Assessment of the effect of nitrogen gas on passive containment cooling system performance

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1. Introduction

As a part of the passive containment cooling system (PCCS) of Innovative PWR development project, we have been investigating the effect of the nitrogen gas released from safety injection tank (SIT) on PCCS performance. With the design characteristics of APR1400 and conceptual design of PCCS, we developed a GOTHIC model of the APR1400 containment with PCCS. The calculation model is described herein, and representative results from the calculation are presented as well. The results of the present work will be used for the design of PCCS.

2. Calculation Methodology

In this section the input parameters used to model APR1400 containment for GOTHIC are described. The containment model consists of control volumes, flow paths, and thermal conductors.

2.1 Calculation Case

The Large-break loss of coolant accident (LBLOCA) and the assumption, that all active components were disabled, were used in the present study. The containment building was initially filled with air. Immediately after the accident initiation, PCCS began to work. The SIT nitrogen gas was assumed to be released into the containment atmosphere directly. The numerical model was computed for 72 hours after the accident initiation.

2.2 Calculation Model

2.2.1 Computer Code

The thermal-hydraulic phenomena in the containment building were calculated using the Gothic code, Version 8.0. The GOTHIC code is designed to calculate the thermal-hydraulic behavior in a containment building from design basis accident and severe accident sequences. Using the GOTHIC code, detailed thermal-hydraulic information in various containment volume can be investigated.

2.2.2 Initial Condition and Input Parameter.

Containment initial conditions are summarized as follows:

<u>Containment</u>
- Temperature : 326.45K
- Pressure : 116.52 kPa
- Relative humidity : 5%

<u>PCCS pool</u>
- Temperature : 322.05K
- Pressure : 97.77 kPa

<u>SIT</u>
- Temperature : 322.05K
- Pressure : 4462.03 kPa

In the present paper, the mass and energy release data from LBLOCA calculation, in the Preliminary Safety Analysis Report of APR1400, were used as the boundary conditions for the GOTHIC calculation. The mass and energy discharge rates are shown in Fig. 1 and Fig. 2.

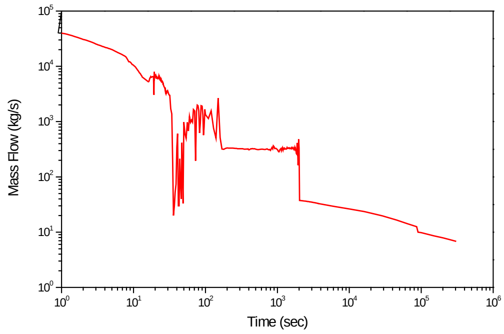

Fig. 1. Mass discharge rate (kg/s) for LBLOCA.

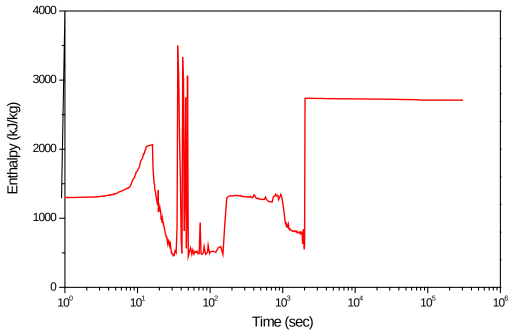

Fig. 2. Enthalpy discharge (kJ/kg) for LBLOCA

Fig. 3 shows the mass discharge rate of nitrogen gas released from SIT

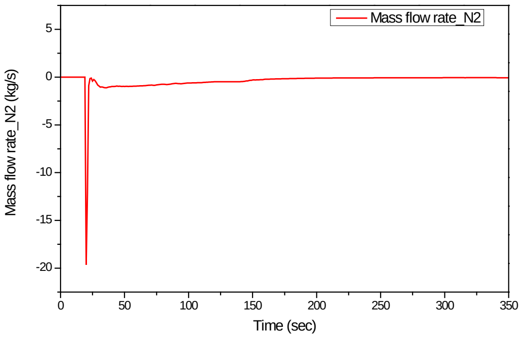

Fig. 3. Mass discharge rate (kg/s) of nitrogen gas.

2.2.3 GOTHIC Model

The nodalization of containment volume for the GOTHIC computation is shown in Fig. 4. The calculation model was composed of 6 control volumes, 8 flow paths, 4 components, and 19 thermal conductors. The containment volume was divided into containment atmosphere volume and IRWST volume. The each of four SITs was modeled as a single volume filled with nitrogen gas, respectively. Each heat exchanger of PCCS (PCCX) was also modeled as a subdivided single volume. Direct/UCHIDA and DLM-FM were used as the condensation model of passive heat sinks and PCCX.

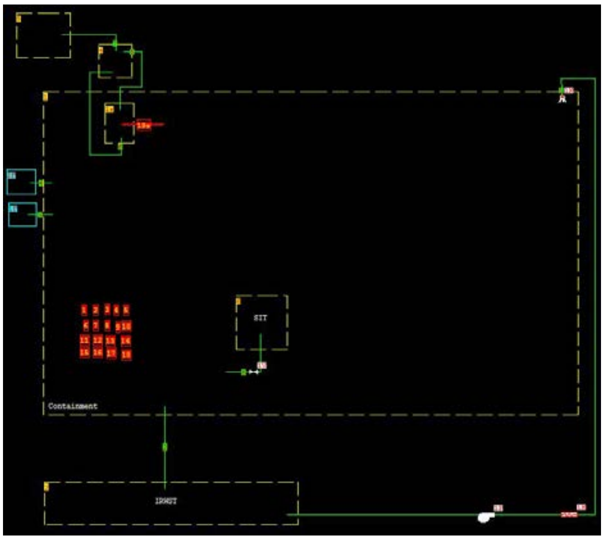

Fig. 4. GOTHIC containment model.

3. Calculation Results

The calculation cases are summarized in Table 1. Fig. 5 shows the response of the containment pressure of case 1 and 2. At 19.52s, the SIT nitrogen gas was released into the containment atmosphere. The amount of released nitrogen gas is approximately 3 vol% of the amount of air that was inside the containment. As seen from the figure, it was observed that the pressure of case 2 is slightly higher than case 1. It is determined that the expansion of released nitrogen gas and reduction of the heat removal rate by thermal conductors influence the containment pressure rise.

Table. 1 Calculation case

Case No.	Condensation model		Nitrogen gas
	Passive heat sinks	PCCX	
1	UCHIDA	DLM-FM	X
2	UCHIDA	DLM-FM	O
3	UCHIDA	UCHIDA	X
4	UCHIDA	UCHIDA	O

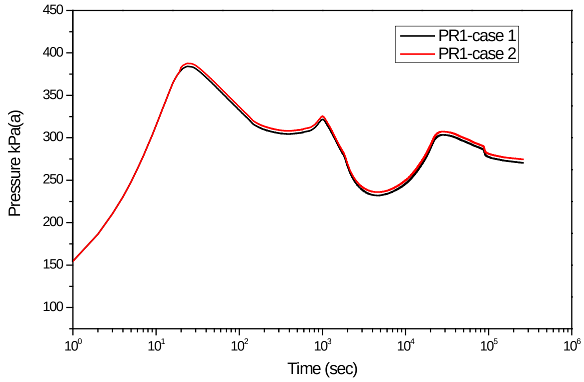

Fig. 5. Comparison of containment pressure transient response of case 1 and 2.

Fig. 6 and Fig. 7 show the comparison of heat removal rate of thermal conductors of case 1 and 2. The difference of heat removal rate is negligible. It suggests that there is no reduction of heat removal rate due to the released nitrogen gas. The heat removal rate of thermal conductors generally decreases as the concentration of the non-condensable gas rises. Review in detail, the heat removal rate by passive heat sinks with UCHIDA condensation model affected only by the non-condensable gas concentration is reduced. However, HX of PCCS with DLM-FM condensation model heat removal rate is decreased immediately after the nitrogen gas release, but rose again. For DLM-FM model, heat transfer rate is increased as the pressure rise. Because of this, heat removal rate by PCCS is expected to increase. In Fig. 8 it becomes clearer. If the condensation model of PCCX is UCHIDA, it can be seen that the heat removal rate is reduced regardless of the increase in the containment pressure. Due to this complementary relationship, the heat removal rate difference is determined to be little. Hence, the cause of containment pressure rise is from the expansion of the released nitrogen gas rather than reduction of heat removal rate.

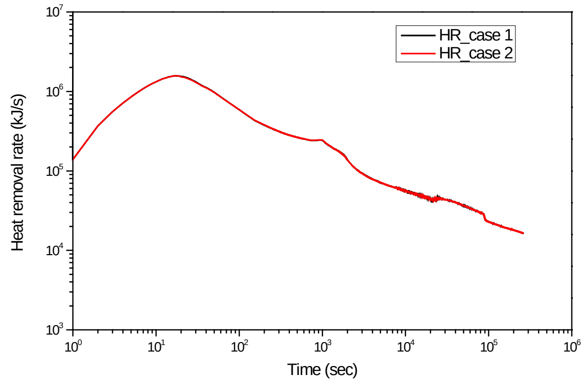

Fig. 6. Comparison of total heat removal rate of thermal conductors of case 1 and 2.

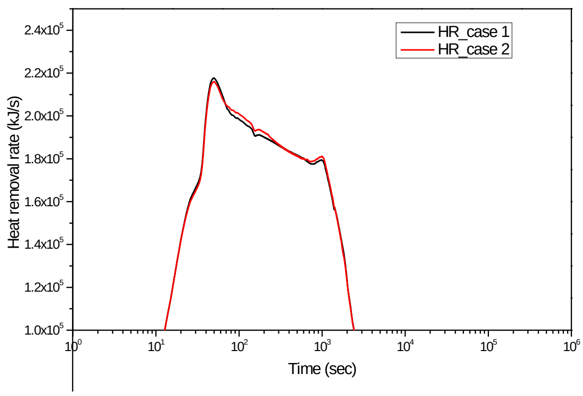

Fig. 7. Comparison of heat removal rate of PCCS conductor of case 1 and 2.

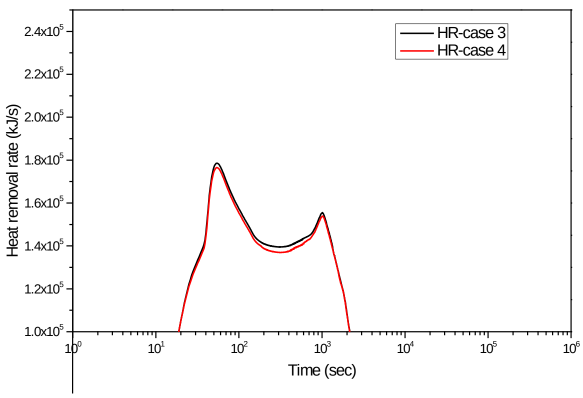

Fig. 8. Comparison of heat removal rate of PCCS conductor of case 3 and 4.

4. Conclusions and Further Studies

APR1400 GOTHIC model was developed for assessment on the effect of SIT nitrogen gas on passive containment cooling system performance. Calculation results confirmed that influence of nitrogen gas release is negligible; however, further studies should be performed to confirm effect of non-condensable gas on the final performance of PCCS. These insights are important for developing the PCCS of Innovative PWR.

ACKNOWLEDGEMENT

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