heat loss of structure as shown in Table 1. All the initial conditions of components were measured as designed values but the wall temperature on the LCA was increased to compensate the excessive passive heat sink due to heat capacity of LCA tanks. Experimental results were displayed as non-dimensional values according to the data management policy.

Table 1 Initial Conditions of Components.

	Temperature (℃)		Water level (m)	
	Design	Measured	Design	Measured
IRWST	50	50 (Bulk)	8.5	8.5
RRT	50	50 (Bulk)	6.24	6.24
ECT	100	100 (Bulk)	8	8
LCA	50	100 (Wall)*	0	0

3.1 Injected steam mass flow rate

The injected steam flow rate at the break point was obtained as the design flow rate with an additional steam flow rate to compensate for heat loss. Heat loss test was conducted to quantify the minimum steam flow rate to maintain LCA pressure as constant. The sum of the design value and the compensated heat loss was simulated. Figure 2 shows the steam flow rate injected into the LCA, and while the steam injection flow rate was high at the beginning of the accident simulation, the steam flow rate decreased to about 10% after one day (86,400 seconds). To precisely measure the injected steam flow rate, two mass flow meters with different measurement ranges were installed in a steam supply line, and thus instantaneous flow rate disturbance occurred when changing from a high flow meter (QM-SS-01) to a low flow meter (QM-SS-02) in about 12,500 seconds. However, considering the total test time scale, it can be confirmed that there was no significant effect on the test due to its momentary change.

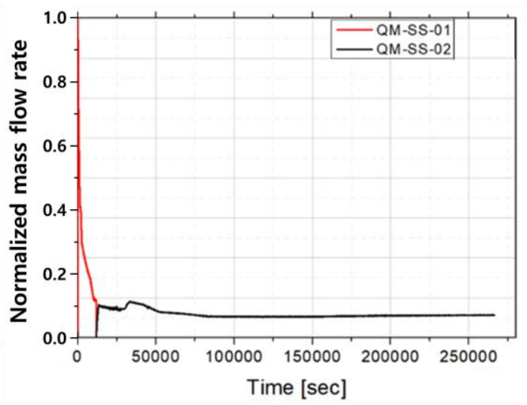

Fig. 2. Simulation of break mass flow rate

3.2 Pressure distribution

Figure 3 presents the pressure distribution of major components. At the beginning of the SBLOCA simulation, the pressure of LCA_RV (PT-RV) rapidly rose due to the high flow rate of steam flowed into the LCA. At the same time, the pressure of the IRWST (PT-IRWST) also rose sequentially as the mixture of non-condensable gas and the steam filling the LCA was discharged to the IRWST through the CPRSS discharge line (CDL) and pressure release line (PRL). The steam discharged into the IRWST was condensed due to the direct contact condensation by the coolant in the IRWST. Only the non-condensable gas could penetrate the IRWST and was accumulated at the upper part of the IRWST. When the pressure of IRWST became higher than the water pressure of RRT, the non-condensable gas of IRWST was discharged into RRT and UCA, which increased the pressure of RRT and UCA (PT-RRT and PT-UCA). The pressure differences between each tank were due to the differences of water pressure.

The pressure rise of the abovementioned major components occurred within a short time (around 1,000 seconds) with the SBLOCA simulation, and after the pressure of LCA_RV reached the highest point, the pressure of IRWST, RRT, and UCA increased very slightly. This means that the non-condensable gas placed in the release path was discharged significantly at the beginning of the SBLOCA, however, the non-condensable gas placed in the lower part of the LCA_RV was not discharged since it was located far from the steam injection point. It also means that if the LCA is not sufficiently pressurized, it is difficult for the non-condensable gas to overcome the water pressure of each tank and move to the UCA.

After 50,000 seconds, the pressure of LCA reduced as the amount of injected steam mass flow decreased following the reduction of simulated residual heat. After 1 day, it remained below 80% of the maximum pressure at the beginning of the SBLOCA simulation.

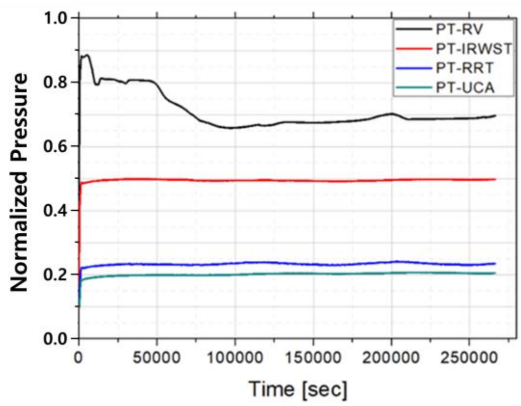

Fig. 3. Pressure distribution in components

3.3 Temperature distribution

Temperature distribution of each component informs the heat transfer characteristics in SMART CPRSS. As shown in Fig. 4, the temperatures of the water inside the ECT, IRWST, and RRT gradually decreased due to heat loss to the atmosphere (i.e. natural cooling) despite the conditions under which the injected steam was compensated for heat loss. On the other hand, the temperatures of the LCA including LCA_RV, LCA_Lid, LCA_CMT, and LCA_SIT were maintained at the saturated steam temperature by the injection of compensated steam flow rate. Especially, since the heat loss amount by natural cooling of ECT was relatively larger than the amount of heat transfer from CHX to ECT, the water temperature of ECT continued to decrease and it was in balance with injected steam flow rate into LCA. It means that the pressure of LCA can be maintained by passive heat sink in the system.

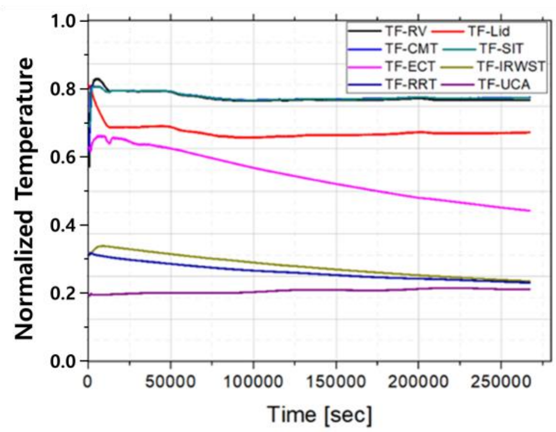

Fig. 4. Temperature distribution in components

4. Conclusions

A passive cooling test with full-height test facility, SISTA2, was conducted during 3 days. It was confirmed that the LCA pressure can be maintained under the peak pressure at the beginning of SBLOCA simulation with passive heat sink, for example, natural cooling of ECT. As a further study, it seems necessary to conduct conservative condition test under which the temperature of ECT is maintained as constant.

ABBREVIATION

CPRSS: containment pressure and radioactivity suppression system
LCA: lower containment area
IRWST: In-containment refueling water storage tank
RRT: radioactive material removal tank
UCA: upper containment area
PRL: pressure relief line
RTL: radioactive material transport line
CHRS: CPRSS heat removal system
CSL: CPRSS steam line
CDL: CPRSS discharge line
CRL: CPRSS return line
CHX: CPRSS heat exchanger
RV: reactor vessel
CMT: core make-up tank
SIT: safety injection tank

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