

Preliminary Analysis of SBLOCA for Innovative Small Modular Reactor (iSMR) using MARS-KS code

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1. Introduction

Small Modular Reactor (SMR) has been recently highlighted as an alternative to the larger nuclear power plant since SMR has many advantages, such as reduced capital cost, selection of site locations, and distinct safety, security, and nonproliferation advantages.

NuScale has developed a 50MWe SMR and NuScale received the design certification approval from US Nuclear Regulatory Commission (NRC) in September, 2020.

Korea Hydro and Nuclear Power Company (KHNP) has started to develop a conceptual design of innovative SMR (iSMR) from 2020. The development goal of iSMR is to have economic benefits and to secure an equivalent level of safety compared to the competing SMR type.

This paper deals with small break loss-of-coolant accident (SBLOCA) to determine the conceptual design and sizing of iSMR. Firstly, we performed benchmark analysis for NuScale SMR using MARS-KS code based on publicly available data. From the benchmark analysis, we developed iSMR analysis model to analyze SBLOCA and containment pressure-temperature analysis based on the conceptual design data of iSMR. This paper also shows the preliminary sensitivity analysis results according to several design options of iSMR.

2. Benchmark Analysis for NuScale SMR

2.1 Analysis model for NuScale SMR

Fig. 1 showed the nodalization for NuScale SMR. The reactor vessel consists of active core, riser, pressurizer, downcommer, and lower head. The average flow area of each component was used in NuScale Design Control Document (DCD) [1]. The steel safeguard vessel contains the reactor vessel. The safeguard vessel was partially submerged into the ultimate heat sink.

The emergency core cooling system of NuScale SMR had three reactor vent valves (RVVs) and two reactor recirculation valves (RRVs). When the differential pressure between the safeguard vessel and the reactor coolant system becomes lower than 1,000 psi, the engineered safety feature actuation signal (ESFAS) is activated. All the RVVs and the RRVs are opened due to ESFAS. As shown in Fig. 1, the RVVs and the RRVs

are modeled as trip valves (395, 396, 397, 398, 399) in MARS-KS code.

The safeguard vessel was modeled as two channel vertical annulus components connected by cross flow junctions. The surface heat transfer between the safeguard vessel and the ultimate heat sink was modeled as a heat structure (410).

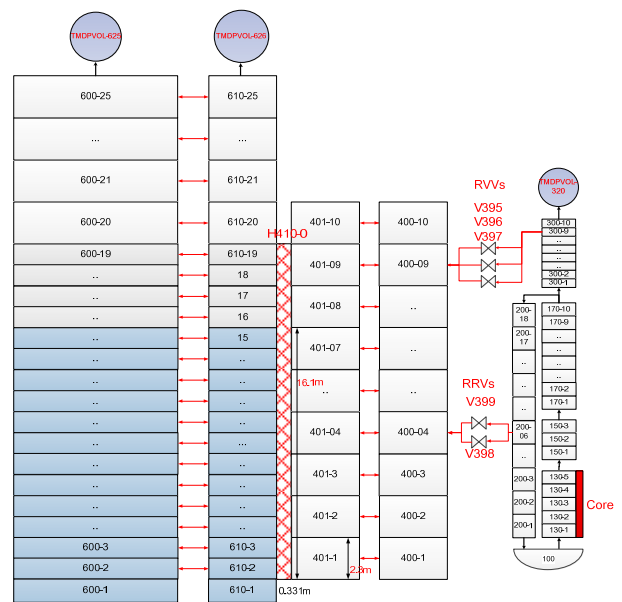


Fig. 1. MARS-KS nodalization for NuScale SMR

2.2 Analysis Results

The accident scenario was determined as Inadvertent RRV Actuation, which is SBLOCA case. This case is the limiting case for the containment response analysis. Initiating event is one of RRV is inadvertently opened at time zero. Due to this, the reactor inventory discharges to the containment vessel. The RCS pressure decreases and the containment vessel pressure increases. The remain RRV and three RVVs are opened when the differential pressure between the containment and the RCS.

Fig. 2 showed the comparison results between the MARS-KS benchmark analysis and NuScale DCD data. As shown in the left of Fig. 2, MARS-KS code well predicted the break flow rate. Until 90 seconds, the break flow occurred only through the inadvertent opened RRV. Near 90 seconds, ESFAS signal was activated and all valves were opened.

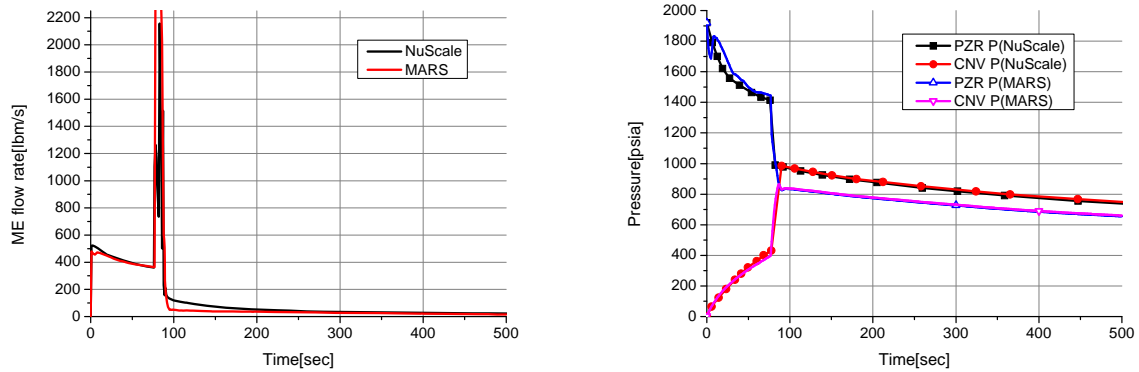


Fig. 2. Benchmark analysis results for NuScale SMR (Left: break flow rate, Right: RCS and containment pressure)

Before the activation of ESFAS, the RCS and containment vessel pressure were well predicted. In contrast, containment peak pressure was underestimated in MARS-KS code. Although the lack of detailed design data of NuScale, MARS-KS code quite well predicted SBLOCA behavior and the containment response. Based on the benchmark analysis, the same analysis methodology was used to analyze the iSMR SBLOCA.

3. Analysis for iSMR

2.1 Conceptual design of iSMR

The core of iSMR has 69 fuel assemblies to generate total 540MW thermal power. The fuel assembly has 17x17 rod array and the fuel height is 2.4 meters.

iSMR adopts an in-vessel control rod driving mechanism (CRDM) and helical coil steam generator design. To increase the thermal power, the canned motor reactor coolant pumps were introduced.

The containment vessel design is not determined yet but the detail size of the containment vessel will suggest in this paper. The containment vessel is completely submerged in the ultimate heat sink.

The RVVs and RRVs design are not determined yet thus we use the modeling data from the benchmark analysis. As shown in Fig. 4, the containment design parameters were changed such as the lower annulus gap and the upper annulus gap. These design parameters determine the containment free volume and the heat transfer area.

Fig. 5 presents the nodalization of iSMR.

2.2 Analysis Results

Similar with the benchmark analysis, the accident scenario was determined as Inadvertent RRV Actuation.

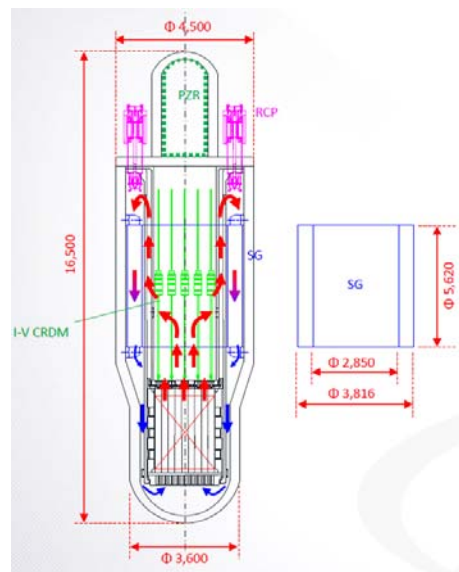


Fig. 3. Conceptual design of iSMR

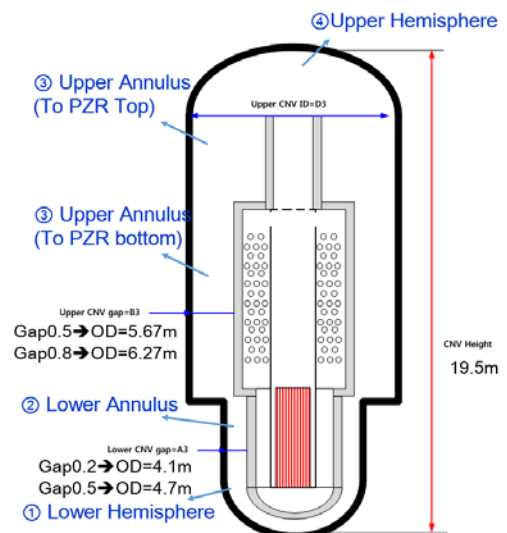


Fig. 4. Containment vessel design parameters.

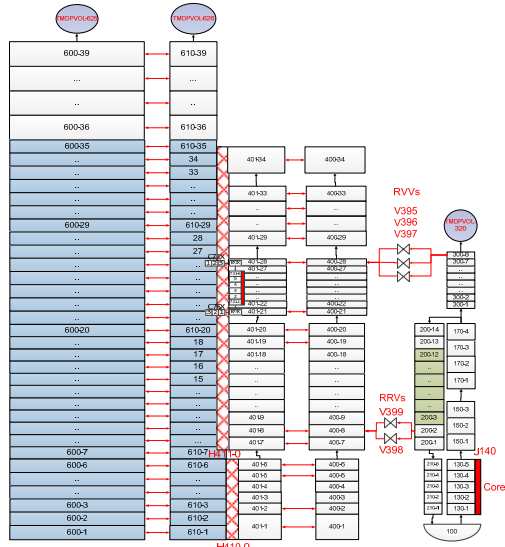
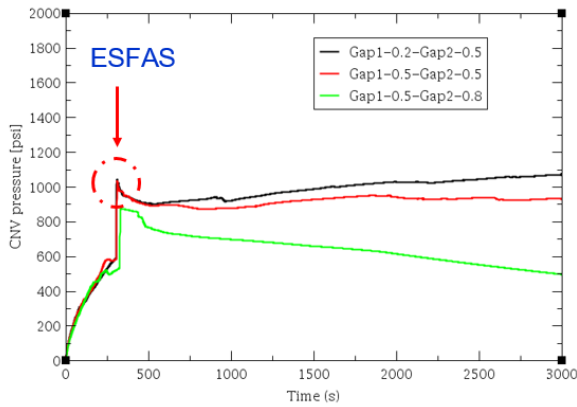


Fig. 5. Nodalization of iSMR.

Fig. 6 showed the containment pressure behavior. The black line represents the smallest free volume case. In the right of Fig. 6, the containment pressure reached about 2000 psi in the smallest free volume case. The red and green line case increased the lower annulus gap size. Due to the increased free volume, the containment pressure is drastically decreased. For the long term



cooling, the red and green line cases showed a good performance of the long term cooling in the containment vessel.

All cases did not occur the core uncover, as shown in Fig. 7. The collapsed water level is always higher than the top of fuel. Due to this, there were no peak cladding temperature during this analysis, as shown in Fig.8.

3. Conclusions

To analyze the iSMR conceptual design, we developed the MARS-KS analysis model using a series of the NuScale benchmark analysis. Based on the sensitivity analysis, the conceptual design of the containment vessel for iSMR was suggested. From the containment response analysis in the limiting accident case, the containment vessel can meet the containment design requirements.

REFERENCES

[1] NuScale, Chapter 6, Engineered Safety Features, 2020.

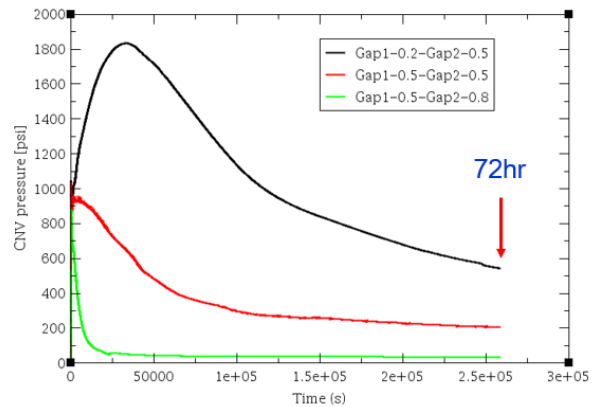


Fig. 6. Containment pressure behavior (Left: short term, Right: long term)
 (Gap1=lower annulus gap, Gap2=upper annulus gap)

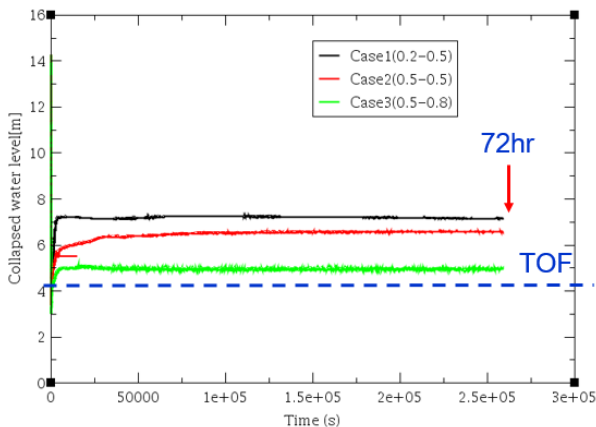


Fig. 7. Collapsed active core water level

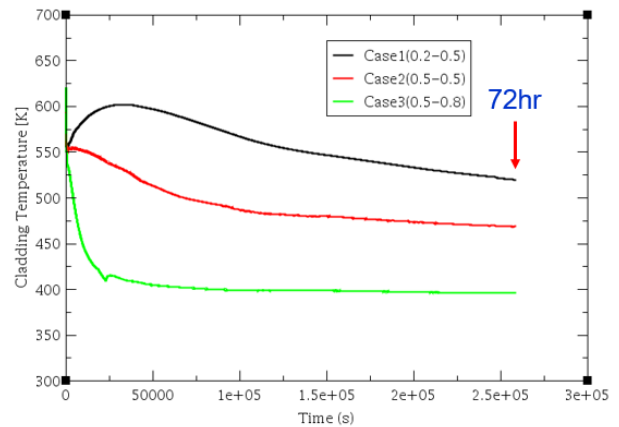


Fig. 8. Cladding temperature