Transient Simulation in the Upper Plenum of the MONJU with MARS-LMR

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1. Introduction

The KAERI (Korea Atomic Energy Research Institute) analyzed a thermal hydraulics in an upper plenum of the MONJU using MARS-LMR code. The MONJU is a Japanese sodium cooled fast reactor, which is a MOX-fueled, loop-type reactor producing 714 MWth. The MARS-LMR code is based on the MARS code for a safety analysis of a liquid metal reactor, and the MARS code has been developed by coupling RELAP and COBRA-TF in the KAERI. A geometrical data and time-dependent inlet conditions were used, which is provided to participants of IAEA (International Atomic Energy Agency) CRP (Coordinating a Research Project) named "Benchmark Analysis of Sodium Natural Convection in the Upper Plenum of the MONJU Reactor Vessel" by the JAEA. One-dimensional thermal hydraulic analysis was implemented using MARS-LMR code to validate the thermal-hydraulic models of the MARS-LMR code and identify important phenomena such as the buoyancy effect and thermal stratification.

2. Methods and Results

The reactor vessel of the MONJU is a cylindrical type with three outlet nozzles. Figure 1 shows the geometry of the MONJU RV upper plenum. A cylindrical inner barrel is located at radially more inner region of 50 cm from the inside wall of the reactor vessel. There are 48 LFHs (Lower Flow Holes) at 1.63 m height and 24 UFHs (Upper Flow Holes) at 2.55 m height from the top of a support plate.

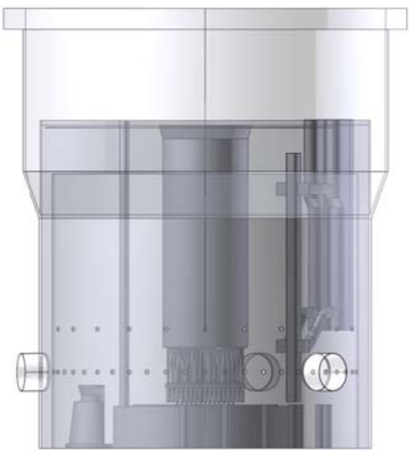

Fig. 1 Geometry of the MONJU RV upper plenum

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

Figure 2 shows a top view of the MONJU core subassemblies (S/As). The core subassemblies consist of inner divers, outer divers, neutron sources, blankets, neutron shielding, and control rods. A heat generated in the core is cooled by the sodium which flows into the reactor vessel through three inlet nozzles, and flows out the loop through three outlet nozzles. 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. Table 1 describes major design parameters of the MONJU.

This study simulated the flow behavior of the primary sodium in the MONJU reactor vessel. The core regions are divided into six regions in the MARS-LMR calculation. The boundary condition of the inlet is defined with the condition of the core outlet.

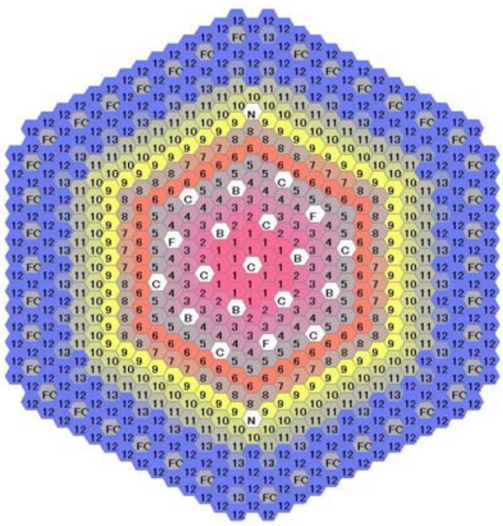

Fig. 2 Configuration of the reactor core

An input deck for a steady state is generated for the MARS-LMR calculation, and the steady-state calculation is performed at 40 % power condition. Figure 3 shows a nodalization for the one-dimensional analysis with the MARS-LMR. The core region is divided into 6 channels, and the hot pool region is divided into 3 regions: a radially inside region of an inner barrel (volume number: 230), a radially outside region of an inner barrel (volume number: 100), and an overflow region (volume number: 240). 48 LFHs and 24 UFHs are modeled as pipes (volume number: 801 and 901, respectively) to consider an abrupt area change due to a flow hole. Sodium in a lower position than a core barrel (volume number: the 1st node of 230) assumed to remain in a low temperature.

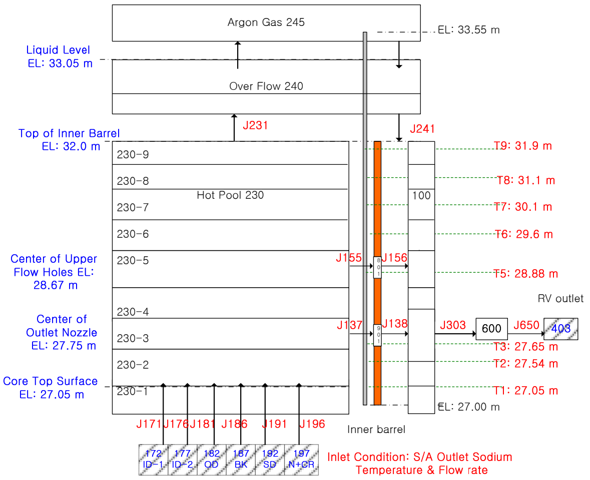

Fig. 3 Nodalization for the 1-D analysis with MARS-LMR

Figure 4 and figure 5 show flow rates of the RV upper plenum, flow holes, and overflow region in steady-state calculations of a 1-D analysis. In this calculation, the flow rate of a LFH is 2.32 kg/s, while the flow rate of an UFH is 1.55 kg/s. The over-flow rate over the inner barrel is calculated as 1878.8 kg/s.

Figure 6 to 15 show a transient result calculated in the MONJU RV upper plenum until 3600 sec after a turbine trip. A thermal stratification phenomenon is observed as shown in Figure 6. Coolant temperature remarkably decreases until about 600 sec after the turbine trip, and then the coolant is cooled slowly after 600 sec. Sodium under the 5th node with UFHs are well mixed by natural convection flow, so their temperatures become to be almost same. On the other hands, sodium over the 5th node shows a thermally stratified condition.

Figure 7 to 8 show sodium flow rates in the RV upper plenum, flow holes, and overflow region in transient calculations. In this calculation, the maximum flow rate of a LFH is estimated as 6.4 kg/s at 1498 sec, while the maximum flow rate of an UFH is 5.3 kg/s at 1922 sec after a reactor trip. The over-flow rate over an inner barrel decreased into zero after 2882 sec, which results in stagnations of sodium temperatures in the region from the 6th node to the 9th node of 230.

Figure 9 to 16 show comparisons of the calculated temperatures in the 1-D analysis with the MONJU System Start-up Tests(SSTs) data. The calculated results show a good agreement with the MONJU experimental data until 2500 sec after the turbine trip. However, the calculated temperature at the 9th node near the top of an inner barrel is lower than the experimental data. It is considered as limitation of the one-dimensional analysis, because the over-flow region has multi-dimensional flow phenomenon.

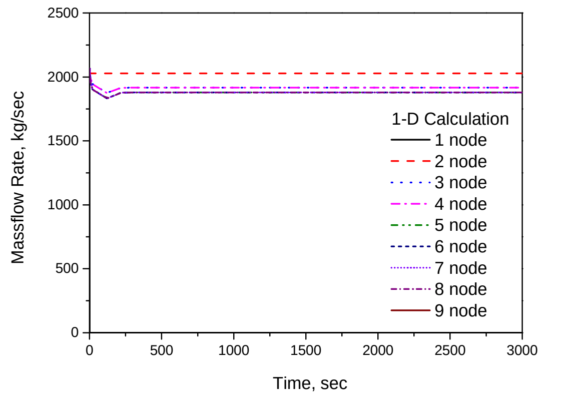

Fig. 4 Flow rates along the RV upper plenum in the steady-state analysis

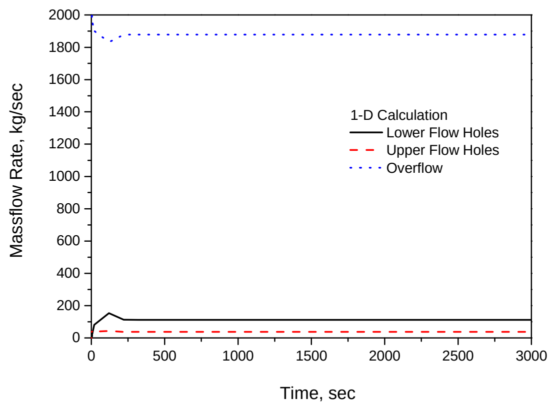

Fig. 5 Flow rates of flow holes and overflow in the steady-state analysis

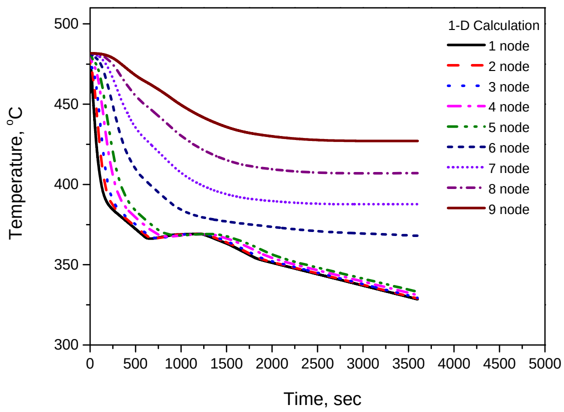

Fig. 6 Temperature stratification under the transient condition

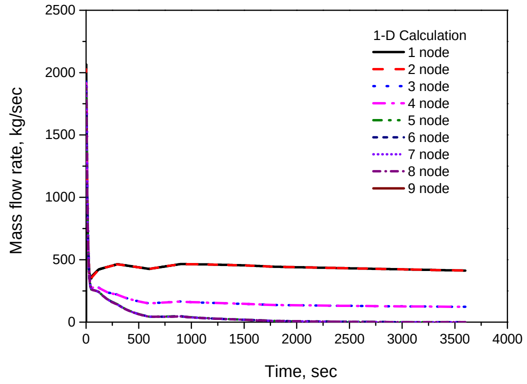

Fig. 7 Flow rates along the RV upper plenum in the transient analysis

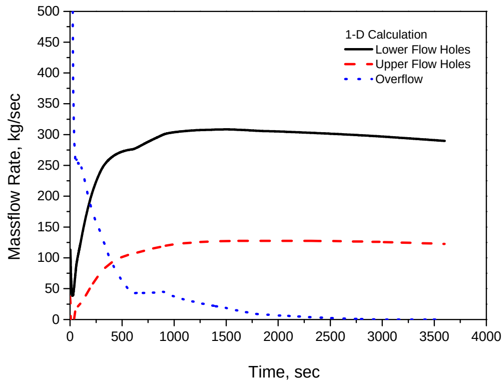

Fig. 8 Flow rates of flow holes and overflow in the transient analysis

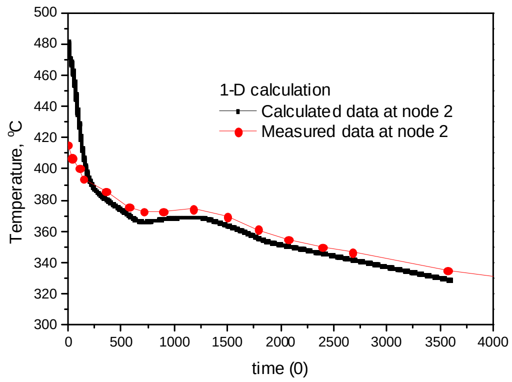

Fig. 9 Temperatures at the 2th node of 230 during the transient calculation

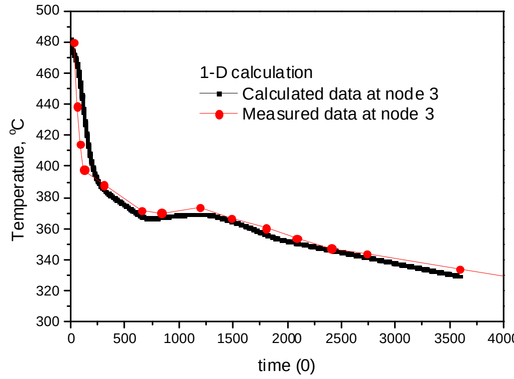

Fig. 10 Temperatures at the 3th node of 230 during the transient calculation

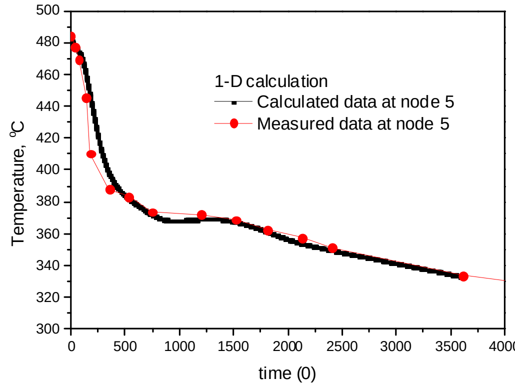

Fig. 11 Temperatures at the 5th node of 230 during the transient calculation

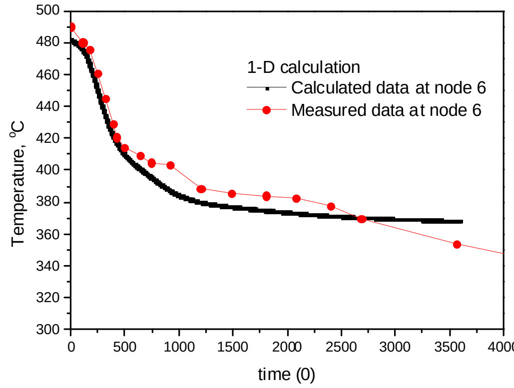

Fig. 12 Temperatures at the 6th node of 230 during the transient calculation

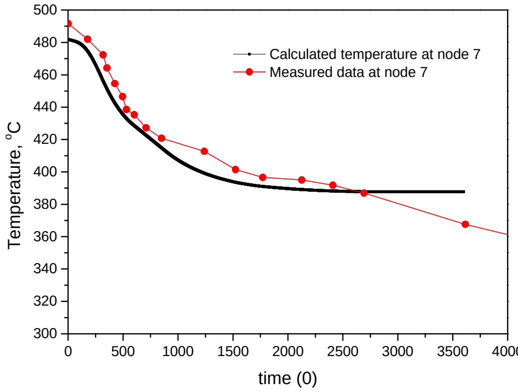

Fig. 13 Temperatures at the 7th node of 230 during the transient calculation

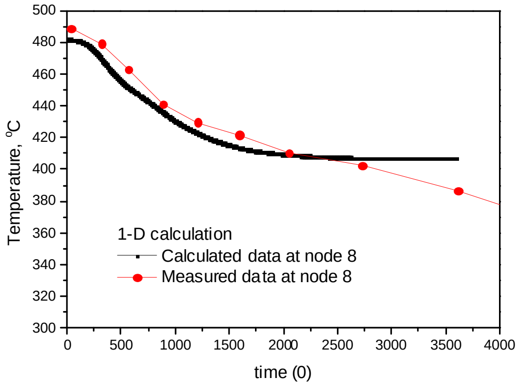

Fig. 14 Temperatures at the 8th node of 230 during the transient calculation

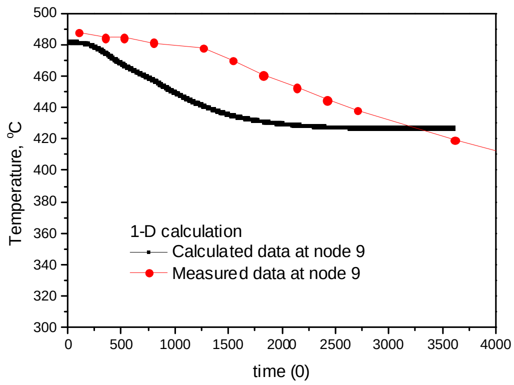

Fig. 15 Temperatures at the 9th node of 230 during the transient calculation

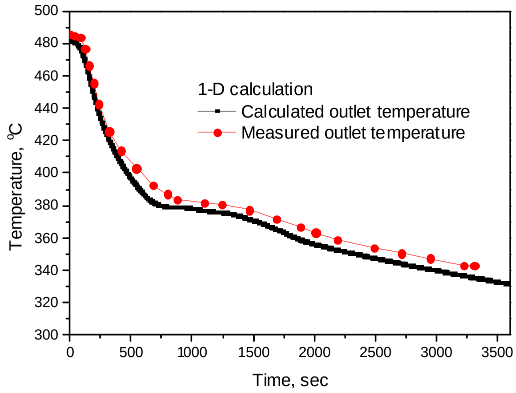

Fig. 16 RV outlet temperature during the transient calculation

3. Conclusions

One-dimensional thermal hydraulic analysis was 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. The calculated result shows a good agreement with the MONJU experimental data. 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 modeling of an over-flow region as one dimensional volume, because the over-flow region has multi-dimensional flow phenomenon. Therefore, the multi-dimensional flow in the over-flow region is a point to be considered for further studies.

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