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Preliminary Study on Design of Passive Containment Cooling System (PCCS)

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1. Introduction

After the Fukushima nuclear power plant accident, one of the most important design change issues is a new concept of an entirely passive safety system including the current design modification. To passively cooldown the steam released from the primary or secondary sides of the reactor into the containment during accident conditions, the design of Passive Containment Cooling System (PCCS) is strongly required. Because the coolant recirculation between the primary RCS and containment is restricted by a steam cooling capacity of the PCCS, the proper passive cooling design of the PCCS is very important. Two design concepts are compared in this paper: the internal containment Heat Exchanger (Hx) design and the external containment Hx design. The MARS-KS code was used for the performance evaluation with varying several design parameters.

2. Design of PCCS

2.1 General Assumption

The reactor power and decay heat curve of APR1400 was used to evaluate the cooling capacity of the PCCS. A vertically arrayed Hx tubes in the PCCS were designed by referring the design of the Passive Auxiliary Feedwater System (PAFS). A total of 480 tubes with a diameter of 2 inch and a length of 8.5 m were assumed. The bundle effect was neglected in the modeling. To model the containment, the effects of the internal structures were neglected while the height and effective volume above the RCS level were preserved.

The difference between two PCCS designs is the location of the Hx tubes. The location affects not only the condensation heat transfer but also the possibility of release of radioactive materials to an environment.

2.2. Internal Hx Design and Nodalization

Figure 1 shows the MARS-KS model of the PCCS with internal Hx. The Hx tubes are located in a upper region of the containment. Containment (MD110) was modeled with a multi-dimensional component with 3, 4, and 5 nodes in radial, azimuthial, and axial direction, respectively. The Hx tubes (P260, P261) and the condensing pool (P240) were modeled with pipe components. Decay heat from the reactor core was simulated by the steam injection via a time dependant junction (TDJ105) with the assumption that the decay heat is consumed to generate the steam.

2.3. External Hx Design and Nodalization

External Hx design is identical to that of the internal design except the location of Hx as shown in Fig. 2.

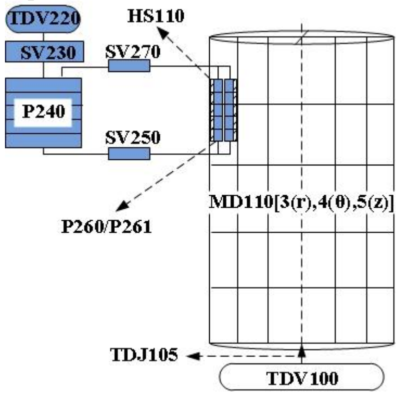

Fig. 1. MARS model for internal Hx design

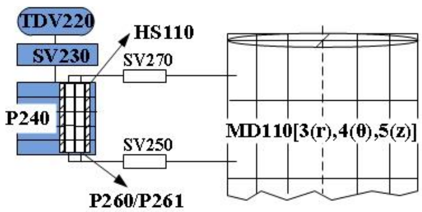

Fig. 2. MARS model for external Hx design

3. Evaluation of Cooling Capability

A sensitivity study was performed by varying 4 effective parameters on the design: 1) Location of Hx tube, 2) size of the node where the Hx is located, 3) existence of non-condensable gas, and 4) the heat transfer area of Hx tube. A total of 10 cases were calculated as given in Table 1.

3.1Location of Hx Tube

When the identical node and initial condition were applied, the heat removal capability can be estimated from Fig. 3. In the case of the internal Hx design, the condensation heat transfer coefficient (HTC) increases and the containment pressure is effectively decreased.

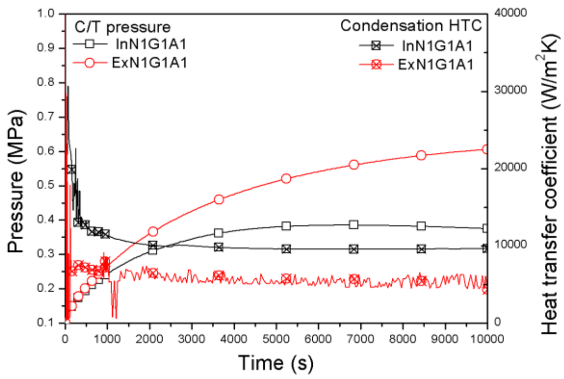

Fig. 3. Effect of Hx tube location

Table 1. Calculation matrix

Design	Node size of containment	Initial condition of containment	Heat transfer area	Case Name
Internal	1m (3D)	steam 100%	x 1	InN1G1A1
			x 2	InN1G1A2
			x 4	InN1G1A3
		air 100%	x 1	InN1G2A1
		air 100% + 10% of air injection		InN1G3A1
	2m (3D)	steam 100%		InN2G1A1
	4m (3D)	steam 100%		InN3G1A1
	25m (1D)	steam 100%		InN4G1A1
External	1m (3D)	steam 100%		ExN1G1A1
		air 100%		ExN1G2A1

3.2 Node Size

As shown in Fig.4, the HTC increases with an increase of the containment node size. The condensation heat transfer model used in the MARS-KS code is Shah's model developed in 1979, which has a strong function of static quality. Thus, the decrease of containment pressure is large in the case of a large node.

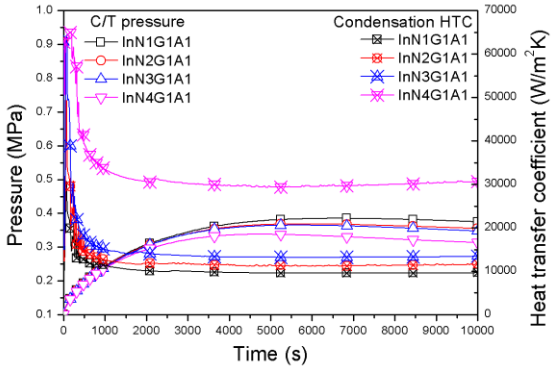

Fig. 4. Effect of node size

3.3 Non-condensable Gas

Three calculations were performed with a change of filling gas in the containment to estimate the effect of a non-condensable gas. As initial conditions, 100 percent of the air or steam was assumed. The third case assumed 100 percent of air for the initial condition and additionally injected air flow corresponding to 10 percent of injected steam flow. As shown in Fig. 5, the HTC decreases when the air exists in the containment so that the pressure of the containment increases.

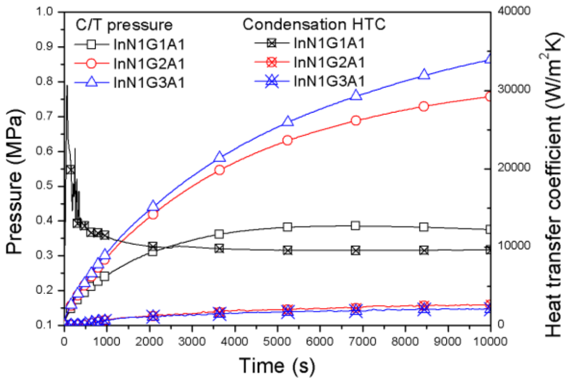

Fig. 5. Effect of non-condensable gas

3.4 Heat Transfer Area

Considering a design of fins at the outside surface of the Hx tubes, the sensitivity tests were performed by varying the tube surface area, but the flow area was preserved. As shown in Fig. 6, the pressure of the containment decreases with an increase in the surface area while the HTC is not considerably changed.

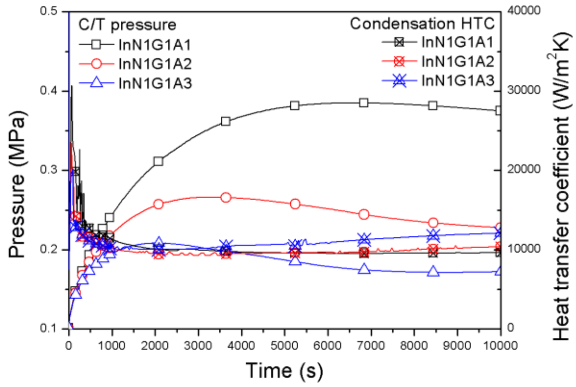

Fig. 6. Effect of heat transfer area

4. Conclusions

The PCCS was conceptually designed based on the design data of the APR1400 such as the decay heat power, the size of containment, the Hx tube size, and so on. The calculation results show that the PCCS with external Hx tubes has more efficient cooling capability than that of internal Hx tube design. Also, it seems to need a fin design at the surface of the Hx tubes to increase the heat transfer area because the existence of air in the containment significantly deteriorates the condensation heat transfer. However, since the HTC calculated by the MARS-KS code is strongly dependant on the node size, it is required to quantitatively validate the heat removal capacity of the conceptually designed PCCS estimated in this paper.

ACKNOWLEDGEMENT

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