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Conceptual Validation Test of CPRSS with SISTA

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1. Introduction

The integral type reactor, SMART [1], uses direct contact condensation in the in-containment refueling water storage tank (IRWST), and wall condensation in the vertical heat exchanger (HX) in the emergency cooldown tank (ECT) as a passive containment cooling system (PCCS) when a break accident occurs. The containment consists of lower containment area (LCA) and upper containment area (UCA). The PCCS of SMART is called as containment pressure and radioactivity suppression system (CPRSS). The IRWST and the HX of ECT prevent over-pressurizing and over-heating of the LCA as well as reduce amount of radioactive substance into the UCA.

Korea Atomic Energy Research Institute (KAERI) carried out a pre-project engineering (PPE) for export of system-integrated modular advanced reactor (SMART). The objective of this study is a thermal-hydraulic validation of the CPRSS design concept with a scaled down test facility, SMART IRWST separated test apparatus (SISTA).

2. Features of Experimental Facility: SISTA

In this section the features of CPRSS, such as design concept and main components will be described and the scaled down test facility, SISTA is introduced.

2.1 CPRSS

The CPRSS was designed to suppress the increase of pressure and temperature (P/T) in the containment area following accident such as loss of coolant accident (LOCA), and to remove the radioactive fission products from the reactor containment area. The system keeps the containment area P/T from exceeding the design values with sufficient margin during 72 hours without AC power sources or operator actions. After 72 hours, the CPRSS decreases the LCA P/T with the support of the non-safety system and maintains the LCA P/T with the increased design margin.

As shown in Fig. 1(a), the CPRSS is comprised of CPRSS lid, pressure relief lines (PRLs) and PRL-spargers, an IRWST, radioactive material transport lines (RTLs) and RTL-spargers, two radioactive material removal tanks (RRTs), CPRSS heat removal system (CHRS) as a subsystem of the CPRSS, and instruments. The CHRS consists of four mechanically independent trains. Each train of CHRS comprises one CPRSS heat exchanger (CHX), a CPRSS steam line (CSL), two CSL isolation valves, a CPRSS discharge line (CDL) and CDL-spargers, two CDL isolation valves, a CPRSS return line (CRL), one CRL isolation valve, one emergency cooldown tank (ECT) [2].

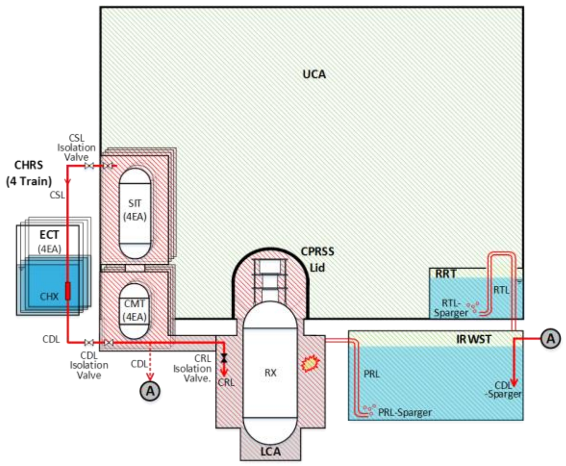
2.2 SISTA

The SISTA is a 1/5,000 scaled down separated effect test facility to validate the CPRSS design concept during anticipated accidents, small break loss of coolant accident (SBLOCA). The SISTA was scaled down following the Ishii's scaling method [3]. Table I shows a scaling table of SISTA. The reduced height of test facility affects characteristics of thermal mixing caused by distorted natural circulation. The Ishii's scaling method considers the effects of reduced height by conducting the scaling analysis and adopting appropriate scaling ratios in time, power, steam flow rate and so on. The ideal geometric ratios of scaling are 1/10 of height, 1/500 of area and 1/5,000 of volume from prototype.

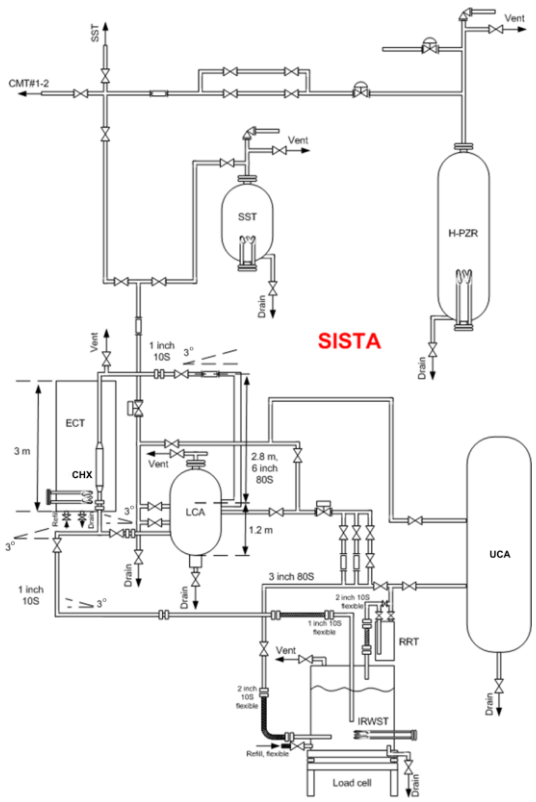
As shown in Fig. 1(b), the SISTA consists of steam injection systems, LCA, ECT & CHX, IRWST, PRL & CDL spargers, RRT & RTL sparger, and UCA. The steam injection systems are composed of steam supply Tank (SST) of SMART-ITL and pressurizer (PZR) of Hybrid Safety Injection Tank (HSIT), which is called as H-PZR, for low and high pressure steam injection, respectively. The IRWST plays as a heat sink, which is equipped with two spargers to induce thermal mixing in the water tank. The UCA (break pool) is a pressure boundary which is connected to the top of the RRT, and it was closed during the experiments. The design values of CPRSS had been modified and the previous SISTA [4] was refurbished.

Table I: Scaling Table

Parameters	Scale Ratio	Value
Height, h_{0R}	h_{0R}	1/10
Diameter, d_{0R}	d_{0R}	$1/10\sqrt{5}$
Area, a_{0R}	$d_{0R}^{\ 2}$	1/500
Volume, V_{0R}	$d^2_{0R}\, h_{0R}$	1/5,000
Time	$h_{0R}^{\ 1/2}$	$1/\sqrt{10}$
Flowrate	$a_{0R}\, h_{0R}^{\ 1/2}$	$1/500\sqrt{10}$
Hydraulic pressure	h_{0R}	1/10



(a) Schematic of CPRSS



(b) Schematic of SISTA

Fig. 1. Schematic of CPRSS and SISTA

3. Conceptual Validation Test Results

The SBLOCA scenario was simulated with a scaled-down break nozzle in the LCA. The location of the steam inlet nozzle on the LCA was determined considering the location of safety injection line of the SMART. The scaled down injected mass flow rate following the scaling table was simulated through the inlet nozzle. The design values of boundary steam flow rate, pressures and temperatures were defined by MARS-KS 1.4 code calculation results [5].

3.1 Boundary condition: steam injection flow rate

Fig. 2 shows the comparison of design values and experimental values. After passing the measurement available range of the flowmeter, the injected steam mass flowrate was estimated based on the mass of the condensed steam using the load cell installed in the IRWST. Measurements were not made in the range of about 600 seconds to 700 seconds, but the continuity of the two graphs can be seen that the initial transient simulation for 6,000 seconds fits well compared to the design value. After 6,000 seconds, the test was not possible due to the limitation of the amount of steam supplied from the H-PZR.

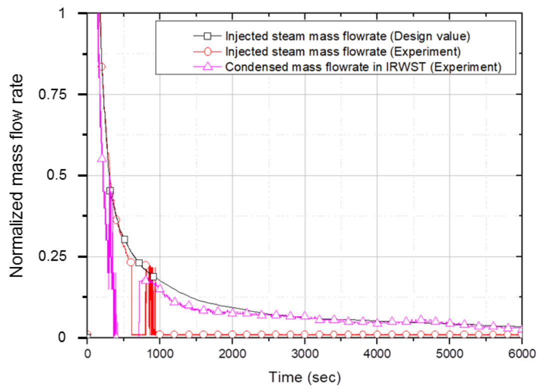
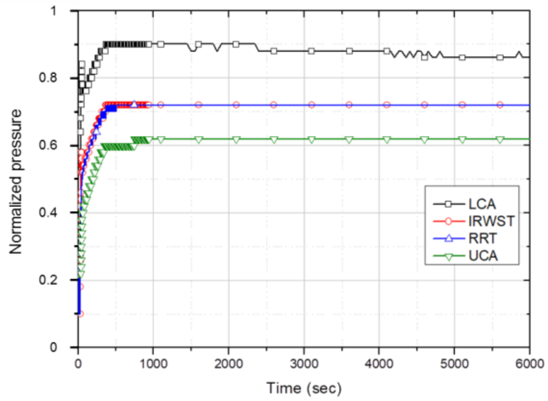


Fig. 2. Normalized mass flow rate in conceptual test

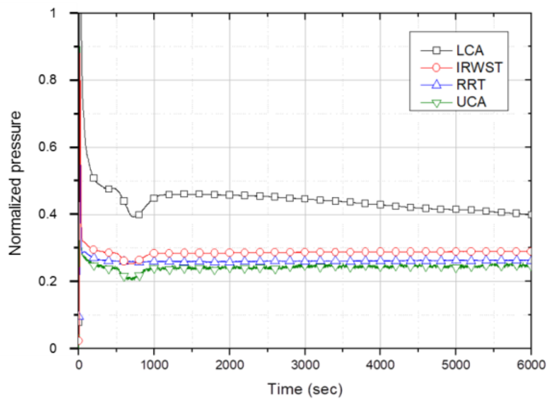
3.2 Pressure behavior

Fig. 3 shows the overall pressure behavior in the SISTA. Compared to the design values, the experimental results have lower pressure values. The UCA is the boundary pressure in the system, the other part is determined by the pressure value based on the UCA. It can be explained as that the UCA is not enough pressed against the design value. Assuming that the mass flowrate injected into the LCA is similar to one from the LCA to the IRWST, the reasons why the UCA pressure is not pressurized are that 1) heat loss due to the structure and 2) difference of non-condensable gas behavior between design and experiment in the LCA. In the design, the heat loss due to the LCA structure is neglected, but there is heat loss due to the low temperature structure in the experiment. Even the LCA structure is preheated by tracing heater to 100 ℃ or more before the experiment, but the heat loss in the structure cannot be ignored. Also, while calculating the design values by MARS code, the steam inflow was simulated at the bottom of the LCA, but in the experiment it flows in the lateral direction of LCA and is also emitted to the lateral direction of PRL outlet.

That induced the flow distribution formed inside the LCA was not proper to move non-condensable gas from the LCA than the design condition.



(a) Design value

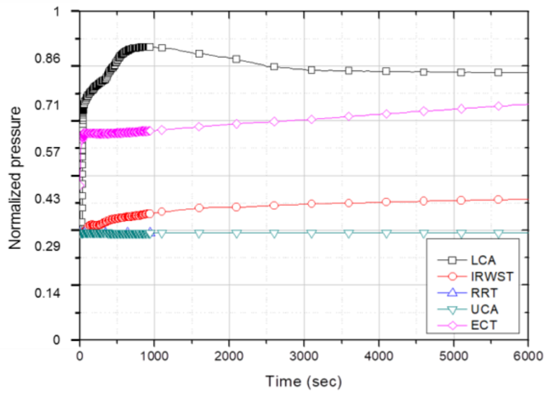


(b) Experimental results

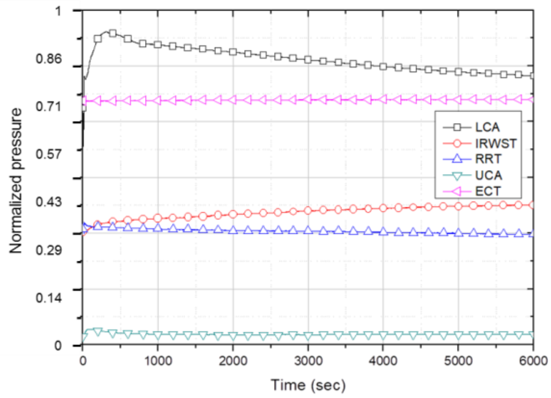
Fig. 3. Normalized pressures in conceptual test

3.3 Temperature distribution

Fig. 4 presents the overall temperature behavior in the SISTA. The temperature distributions of the design values and the experimental values are similar except for the temperature of UCA. Initial temperature of the UCA cannot be controlled because there is no heat source such as heater inside. It can be seen that the temperature increase rate of each component slightly differs, but the temperature of each component after 6,000 seconds has similar value. Although the pressure distribution of each component is different, it can be confirmed that the design value and the experimental result are similar because the mass flowrate is similar to each other.



(a) Design value



(b) Experimental results

Fig. 4. Normalized temperatures in conceptual test

4. Conclusion

The SISTA which is a separate effect test facility for a conceptual validation of SMART CPRSS was constructed and the SBLOCA scenario was simulated. The main components of SMART CPRSS were reduced and simplified, but it was able to simulate thermal hydraulic phenomena similar to the design values of the prototype.

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