Analysis of Thermal Mixing Behavior of the Emergency Cooling Tank using the CUPID Code

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1. Introduction

Recently, Korea has launched a program to develop an innovative Small Modular Reactor (i-SMR) with 540 MWth. This i-SMR adopts two passive safety systems, the Passive Auxiliary Feedwater System (PAFS) and the Passive Containment Cooling System (PCCS), to provide both of emergency core cooling and long-term cooling. These two systems are located in a single heat exchanger called the Emergency Cooling Tank (ECT). Therefore, accurately predicting the thermal mixing phenomenon inside the tank during the simultaneous operation of both passive safety systems is essential for evaluating the residual heat removal capability. In this paper, we provide supplementary information for the design of the i-SMR's ECT based on three types of sensitivity analyses using the geometry information of SMART.

2. Calculation Conditions and Results

2.1 Problem Definition

As shown in Figure 1, the PAFS heat exchanger is located in the bottom region off the ECT and the inlet and outlet pipes of PCCS are connected to the ECT. In the event of an accident where both PAFS and PCCS operate simultaneously, thermal mixing occurs inside the ECT due to natural convection, which determines the inlet temperature of the PCCS. Since the inlet temperature of the PCCS is a key indicator of its heat removal performance, three kinds of sensitivity analyses were performed based on: 1) the height difference between the PCCS and the ECT, 2) the location of the connecting pipes, and 3) the operation of the PAFS. The sensitivity analysis cases are summarized in Table 1.

Table 1. Sensitivity calculation cases

Differential Head	
Case1	3.6 m
Case2	7.2 m
Case3	10.8 m
Locations of Connecting Pipes	
Case4	Reference case
Case5	Variation of inlet pipe location
Case6	Variation of outlet pipe location
PAFS Operation	
Case7	PAFS Activation
Case8	PAFS Inactivation

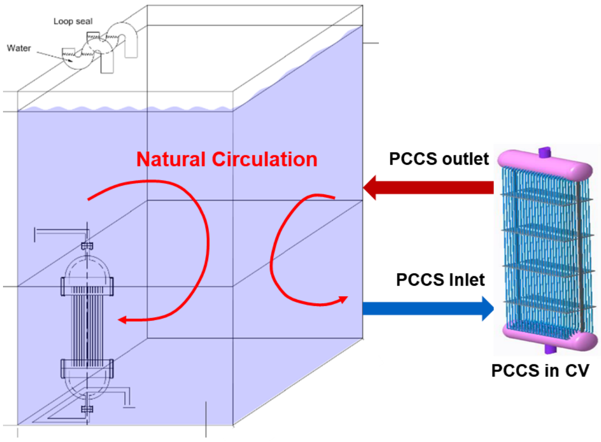

Fig. 1. Conceptual Diagram of ECT

2.2 Differential Head

Sensitivity calculations were performed by varying the height difference between the PCCS and the ECT, as shown in Figure 2. As the height difference increased, the natural convection flow rate increased, resulting in an increase in the heat removal rate through the PCCS. Consequently, as shown in Figure 3, the fluid temperature at the PCCS outlet pipe increased, but there was no significant difference in the fluid temperature at the inlet pipe.

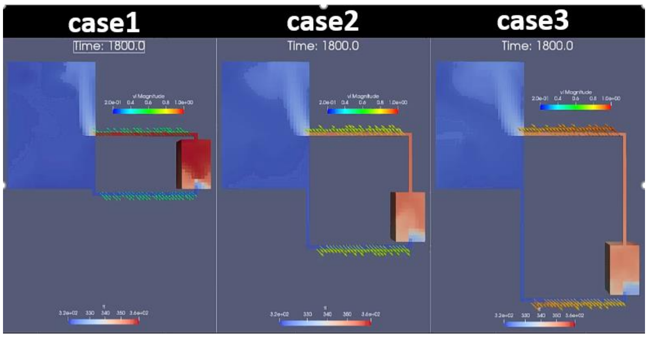

Fig. 2. Geometries and calculation results of sensitivity cases for the differential heat

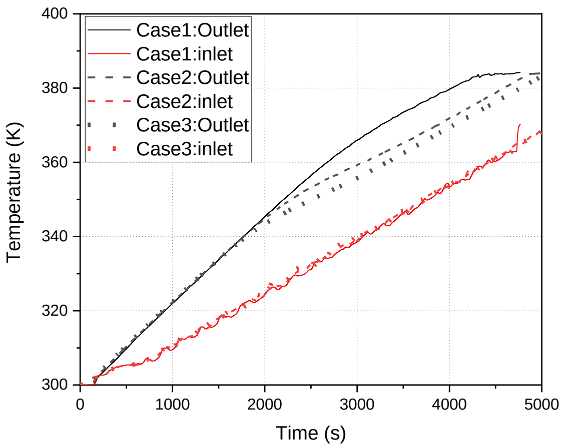

Fig. 3. Calculation results of cases 1 to 3

2.3 Locations of Connecting Pipes

As shown in Figure 4, sensitivity analysis was performed for the connecting locations of PCCS's inlet and outlet pipes. The thermal mixing behavior in ECT was not changed significantly depending on the relative position of PCCS pipes and PAFS. As a result, there was no significant difference in the fluid temperature of the PCCS inlet pipe in cases 4 to 6.

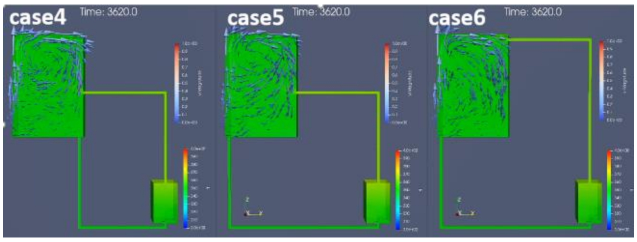

Fig. 4. Geometries and calculation results of sensitivity cases for the locations of connecting pipes

2.4 PAFS Operation

Since the PAFS heat exchanger is located in the bottom region of the ECT, it promotes heat mixing by enhancing natural convection when the PAFS is in operation. The temperature distribution inside ECT and the PCCS inlet temperature according to the operation of PAFS were calculated. When PAFS fails, the natural circulation by the buoyancy flow in the ECT disappears. Therefore, the hot water discharged from the PCCS outlet pipe is stratified as a thermal layer on the upper part of ECT, and the fluid temperature of the PCCS inlet pipe remains low, close to the initial temperature.

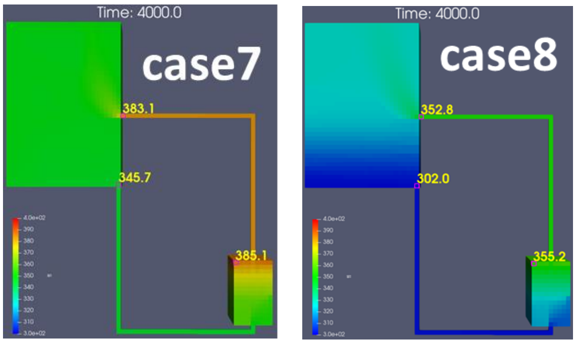

Fig. 5. Calculation results of sensitivity cases for the PAFS operation

3. Conclusions

Three kinds of sensitivity calculations were performed to generate the auxiliary data for the ECT design. The height difference between ECT and PCCS showed results proportional to natural convection flow rate and heat removal performance, while the connection pipe position had a very minimal impact. In the event of a PAFS failure, the fluid temperature of the PCCS inlet pipe decreased, resulting in an increase in PCCS heat removal performance. This implies that the one-dimensional simulations, which are used in the current ECT design and safety analysis, will show conservative results since it use the average fluid temperature as the PCCS inlet temperature,

REFERENCES

[1] NuScale Power, NuScale Standard Plant Design Certification Application: Chapter fifteen, Corvallis, Oregon, 2016.