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Containment PT Analysis According to the Several PCCS Design using MARS-KS 1.4 code

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1. Introduction

After Fukushima accident, the importance of passive safety system has been emphasized. Especially, passive safety systems, which conclude passive containment cooling system, passive core cooling system and etc., are continually being developed to ensure containment integrity for long-term cooling under severe accident condition such as a station black-out (SBO). At present, studies on the development of passive cooling systems in Gen III and Gen III+ nuclear power plants are actively conducted for accident mitigation by long-term heat removal.

The present study focuses on passive containment cooling system (PCCS). A containment is the last barrier for preventing radioactive materials release to the environment. Various PCCS concepts and designs have been suggested and already adopted on several nuclear power plants such as AP600/1000 (USA), ESBWR(USA), VVER1200 (Russia) [1]. In Korea, iPOWER, which is now under development by KHNP, adopts the heat exchanger type of PCCS which is similar with VVER1200 [2].

In this study, various types of PCCS are analyzed to evaluate natural circulation capability and the heat removal performance of containment. This study provides a technical basis for the selection of suitable PCCS type for underground nuclear power plant.

2. Methods and Results

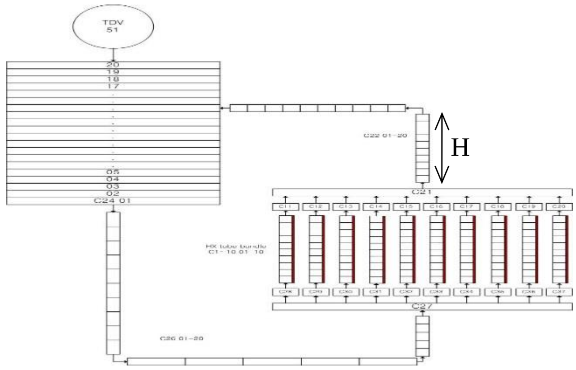
2.1. PCCS Modeling

A preliminary performance evaluation is carried out by using MARS-KS code to evaluate the natural circulation and heat removal ability of PCCS which includes a shell-and-tube type heat exchanger. The design data of PCCS is obtained from heat exchanger design of iPOWER. The PCCS of iPOWER consists of total four trains, but in this study, only one train is modeled and analyzed. The specific design dates used in the heat exchanger modeling are given Table 1.

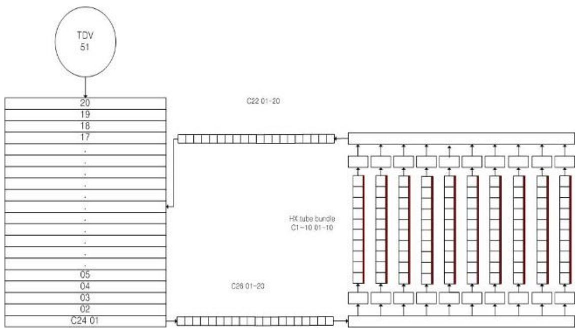
Table I: Specific design data of heat exchanger [3]

Parameter	Upper/lower head	Heat exchanger tube
O.D(m)	0.4/0.3	0.04
Thickness(cm)	0.3/0.3	0.3
Length(m)	3.44/3.44	5
Numbers	1/1	252
Arrangement	-	6×42

In order to analyze the natural circulation performance according to the location of the heat exchanger and the piping connected to the passive containment cooling tank (PCCT), two types of PCCS are modeled as shown in Figure 1.



Case 1



Case 2

Fig. 1. MARS-KS nodalization of passive containment cooling system

In Figure 1, the one train of PCCS has ten bundle of heat exchanger with each bundle header. The one bundle of heat exchanger has 6×42(252) tubes. The heat transfer area of one bundle is $380m^2$, and total heat transfer area is $3800\,m^2$. In this study, the one bundle of heat exchanger is modeled as one lumped pipe. And, a total of ten heat exchangers are connected to the PCCT through common pipe to form natural circulation loop. It is assumed that the heat is exchanged only between the heat exchanger tubes and dummy volume for modeling of containment.

In case 1, the length of vertical pipe (H) among the connected pipe with PCCT at the upper part of heat exchanger is changed to 1, 5 and 9m. This is to show the natural circulation performance depending on the differential head of heat exchanger and PCCT. PCCT and heat exchanger modeling of case 1 and case2 is the same, but the connection position of pipe is different.

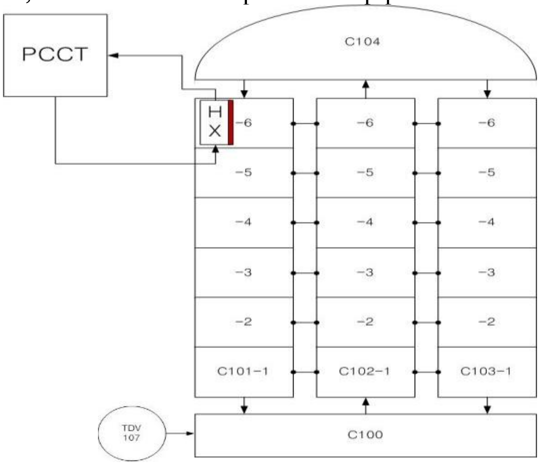


Fig. 2. MARS-KS nodalization of containment

2.2. Containment Modeling

The containment volume is modeled as shown Figure 2 by referring to the containment design data of OPR1000, Yeong-Gwang 3&4. The internal structure in the containment is not considered. For the preliminary performance evaluation of PCCS, it is assumed that the containment is filled with high temperature and pressure steam, and uniform boundary condition continually imposes to containment atmosphere for simulation such as LOCA. Containment initial condition is 390K and 180kPa, and vapor is fully filled.

As shown in Figure 2, the containment is cooled by the heat exchanger through the heat structure directly below the containment dome region. The variables of interest are the pressure and temperature variations at the dome location, mass flow rate at the inlet, that is from PCCT to heat exchanger, and cumulative heat removal amount.

2.3. Analysis Results

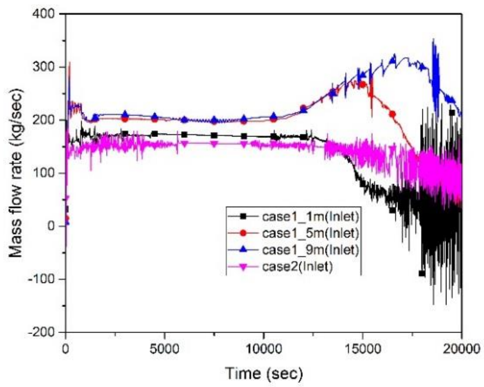


Fig. 3. Comparison of the mass flow rate for the each PCCS designs

Figure 3 shows that the mass flow rate at the inlet in case 1 is higher than that of case 2. Also, it is confirmed that the mass flow rate is the highest when the length of vertical pops is 9m. This means that case 1 has stronger natural circulation ability than case 2. In case of natural circulation, with larger height difference between heat source and heat sink, there are greater driving force. Therefore, there is better natural circulation formed due to the difference of head by higher elevation difference between PCCT and heat exchanger. However, it shows that mass flow rate is decreased after about 15000s.

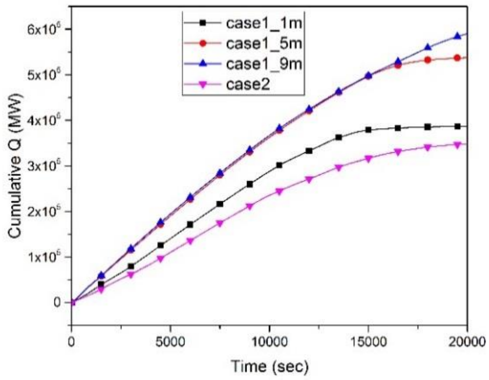


Fig. 4. Comparison of Cumulative heat removal amount for each PCCS designs

Because the natural circulation of case 1 is more active, the accumulated heat removal from the containment is also higher in case 1 as shown in Figure 4. As the mass flow rate decreases in the later part of the transient, the amount of cumulative heat removal also becomes gradually saturated.

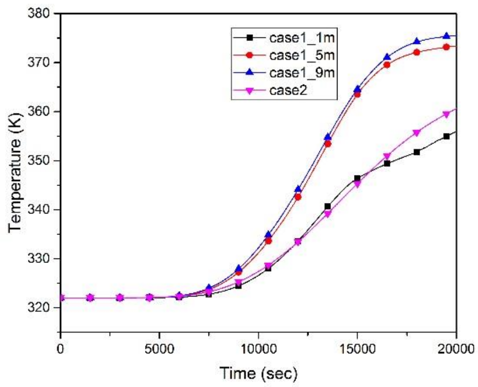


Fig. 5. Comparison of the temperature of bottom on PCCT

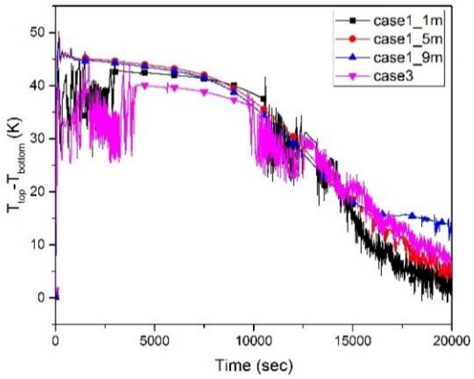


Fig. 6. Comparison of temperature difference between the upper and lower tube of heat exchanger

Figure 5 shows the temperature at the bottom of PCCT. Case 1 shows that the PCCT temperature increases more rapidly than case 2. This is because more heat is removed at earlier part of the transient in case 1. In other words, more heat is taken from the containment to the PCCT. The temperature differences between the upper part and the lower part of heat exchanger in the later part of the transient shown in Figure 6, are smaller than case 2. As a result, because of the reduction in temperature difference, the mass flow rate decreases about 15000s as shown in Figure 3.

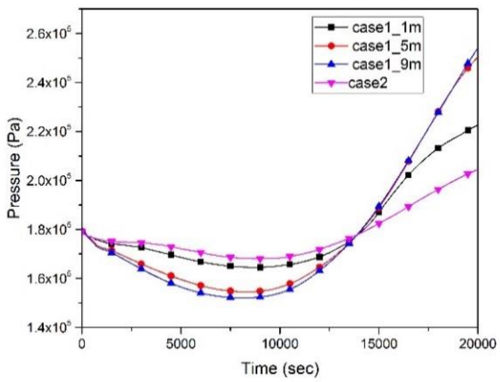


Fig. 7. Comparison of containment temperature variations

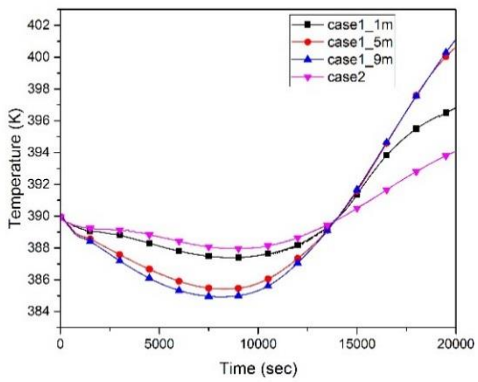


Fig. 8. Comparison of containment pressure variations

Figure 7 and 8 show the pressure and temperature at the containment dome position. Pressure and temperature decrease until roughly 14000s and they increase from 14000s. Until about 14000s, it can be seen that the heat exchanger type of case 1 cools the atmosphere of the containment better. Also, pressure and temperature are calculated to be the lowest when the case 1 is 9m. But, after 14000s, pressure and temperature of case 2 are calculated to be the lowest. As mentioned above, the case 1 of temperature of PCCT increases faster than that in case 2 because the amount of initial heat removal in case 1 is relatively high. Therefore, the temperature difference in natural circulation decreases over time as compared to case 2, so the natural circulation ability decreases. As a result, the pressure and temperature of containment continually increase with time.

3. Conclusions

This study is conducted to investigate the heat removal performance according to the connection method of PCCS and heat exchanger. Case 1 has more heat removal than case 2. But, as time goes on, the pressure consistently increases as compared to case 2. This is considered to be influenced by the condition of the containment used in this study. In this calculation, the containment is maintained as a constant high temperature and pressure steam, so it has a different aspect with real accident condition such as LOCA. For a more accurate analysis, it is necessary to proceed analysis under the accident condition of the actual power plant. It is also shown that the heat exchanger type of case 2 has sufficient heat removal and natural circulation performance.

In the future, an appropriate PCCS type that can be applied to the underground nuclear power plant considered in this study will be selected. In order to do this, it is necessary to analyze the actual performance of the PCCS in a severe accident condition.

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