Preliminary severe accident analysis of INCV-LOCA in i-SMR using CINEMA code

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1. Introduction

The i-SMR (Innovative Small Modular Reactor) is a state-of-the-art 170MWe integrated pressurized water reactor with enhanced safety, economy and flexibility compared to various SMRs around the world. The i-SMR has secured inherent safety with a simpler design than before by applying passive safety systems using natural circulation. Under all accident conditions including severe accidents, the reactor can be safely shut down and indefinitely maintain long-term cooling without operator action, power supply, or additional coolant supply [1]. There are two kinds of safety valves which connects RV (Reactor Vessel) and CV (Containment Vessel), which envelops RV from outside. EDV (Emergency Depressurization Valve) is located at top of pressurizer, and ERV (Emergency Recirculation Valve) is located at the bottom of SG (Steam Generator). These valves are opened by signal automatically (i.e. no need for operator action). After reactor trip, primary coolant circulates between RV and CV (Containment Vessel) so that residual heat can be removed by PCCS and PAFS. Concept of passive safety features of i-SMR are illustrated in Fig. 1.

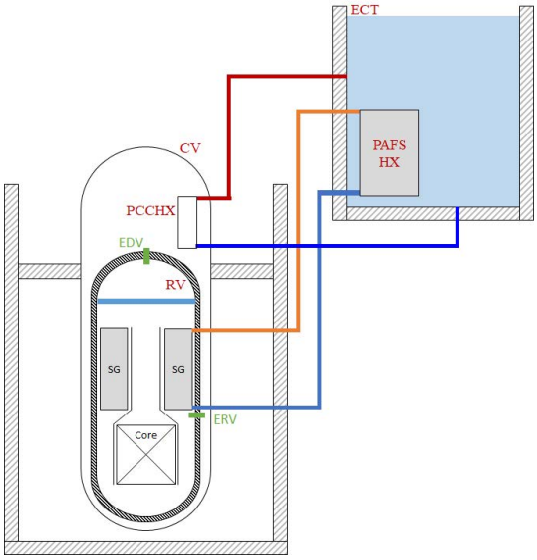

Fig. 1. Safety features of i-SMR [2]

As a representative design feature for i-SMR, large pipe lines for NSSS (Nuclear Steam Supply System) (e.g. cold and hot legs in typical nuclear power plant with large containment) are excluded. However, there are several penetration pipe lines for normal operation such as feedwater, steam line and MMPS (Modular Makeup and Purification System). LOCA (Loss of Coolant Accident) can be occurred by MMPS line break. It is called INCV-LOCA when LOCA occurs within CV. There are two MMPS lines for i-SMR, L/D (Letdown) line is located at the top of SG, and C/G (Charging) is located at the bottom of SG. Penetration pipe lines of i-SMR are illustrated in Fig. 2.

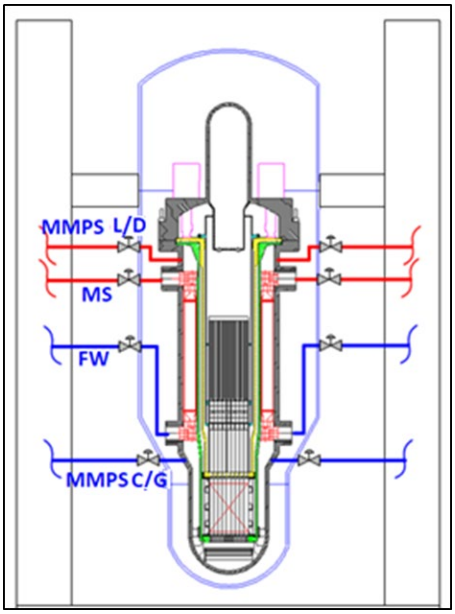

Fig. 2. Penetration pipe lines of i-SMR [2]

CINEMA code is the integral code that can perform linked analysis by integrating individual modules capable of interpreting individual phenomena that occur during a severe accident independently. CINEMA code divides various severe accident phenomena into in-core phenomena and ex-core phenomena. There are three analysis modules in CINEMA code as shown in Fig. 3, ranges of each module are like below [3]:

- CSPACE: System thermal hydraulics and in-core phenomena
- SACAP: System thermal hydraulics and ex-core phenomena
- SIRIUS: FP (Fission Product) behavior

In this research, preliminary severe accident analysis of INCV-LOCA in i-SMR using CINEMA code will be performed. Analysis results based on break location will be presented in section 2, and analysis results based on distribution of decay heat from FPs in section 3.

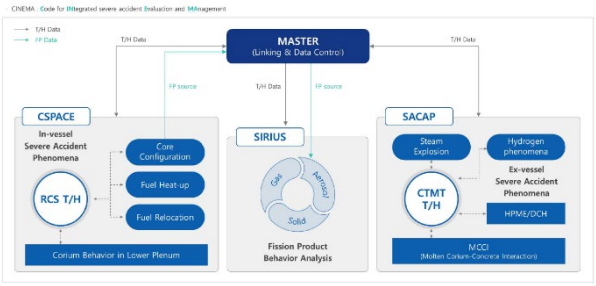

Fig. 3. Structure of CINEMA code [4][5]

2. INCV-LOCA with different break locations

In this section, two cases of INCV-LOCA were analyzed; one is MMPS C/G line break, and the other one is MMPS L/D line break. Break size is equally assumed as 2 inch. Total failure of PAFS and ERV was assumed in this analysis. Table I shows the main events of INCV-LOCA with different break locations in i-SMR. It was assumed that total decay heat comes from molten corium for both cases in this section (i.e. decay heat from released FPs are neglected).

Table I. Main events of INCV-LOCA in i-SMR

Event	Time (C/G line)	Time (L/D line)
INCV-LOCA occurrence	0 s	0 s
Rx, RCP, MFWP trip	13 s	15 s
EDV open (ERV fail to open)	13 s	20 s
Core top uncovering	-	23,039 s
Cladding oxidation	-	30,137 s
SAMG entry (Core exit temp. > 923 K)	-	30,278 s
Gap release (Cladding temp. > 1173 K)	-	30,298 s
Corium relocation to core support plate	-	40,504 s
Corium relocation to lower plenum	-	97,690 s
RV failure	-	-
End of simulation	259,200 s	259,200 s

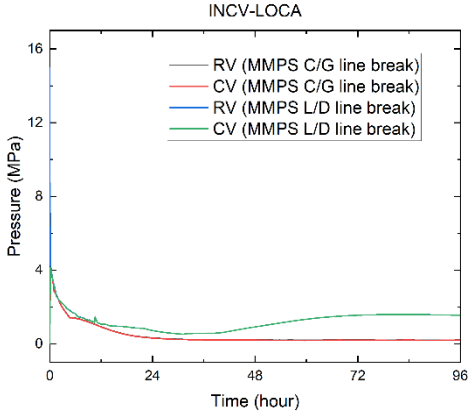

Fig. 4. Pressure change under INCV-LOCA following the break location

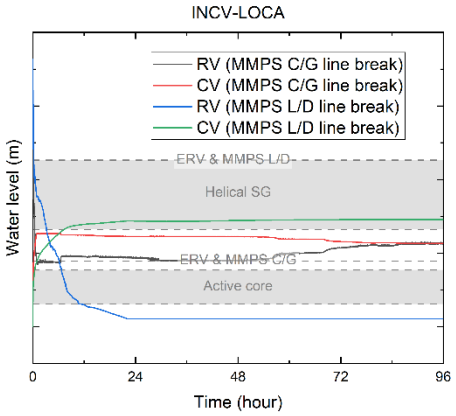

Fig. 5. Water level change under INCV-LOCA following the break location

It was analyzed that there is no core damage in case of MMPS C/G line break, because coolant can be supplied to RV through break so that active core is fully submerged as shown in Fig. 5. However, severe accident can occur in case of MMPS L/D line break, because water level in CV is lower than the MMPS L/D line. The pressure between RV and CV equalizes within an hour, so water level decrease within RV is because of evaporation by residual heat. It was analyzed that RV failure can be prevented by ex-vessel reactor cooling for both cases.

3. INCV-LOCA (MMPS L/D line break) with different distribution of decay heat from FPs

In this section, different distribution of decay heat from FPs for INCV-LOCA (MMPS L/D line break) analysis. The decay heat from released FPs can be a heat source of the system. By using the two-way coupling option in CINEMA, this phenomenon can be considered. If this option is not considered, it is assumed that total residual heat is coming from fuel materials for conservative analysis in terms of core cooling.

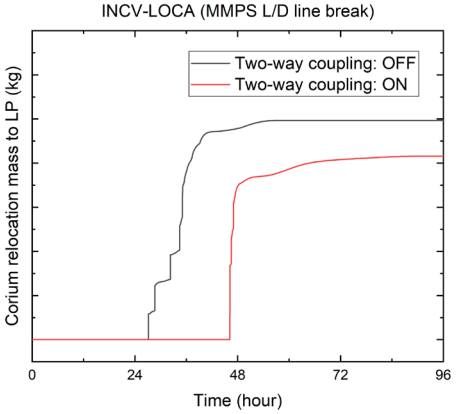

Fig. 6. Corium relocation mass to LP under INCV-LOCA following the two-way coupling option status

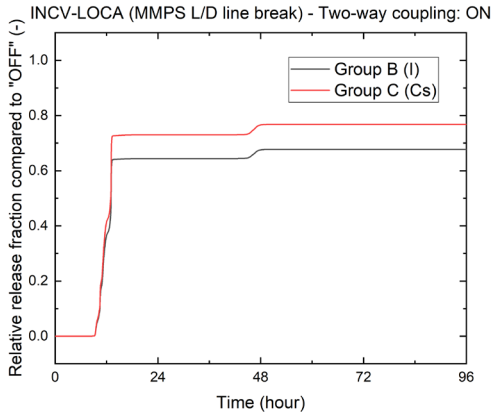

Fig. 7. Relative release fraction to environment in case of two-way coupling option is "ON" compared to the case when the option is "OFF" under INCV-LOCA

In case of two-way coupling is considered, it takes more time for corium relocation to LP (Lower Plenum) as shown in Fig. 6. Also, release fraction of FPs decreases as shown in Fig. 7. Pressure is higher when two-way coupling is considered because the system is directly heated by decay heat from FPs, so more aerosols deposit in RCS and CV by diffusiophoresis.

4. Conclusion

In this research, preliminary severe accident analysis of INCV-LOCA with different break location and distribution of decay heat from FPs in i-SMR using CINEMA code were performed. It was analyzed that there is no core damage in case of MMPS C/G line break, but core damage can occur in case of MMPS L/D line break. If two-way coupling option is considered, corium can be relocated faster and less FPs can be released to environment for the analysis result. Although it is conservative in terms of core cooling when two-way coupling option is "OFF", but this assumption may affect the source term result. Therefore, users should carefully consider whether to use the option or not. Because presented analysis results are preliminary, they may change following the design change later.

Acknowledgement

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[4] KHNP, 'User Manual for CINEMA2.0', July 2022.
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