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Three-dimensional Transient Analysis in the Upper Plenum of MONJU with MARS-LMR

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1. Introduction

A three-dimensional thermal hydraulic analysis was implemented using the MARS-LMR code in the upper plenum of MONJU, which is a Japanese MOX-fueled, loop-type, sodium-cooled fast reactor producing 714 MWth. A system start-up tests(SSTs) had been performed in the MONJU. At that time, the thermal stratification phenomenon is detected in a reactor vessel(RV) upper plenum during a turbine trip test on December 1st, 1995. The SSTs data has been used by many previous researchers for an understanding of a thermal hydraulics in a fast reactor. The JAEA had provided a detailed geometrical data of the reactor vessel upper plenum, and time-dependent inlet conditions of the flow rate and temperature at the reactor core top surface for the transient analysis.

The KAERI(Korea Atomic Energy Research Institute) had studied a numerical analysis of thermal stratification in an upper plenum of the MONJU using the MARS-LMR code. Three-dimensional analysis results have a good agreement with the experimental data and also show a better estimation than that of the one-dimensional analysis. [1]

2. Methods and Results

Figure 1 shows the geometry of the MONJU RV upper plenum. The reactor vessel of MONJU is a cylindrical type with three outlet nozzles. Sodium flows into the reactor vessel through three inlet nozzles, and flows out the loop through three outlet nozzles.

A cylindrical inner barrel is located at a radially more inner region of 50 cm from the inside wall of the reactor vessel. There are 48 LFHs (Lower Flow Holes) at a 1.63 m height and 24 UFHs (Upper Flow Holes) at a 2.55 m height from the top of the support plate. Therefore, there are three flow paths of the sodium from the core to the reactor vessel outlet nozzles: through the LFHs and UFHs, and beyond an inner barrel.

MONJU has a complex UCS (Upper Core Structure) and other structures such as fuel handling systems in the upper plenum. The UCS consists of a honeycomb structure, flow-guide tubes, and fingers. A thermocouple inside the finger measures a fuel assembly outlet temperature. There are 19 control rod guide tubes inside the UCS.

A TC-plug is located at about a 3 m height from the vessel center. The TC-plug has 36 thermocouples, which measure a vertical temperature during a turbine trip test.

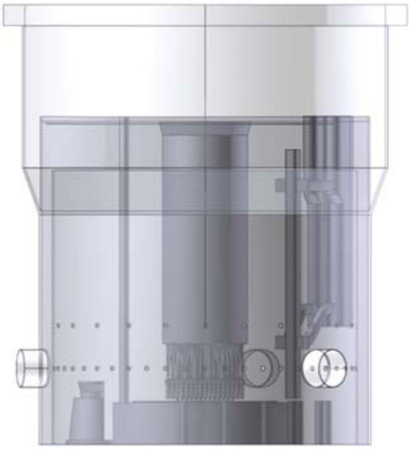

Fig. 1 Geometry of the MONJU RV upper plenum

The core subassemblies consist of inner divers, outer divers, neutron sources, blankets, neutron shielding, and control rods. Figure 2 shows a top view of the MONJU core subassemblies (S/As).

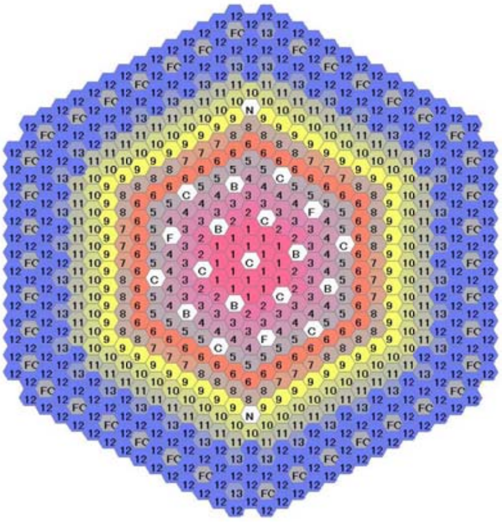

Fig. 2 Configuration of the reactor core

Figure 3 shows a nodalization for a three-dimensional analysis with the MARS-LMR.

A hot pool is divided into 3 regions: a region inside of an inner barrel(volume number: 230), a region outside of an inner barrel(volume number: 100), and a overflow region(volume number: 240). The regions inside and outside of an inner barrel are modeled as three-dimensional cylindrical volumes. The volume of

230 has 270 nodes: number of node in r-direction = 5, number of node in θ-direction = 6, and number of node in z-direction = 9. The volume of 100 has 54 nodes: number of node in r-direction = 1, number of node in θ-direction = 6, and number of node in z-direction = 9.

A core part is divided into 6 parallel channels: inner driver fuel assemblies, outer driver fuel assemblies, control rods, neutron sources, blankets, and neutron shieldings. The core channels are connected with the top of a core barrel. The TC-plug is located in the 4th node in r-direction, the 4th node in θ-direction at volume of 230. Reactor vessel outlets are modeled as three pipes(volume number: 600, 700, and 800). 8 LFHs and 4 UFHs are modeled as a small pipe, respectively.

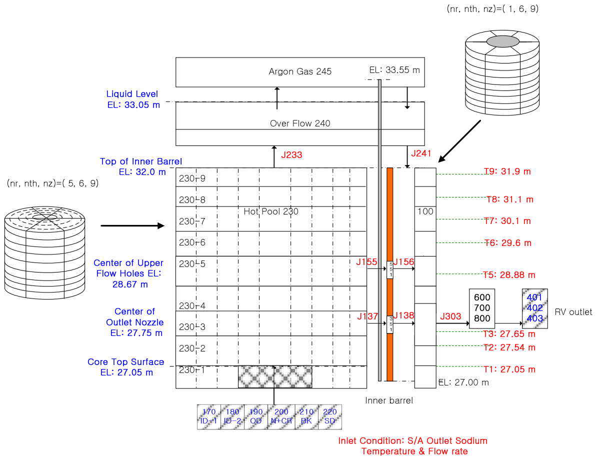

Fig. 3 Nodalization for the 3-D analysis with MARS-LMR

Figure 4 shows a flow rate through the flow holes and an over-flow rate in steady-state calculations of a 3-D analysis. In this calculation, the total flow rate through the LFHs is 75.3 kg/s, while the total flow rate through UFHs is 85.3 kg/s. The over-flow rate over an inner barrel is about 1867 kg/s. The total flow rate through UFHs is larger than that of the LFHs unlike a result of a 1-D calculation due to a dominant radial-flow instead of an over-flow by a geometrical interruption of an axially located fuel handling system as shown in figure 1.

Figure 5 to 14 show a transient result calculated in the MONJU RV upper plenum until 3600 sec after a turbine trip. A phenomenon of the thermal stratification is observed as shown in Figure 5. Sodium under the 5th node with UFHs is well mixed and its temperature becomes to be almost same. On the other hands, sodium over the 5th node shows a thermally stratified condition.

Fig. 6 shows a flow rate through the flow holes and an over-flow rate in the transient calculations. In this calculation, the maximum flow rate through the LFHs is estimated as 190.39 kg/s at 994 sec, while the maximum flow rate through the UFHs is 267.3 kg/s at 995 sec after a reactor trip. The over-flow decreased to 5.6 kg/sec until 600 sec, and then increased to about 9 kg/sec. The sodium keeps overflowing an inner barrel during a simulation time of 3600 sec. Consequently, sodium over UFHs steadily continues to be cooled by the over-flow. Therefore, sodium temperatures constantly decrease in the region from the 6th node to the 9th node of 230 unlike the stagnations shown in a result of the 1-d analysis.

Figure 7 to 14 show comparisons the calculated temperatures in the 3-D analysis with the MONJU SSTs data in the RV upper plenum. A calculated result shows a good agreement with the MONJU experimental data until 3600 sec. The results of the 3-D analysis show a better estimation than that of the 1-D analysis. However, a calculated temperature at the 9th node near the top of an inner barrel is lower than the experimental data like a result of the 1-D analysis. It is also considered to be due to the modeling of the over-flow region as one dimensional volume.

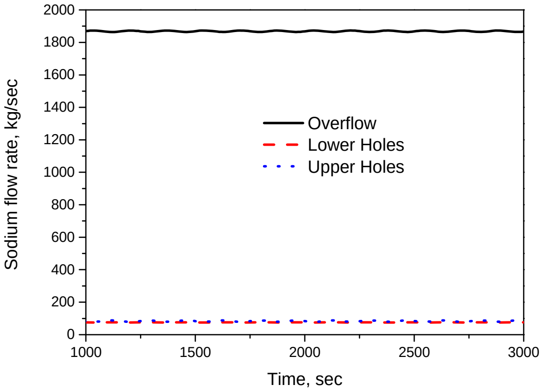

Fig. 4 Flow rates of flow holes and overflow in the steady-state analysis

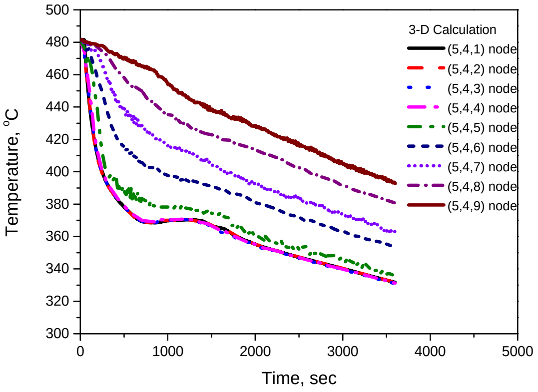

Fig. 5 Temperature stratification under the transient condition

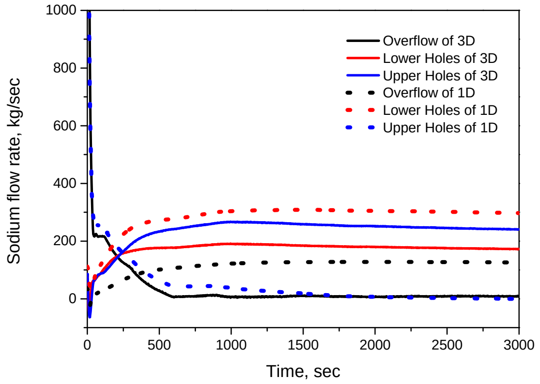

Fig. 6 Flow rates of flow holes and overflow in the transient analysis

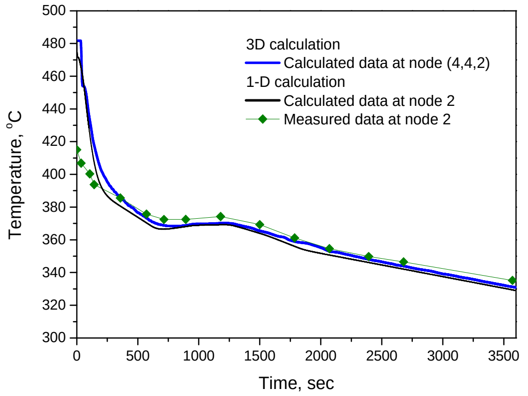

Fig. 7 Temperatures at the (4,4,2) node of 230 during the transient calculation

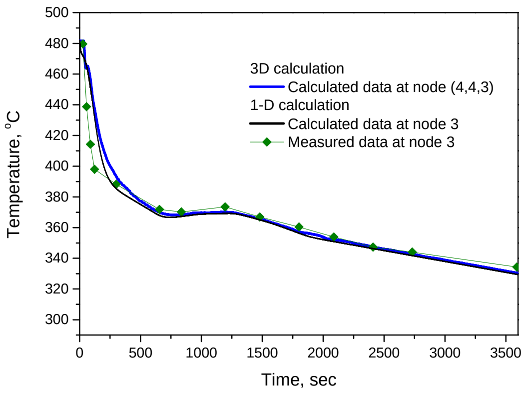

Fig. 8 Temperatures at the (4,4,3) node of 230 during the transient calculation

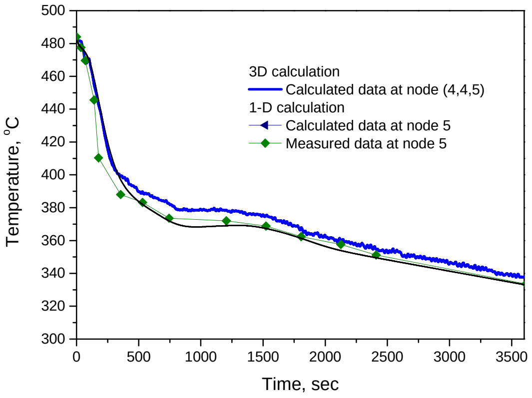

Fig. 9 Temperatures at the (4,4,5) node of 230 during the transient calculation

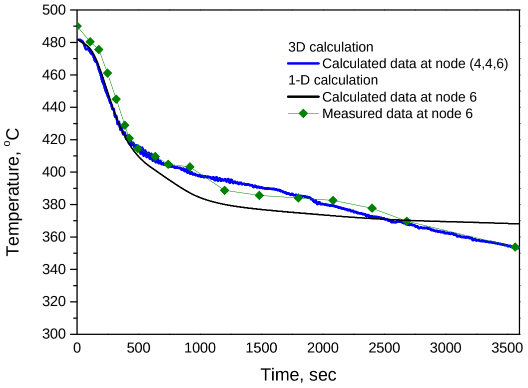

Fig. 10 Temperatures at the (4,4,6) node of 230 during the transient calculation

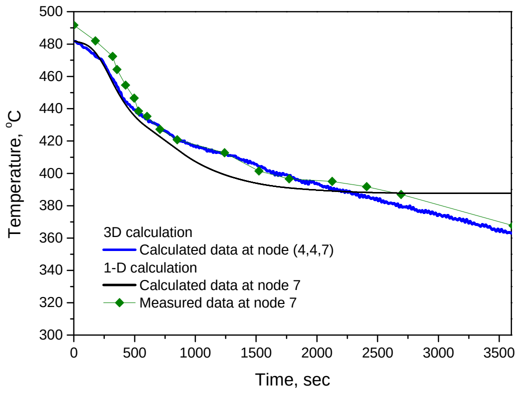

Fig. 11 Temperatures at the (4,4,7) node of 230 during the transient calculation

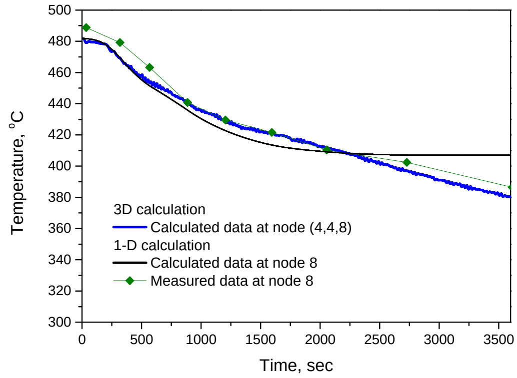

Fig. 12 Temperatures at the (4,4,8) node of 230 during the transient calculation

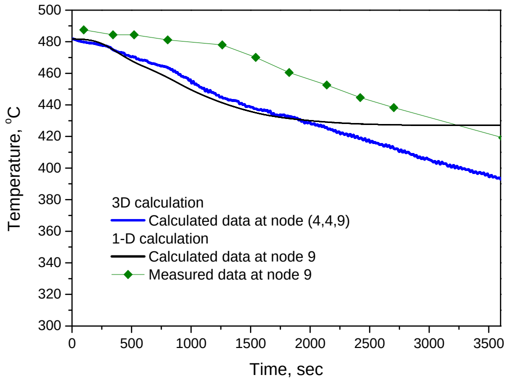

Fig. 13 Temperatures at the (4,4,9) node of 230 during the transient calculation

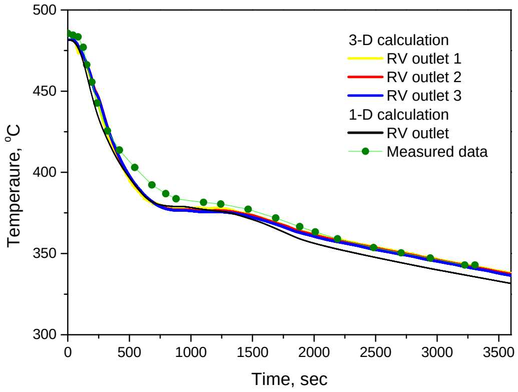

Fig. 14 RV outlet temperature during the transient calculation

3. Conclusions

Three-dimensional thermal hydraulic analyses are implemented in MARS-LMR code to validate the thermal-hydraulic models of the MARS-LMR code and identify important phenomena such as buoyancy effect and thermal stratification. A calculated result shows a good agreement with the MONJU experimental data. The results of a 3-D analysis show a better estimation than that of a 1-D analysis. In the steady-state calculation, the total flow rate through UFHs is larger than that of the LFHs unlike a result of a 1-D calculation due to a dominant radial-flow instead of an over-flow by a geometrical interruption of an axially located fuel handling system. In the transient calculation, the sodium keeps overflowing an inner barrel during a simulation time of 3600 sec in the 3-D analysis. As a result, sodium over UFHs steadily continues to be cooled in the 3-D analysis. However, a calculated temperature at the 9th node near the top of an inner barrel is lower than an experimental data. It is considered to be caused by a modeling of an over-flow region as one dimensional volume, because the over-flow region has a multi-dimensional flow. Therefore, the multi-dimensional flow in the over-flow region is a point to be considered for further studies.

REFERENCES

[1] Kwi-Lim Lee, et al., Transient Simulation in the Upper Plenum of the MONJU with MARS-LMR, Transactions of the Korean Nuclear Society Autumn Meeting
Pyeongchang, Korea, October 30-31, 2014

[2] Seok-ki Choi, et al., Numerical Analysis of Thermal Stratification in the Upper Plenum of the MONJU Fast Reactor, Nuclear Engineering and Technology, volume 45, issue 2, 191-202, 2012.

[3] Hiroaki Ohira, et al., Numerical Simulation of Upper Plenum Thermal-Hydraulics of Monju Reactor Vessel Using High Resolution Mesh Models, Journal of Energy and Power Engineering, 7, 679-688, 2013.

[4] Makoto Shibahara, et al., Numerical Study on Thermal Stratification Phenomena in Upper Plenum of LMFBR “MONJU”, Nuclear Engineering and Design, 258, 226-234, 2013.

[5] Fumiaki Yamada, et al., Numerical Simulation of MONJU Plant Dynamics by SUPER-COPD Using Previous Startup Tests Data, Proceedings of ASME 2010 3rd Joint US-European Fluids Engineering Summer Meeting and 8th International Conference on Nanochannels, Microchannels, and Minichannels FEDSM2010-ICNMM2010, August 1-5, 2010, Montreal, Canada, 2010.