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# Analysis on the Effect of the In-Vessel Coolant Injection in a Severe Accident of a Small Modular Reactor with a Metal Containment Vessel

Sang Ho Kim, Jaehyun Ham, Donggun Son
*Intelligent Accident Mitigation Research Division, KAERI, 989-111 Daedeok-daero, Yuseong-gu, Daejeon*
**Corresponding author: sangho@kaeri.re.kr*

## 1. Introduction

Various types of small modular reactors (SMRs) are being developed in various countries. Due to its greatest advantage as a proven technology, a pressurized-water reactor (PWR) using light water as a coolant is being developed the most among various reactor types.

Among the various design concepts of PWRs using light water as a coolant, one of the design concepts of the PWR-type SMRs is designed with a metal containment vessel that surrounds a reactor vessel. Because of the containment design which is totally different with those in a conventional operating large PWRs such as OPR1000 and APR1400 in Korea, the phenomena in a containment during a severe accident exhibit unique characteristics.

Even though the frequency of the occurrence of a severe accident is extremely low in a SMR, the capability of mitigation for a severe accident has to be proven for the license of a reactor. It brings the point to that the analysis for a severe accident is needed to prove that the safety criteria are met even though a severe accident occurs.

The purpose of this paper is to analyze the effect of the coolant injection in a severe accident of an SMR with a metal containment vessel.

## 2. Analysis Method

In order to analyze the effect of the in-vessel coolant injection (IVI) in a severe accident of a SMR, a design concept of the SMR with a metal containment vessel is adopted. The main components of a reactor coolant system are installed in an integrated reactor vessel. The thermal power of the reactor is 540 MW. The reactor vessel is installed inside a metal containment vessel. When an initial event occurs, all the isolation valves installed on the containment vessel get closed. The SMR is designed with various engineered safety features (ESFs). In this analysis, their multiple failures are conservatively assumed for the analysis of severe accident scenarios.

For the severe accident analysis, a CINEMA (Code for INtegrated severe accident Evaluation and MAnagement) was adopted [1]. The core, fluid and heat structures in a reactor vessel and containment vessel were modeled for the severe accident using the CINEMA.

The initial event in the analysis was assumed to be the break of the pipe connected from the interfacing system to reactor vessel. The break point is outside the containment vessel. After the occurrence of the loss-of-coolant accident (LOCA) in the interfacing system outside the containment vessel, the failures of the isolation valves on the pipe were additionally assumed. This scenario would cause the early occurrence of a core damage due to the continuous leakage of a coolant from the reactor vessel to the outside.

The analysis cases are divided into two categories. In the first case, there is no coolant injection and only the loss of the coolant conservatively in spite of the occurrence of the severe accident. No system for removing decay heat is applied in the analysis. Therefore, this accident is selected as the most conservative severe accident scenario.

In the other, the coolant injection into the reactor vessel is assumed to be implemented by the operator action after reaching the entry conditions for the severe accident management. The delay time of 30 minutes is additionally applied to the analysis cases. The operator turns on the pump and injects the coolant into the reactor vessel for supplying the water and removing decay heat. In the analysis cases for the IVI, the name of the case is defined as the “IVI-mass flow rate (kg/s)”. In the case without the IVI, it is set as the “Base Case” in the Chapter 3.

## 3. Analysis Result

In this Chapter, the analysis results are introduced. The main severe accident sequences of the base case and IVI-1.5 case are summarized in Table I and Table II.

Table I: Main Sequence of the Base Case

| Time (hr) | Event |
|---|---|
| 0.0 | -LOCA in the Interfacing System<br>-Failures of isolation valves<br>-Failures of ESFs |
| 1.6 | Entry of severe accident condition |
| 10.6 | Failure of reactor vessel |

Table II: Main Sequence of the IVI-1.5 Case

| Time (hr) | Event |
|---|---|
| 0.0 | -LOCA in the Interfacing System<br>-Failures of isolation valves<br>-Failures of ESFs |
| 1.6 | Entry of severe accident condition |
| 2.1 | The start time of IVI |

The corium mass in a lower plenum of a reactor vessel is shown in Fig. 1. In the base case, the corium is not cooled due to the loss of the coolant in the reactor vessel and no additional supply for the decay heat removal. The corium is relocated to the lower plenum of a reactor vessel in the base case.

In the IVI cases, the coolant is injected into the reactor vessel with the delay of operator action after the entry condition of a severe accident as shown in Fig. 2. 0.5 kg/s is injected in the IVI-0.5 case. 1.5 kg/s is injected in the IVI-1.5 case.

Fig. 3 shows the water volume in a reactor vessel. In the base case, there was no water in a reactor vessel about seven hours after the initial event. In the IVI-1.5 case, the continuous injection of water was carried out. Accordingly, the corium was not relocated to the lower plenum and the integrity of the reactor vessel was maintained. Otherwise, due to the lack of the amount of the injected water, the water volume decreased in the IVI-0.5 case. The reactor vessel was failed at about 35 hr.

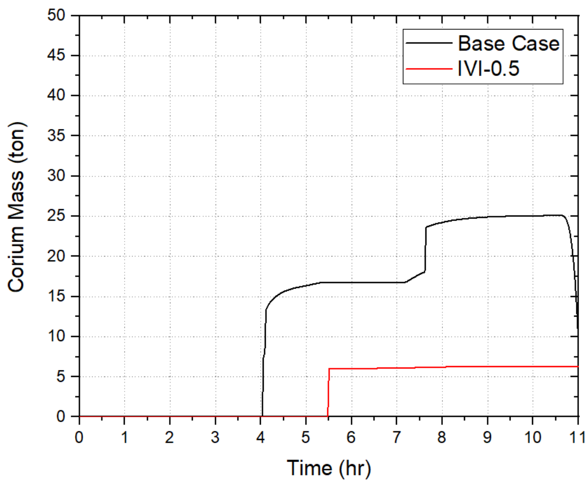


Fig. 1. Corium mass in a lower plenum of a reactor vessel.

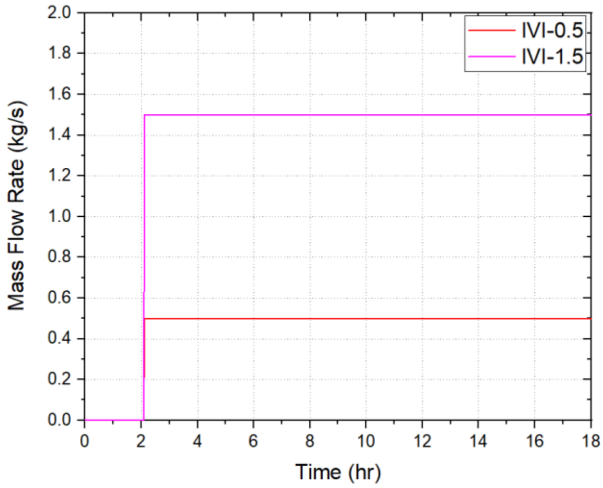


Fig. 2. Mass flow rate of the IVI to the reactor vessel.

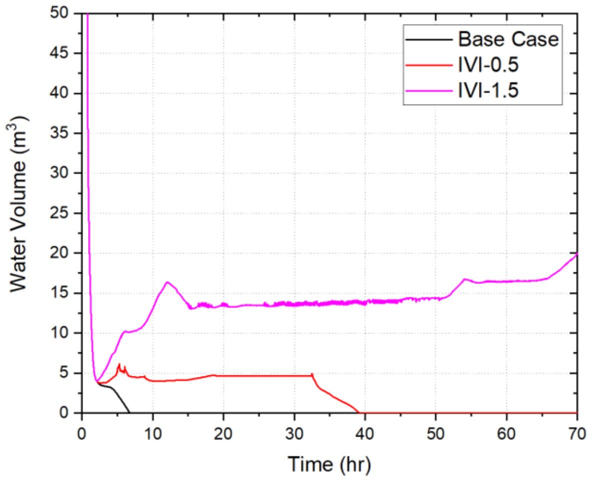


Fig. 3. Water volume in a reactor vessel.

## 4. Conclusions

The effects of the IVI in a severe accident of a SMR designed with a metal containment vessel have been analyzed in this paper. Even though the core damage frequency of a SMR is extremely low, the management plan for a severe accident has to be prepared. In addition, it can be proven that a SMR has the mitigation capability for a severe accident. Most of the SMRs have the inherent safety capability even for a severe accident. The extremely conservative severe accident scenario is adopted and analyzed in this paper. The manual operation of a small pump installed in the interfacing system can remove the decay heat and stabilize the corium with maintaining the integrity of reactor vessel if its mass flow rate to the damaged core is guaranteed in a severe accident. The analyses for the various accident scenarios are proposed as one of the further works.

## Acknowledgement

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## REFERENCES

[1] KHNP, CINEMA User Manual, 2022.07 (2022).