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Preliminary Study on the Cooling Performance of Passive Emergency Core Cooling System

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1. Introduction

The passive emergency core cooling system (PECCS) proposed by Korea Hydro and Nuclear Power (KHNP) is designed to maintain core cooling and prevent nuclear fuel damage in the event of NPP design basis accident (DBA). It has a design feature that allows an unpowered passive injection in lieu of the pump-driven injection method [1]. As illustrated in Figure 1, the PECCS is composed of an injection system consisting of two hybrid safety injection tanks (H-SIT) and two medium pressure safety injection tanks (MP-SIT) and an automatic depressurization system (ADS) consisting of four stages. The H-SIT ensures emergency coolant injection into the core in the high-pressure region between the reactor coolant system (RCS) operation pressure (15.0 MPa) and the MP-SIT operation pressure (4.2 MPa). While its tank design is identical to that of a conventional SIT, the upper part of the tank and the cold leg are connected with a pressure balancing line (PBL), and the gravity-driven injection of cooling water from the tank into the reactor takes place at high pressure.

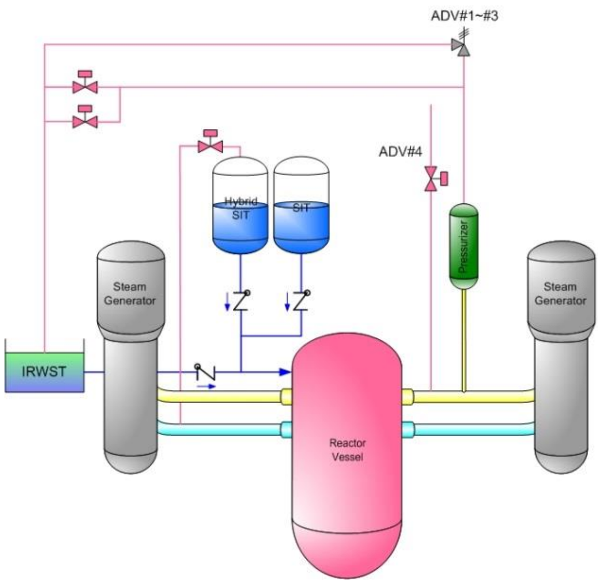

Figure 1 Schematic diagram of PECCS

In this study, an integral effect test (IET) was conducted on a loss of coolant accident (LOCA), which requires the operation of the primary makeup system, in order to confirm the performance of each PECCS component. A LOCA is an accident caused by a pipe break in the reactor coolant pressure boundary that results in a loss of reactor coolant at a rate in excess of the capability of a normal reactor coolant makeup system. A classic small break LOCA (SBLOCA) scenario with a break area of 0.024 square feet (two-inch break) was selected for PECCS performance analysis.

2. Experiments and Results

In this section, the experimental methods and results are suggested and analyzed.

2.1 Experimental setup and conditions

The Integrated Effect Test (IET) of PECCS was performed using an ATLAS (Advanced Thermal-Hydraulic Test Loop for Accident Simulation) already installed in the KAERI. Figure 2 is a schematic representation of the IET facility used in this study, in which SITs #1 and #3 were used as H-SIT and SITs #2 and #4 as MP-SIT. The SIT height and inner diameter are 5.03m and 0.2365m, respectively, and the design pressure and temperature are 17.0 MPa and 350 °C.

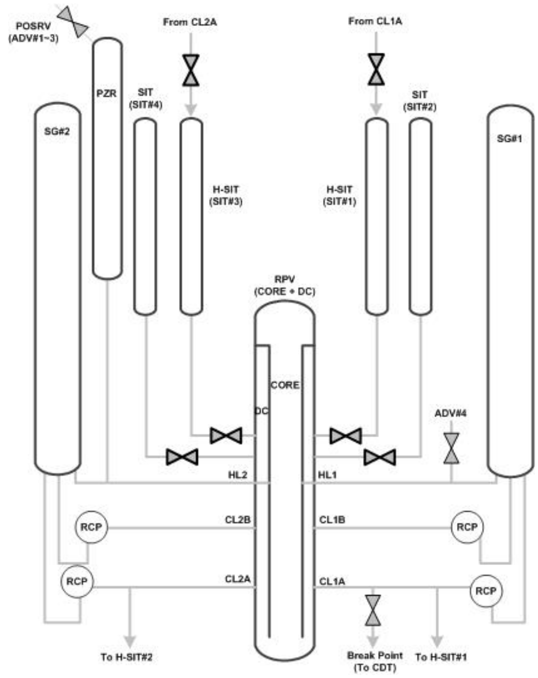

Figure 2 Experimental setup

Table 1 presents the scaling ratio of the ATLAS facility relative to the Advanced Power Reactor Plus (APR+). The newly installed SIT-related systems were also configured in strict adherence to this scaling ratio. The SIT height and inner diameter are 5.03m and

0.2365m, respectively, and the design pressure and temperature are 17.0 MPa and 350 °C.

Table 1 Major scaling parameters of the ATLAS

Parameters	Scaling ratio	ATLAS design
Length (height)	l_{oR}	1/2
Diameter	d_{oR}	1/12.85
Area	d_{oR}^2	1/165
Volume	$l_{oR}\ d_{oR}^2$	1/330
Core temperature rise	T_{oR}	1
Velocity	$l_{oR}^{1/2}$	1/1.414
Time	$l_{oR}^{1/2}$	1/1.414
Core power	$l_{oR}^{1/2}\ d_{oR}^2$	1/233.3
Flow rate	$l_{oR}^{1/2}\ d_{oR}^2$	1/233.3

2.2 Results

Figure 3 plots the pressures of the RCS and the secondary side. The time points of important events are plotted in the Figure as well. At the moment of the cold leg break (0 s), the steady-state pressure of the pressurizer (15.5 MPa) started to decreased and the pressure reached the pressure was reduced to 10.0 MPa (at 141 s), the operation condition of H-SIT. The primary side pressure that had been decreasing sharply began to slow down as it reached ~8.5 MPa, stagnating at ~8.0 MPa without any significant fluctuations for over 2,000 s, thus forming a pressure plateau section. In this relatively stable flat plateau section of the pressure level caused by the loop seal blockage, the pressure is maintained at around the same level despite the continuing coolant discharge through the break. From 3,222 s onwards, when ADVs #1 ~ #3 were opened by the operator, the primary side pressure started to drop again, accelerating from 3,430 s onwards when ADV #4 was opened. On reaching the pressure level of ~1.2 MPa (3,600 s), however, the pressure drop rate began to decrease rapidly as a result of the decrease in the flow rate of the coolant passing through ADV #4 from 3,600 s onwards.

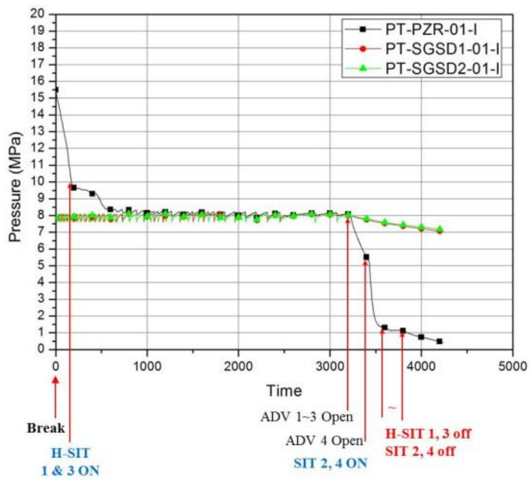

Figure 3 Pressure of PZR and SG

Figure 4 plots the collapsed water levels of the RV. From 0 to 500 seconds after the break, the collapsed water levels of the core region and the down-comer region decreased rapidly due to the decrease in coolant inventory. From the 500 s, the down-comer collapsed water level was maintained relatively stable at around 3.4 m, the level of cold leg and hot leg piping, up to 2,500 s. This phenomenon is caused by the loop seal blockage in the cold leg from this height that allows the water level in the down-comer region connected to the cold leg to remain constant independently of the water level or pressure in the core region. However, the core water level continued to fall past the 500 s mark until it reached the pressure plateau section, where it was maintained constant up to ~2,300 s, and started to fall again for ~200 s. The decrease in water level up to 1,200 s is caused by the primary side pressure fall; the decrease in the core water level is associated with the increase in the pressure difference between the core region and the down-comer region along with a very active boiling of the core coolant prompted by the lowered pressure, given that the coolant is constantly maintained at the saturation temperature. For the same reason, the core water level showed a behavior sensitive to the intermittent pressure change caused by the opening of the MSSV. Once the pressure plateau section is reached, a constant water level is maintained, with the pressure gap between the two sections stabilized. While the pressure is maintained at a stable level for a longer time, the primary side coolant continues to flow out through the break, and the MSSV opening cycle gets longer as the secondary-side coolant inventory decreases with the repeated opening and closing of the MSSV. With decreasing coolant inventory and performance, the core water level gradually falls from 2,300 s onwards. At around 2,500 s, the core water level rose as the down-comer water level was decreasing, which is ascribable to the loop seal clearing.

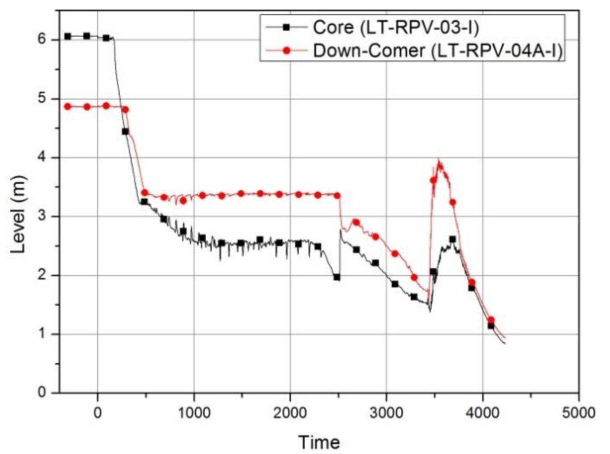

Figure 4 Collapsed Water Level of RV

3. Conclusions

In this study, the simulation of transient accident was performed on the two-inch cold leg break selected from the ATLAS-based SBLOCA scenarios to assess the cooling performance of the passive emergency core cooling system. The H-SIT (SITs #1 and #3) injection starts successfully at the moment when the primary side pressure falls to 10.0 MPa, and the MP-SIT (SITs #2 and #4) injection starts when the pressure falls further to 4.21 MPa. The operation condition such as PCT for ADVs #1 – #4 constituting the auto depressurization system (ADS) needs to be added. The rationale for this modification is the possibility of operation failure of ADVs in appropriate moments if a specific water level condition is configured as the ADV operation condition because the fluid introduced through the PBL affects the SIT water level.

ACKNOWLEDGEMENTS

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[1] S.H. Kang, H.G. Kim, 2013. Preliminary performance and sensitivity analysis of hybrid safety injection system for passive emergency core cooling system. In: Trans. of the KNS Spring Meeting, Gwangju, Korea, May 30–31.