Assessment of CUPID Code for Multi-dimensional LOCA Analysis of NuScale

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1. Introduction

As various types of small modular reactors (SMRs) have been developed throughout the world, NuScale plays a role of the first mover in SMR development. NuScale does not need any active operation for Loss of coolant accident (LOCA)-type scenario by using passive emergency core cooling system (ECCS). A multi-dimensional calculation is required for the LOCA analysis because the major heat removal phenomena is the natural circulation. In this paper, multi-dimensional LOCA analysis were performed by using CUPID code.

2. LOCA Analysis for NuScale Reactor

2.1 NuScale Reactor

NuScale is an integrated SMR and the reactor coolant flow is driven by natural circulation for both of normal and LOCA-type accident conditions [1, 2]. In the LOCA-type scenario, reactor vent valve (RVV) and reactor recirculation valve (RRV) are passively opened and the flow pass of reactor coolant are formed. During the LOCA-type accident, various thermal-hydraulics behaviors are observed such as the boiling, flashing, choking, condensation, radiation heat transfer, and natural circulation as shown in Fig. 1.

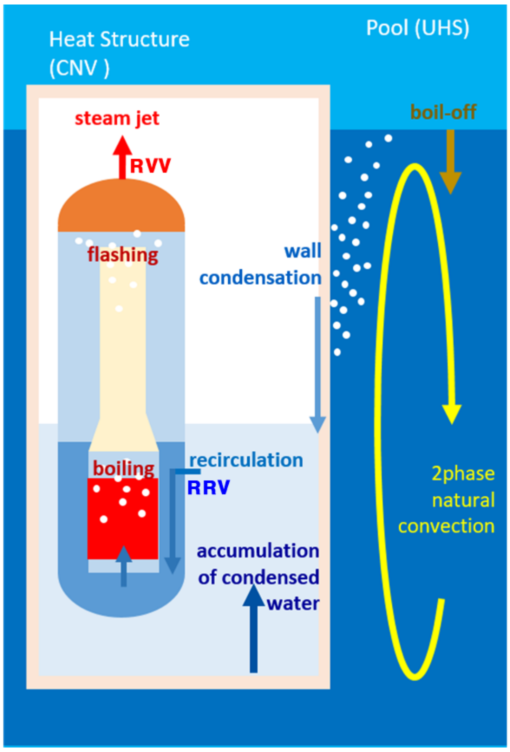


Fig. 1 Schematics of TH behavior in NuScale during LOCA-type scenario

2.2 Grid Generation

Computational grid for NuScale LOCA analysis were generated by an in-house grid generator as shown in Fig. 2. The reactor vessel (RV), containment vessel (CNV), and ultimate heat sink (UHS), and solid walls were modeled by trigonal and hexagonal prism meshes. The number of total meshes are 47,652.

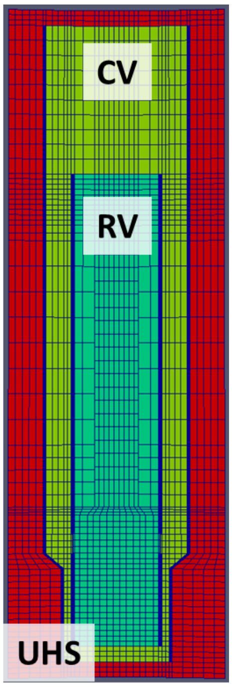


Fig. 2. Computational grid for NuScale

2.3 Initial and Boundary Conditions [3]

Null-transient calculation was performed to simulate the steady-state condition. Initial conditions are as follows:

- Pressure in RV = 13.8 MPa
- Pressure in UHS = 0.1 MPa
- Core power = 192 MWth
- Core inlet temperature = 538.2 K
- Water temperature in UHS = 300 K

RCS flow rate and core outlet temperature were calculated during the null-transient calculation, which were 656.2 kg/s and 587.9 K, respectively. The design values of RCS flow rate and core outlet temperature are 641.5 kg/s and 594.2 K. The discrepancies of calculated RCS flow rate and core outlet temperature are 2.3% and 1.1 %, respectively.
Reactor was assumed to be tripped as soon as LOCA is initiated and ANS-73 decay heat curve was adopted.

Uchida model was used for the wall condensation in the simulation.

3. Calculation Results

3.1 Summary of LOCA Scenario

LOCA is the major design basis accident (DBA) in NuScale. The inventory of coolant can be preserved even in LOCA condition since the RV is enclosed by CNV. Therefore, the core cooling is achieved by the natural circulation if the RVV and RRV are properly operated.

3.2 Calculation Results

After the null-transient calculation for 300s, a stuck open of the pressure relief valve (PRV) assumed. As the steam from the RV releases into the CNV, the pressures of RV decreases and pressure of CNV increases. The pressures of RV and CNV reach the equalization state around 780 s as shown in Fig. 3. The RRV was assumed to open at this equalization state.

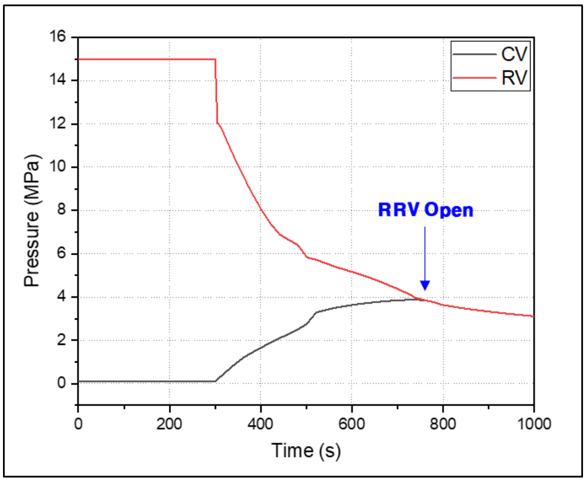
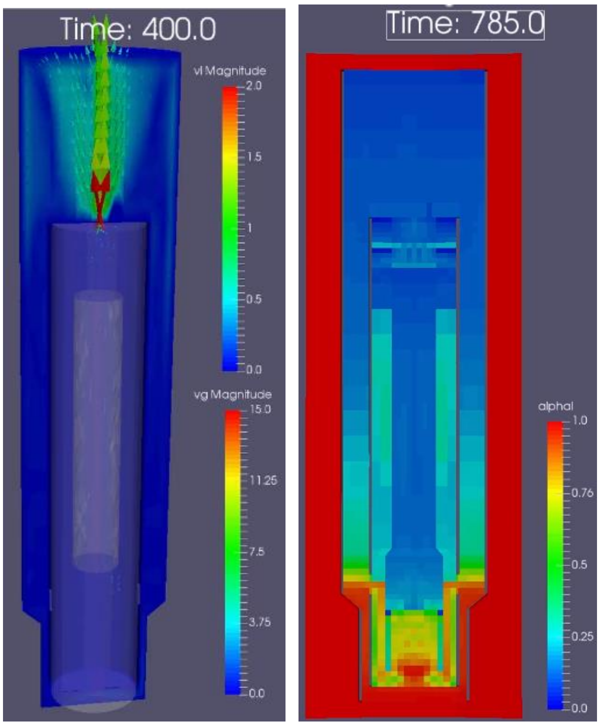


Fig. 3. Transient of RV and CNV Pressures

The flow velocity after PRV opening is calculated by Henry-Fauske choking model. The released steam impinges to CNV walls as shown in Fig. 4 (a) and the wall condensation occurs. As the result of the wall condensation, the condensate is accumulated from the bottom of CNV. The condensate is injected into the CNV after the RRV is opened as shown in Fig. 4 (b) and the active core region is successfully recovered.



(a) Gas velocity (b) Liquid fraction

Fig. 4. Snapshot of calculation results

4. Conclusions

LOCA-type scenario of NuScale was calculated by using the CUPID code. The capability of CUPID was assessed to simulate various TH behavior such as the wall condensation, liquid flashing, boiling, choking flow, and natural circulations. In the future, CUPID will be used to perform the safety analysis of innovative SMR (iSMR), which is being developed in Republic of Korea.

REFERENCES

[1] NuScale Power, NuScale Standard Plant Design Certification Application: Chapter one, Corvallis, Oregon, 2016.

[2] K. Skolik et al., LOCA-type Scenario Simulation for NuScale-SMR with RELAP/SCDAPSIM/MODE3.4, NURETH-18, Portland, OR, August 18-22, 2019

[3] NuScale Power, NuScale Standard Plant Design Certification Application: Chapter fifteen, Corvallis, Oregon, 2016.