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Preliminary analysis on Containment Vessel Coolability of i-SMR using CINEMA

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1. Introduction

There is a focus on research in South Korea on PWR type SMR, known as the i-SMR. Figure 1 shows the preliminary design of the i-SMR [1]. The i-SMR has a metal Containment Vessel (CV) outside the Reactor Vessel (RV) and is cooled by passive safety systems such as the Passive Auxiliary Feedwater System (PAFS), the Passive Containment Cooling System (PCCS), and passive Emergency Core Cooling System (ECCS).

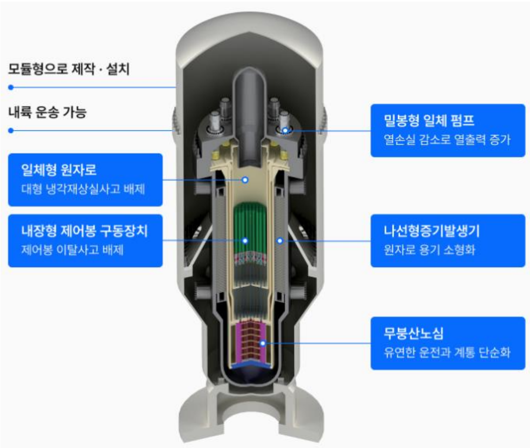

Fig. 1. Concept design of i-SMR [1]

In this study, the TLOFW (Total Loss of Feed Water) scenario with multiple failures of PAFS and ECCS was assumed to verify the cooling capability of the PCCS more definitively. When TLOFW occurs, coolant supply at the secondary side is terminated, leading to pressurization of the RV and reactor trip. Only the PSRV is assumed to function well. Once RV pressure exceeds the allowable PSRV pressure, vapor is released from the RV into the CV. The vapor then condenses at the PCCS and cools the RV outer walls. The accident analysis was performed using the CINEMA(Code for INtegrated severe accident Evaluation and MAnagement)[5].

In this study, as part of the research into severe accident analysis for the i-SMR[2-4], we investigated the CV coolability by the PCCS for a specified hypothetical scenario. Additionally, a comparison of the coolability through external flooding of the CV versus the PCCS was conducted. The analysis covered a 72-hour period following the onset of the TLOFW.

2. Results and discussions

Figure 2 shows the normalized pressure of the RV and CV during the TLOFW accident scenario. The pressure was normalized by the initial RV pressure. As shown in Fig. 2, the initial RV pressure change and transfer to the CV through the PSRV were observed. After approximately 10 hours of accident progression, the decrease in RV pressure was confirmed, which indicates that the reactor system is being effectively cooled.

Figure 3 shows the normalized collapsed water levels of the RV and CV. The water level was normalized by the initial RV water level. The coolant inside the RV evaporates and transfer to CV via the PSRV. Then, the transferred steam condenses at the PCCS. As a result, the RV water level decreases while the CV water level increases. The system remains cool because the RV water level remains higher than the reactor core.

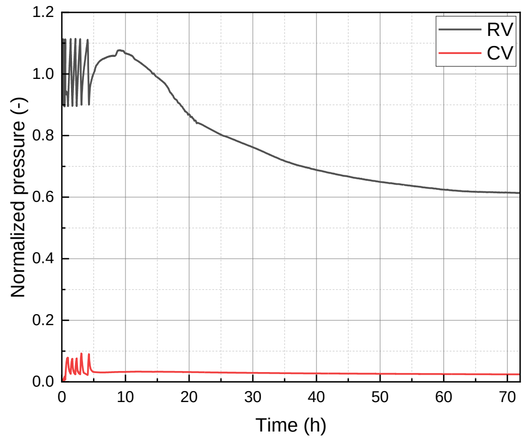

Fig. 2. Normalized pressure of RV and CV

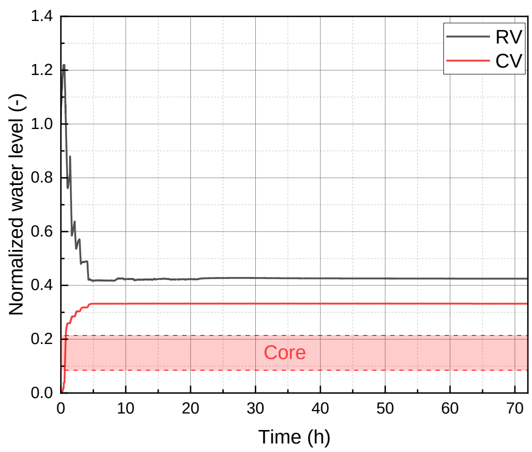

Fig. 3. Normalized water levels of RV and CV

Figure 4 shows normalized core temperatures at the center with different heights. The core temperature was normalized by the initial core temperature at the bottom. The lowest point is denoted as Node[0], with higher nodes (up to Node[4]) representing positions further up in the core. The core temperature remained at low values because the reactor core was submerged in water, as shown in Fig. 3.

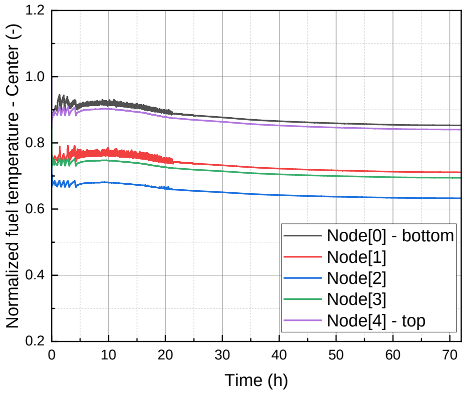

Fig. 4. Normalized core temperature at the center

Next, the heat transfer rate was compared to find the cooling capacity of the PCCS. Figure 5 shows the normalized heat transfer rate with different CV cooling methods: PCCS versus CV external flooding. CV external flooding is one of the ways to cool the reactor system. In the case of external flooding of the CV, there is the advantage of effectively removing the internal heat of the reactor system by cooling through the external surface area of the CV. However, this method has the disadvantage of increased difficulty in maintenance and management. As shown in Fig. 5, it was demonstrated that even without external wall cooling, using only the PCCS could effectively remove decay heat after the accident. This confirms the cooling capability and advantages of the PCCS applied in the i-SMR.

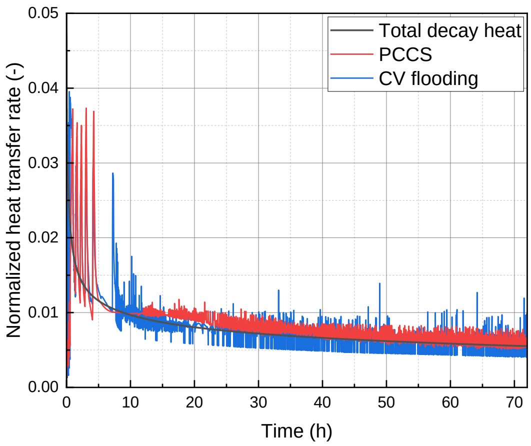

Fig. 5. Normalized heat transfer rate with different CV cooling system (PCCS vs. CV external flooding)

4. Conclusion

In this study, the severe accident analysis code CINEMA was used to evaluate the CV cooling capability of the PCCS during a multiple failure accident involving a TLOFW in an i-SMR type reactor. The results confirm that even in severe accident scenarios where secondary-side feeding is lost and multiple safety systems, such as the PAFS and ECCS, fail, the reactor system coolability can be maintained using only the PCCS, thereby preventing a severe accident. Additionally, it was demonstrated that heat removal beyond decay heat can be achieved without external flooding of the CV, which is advantageous in terms of maintenance and management. However, it should be noted that the current results are preliminary, and reanalysis will be necessary once detailed design parameters and operating conditions are provided in the future.

ACKNOWLEDGMENTS

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