Natural convection cooling in a 3-dimensional pool model of KJRR

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1. Introduction

The Ki-Jang Research Reactor (KJRR) project has been in progress since 2012. The main purpose of the KJRR is to produce various radioisotopes including Mo-99 and neutron-transmutation-doped silicon. The nominal power of the reactor is 15MW. The heat generated from the core is removed by downward forced convection flow. The reactor is an open-pool type where it is submerged under the pool water. There is sufficiently large amount of pool water above the reactor, so that it provides shielding the workers from the radiation as well as the ultimate heat sink.

If primary pumps for cooling the reactor stop by accidental events, decay heat is removed by natural convection of coolant in the pool. When the flow rate of coolant in the core decreases enough after pumps stop, the flap valves, which are installed on the core outlet pipe in the pool, open passively. And the flow in the core is reversed to upward direction by natural convection. Then, the coolant exiting the reactor flows into flap valves through reactor upper guide structure and the pool.

Since the natural convection in the large pool between the reactor structure assembly and the flap valves is expected to be 3-dimensional flow, modeling the flow in the pool as 1-dimension may be inappropriate. Therefore, it is necessary to investigate the effects of multi-dimensional natural convection in the pool on the thermal hydraulics in the core.

Herein, the flow of natural convection in the pool is investigated by modeling 3-dimensional pool of the KJRR. To identify the effect of multi-dimensional modeling, thermal hydraulic results are compared with those from 1-dimensional model.

2. Method and modeling

2.1 Method

Multi-dimensional Analysis of Reactor Safety (MARS) KS 1.4 is used in this analysis in order to investigate multi-dimensional hydrodynamic behavior. MARS is a thermal hydraulic system analysis code providing 3D module and coupling between 1-dimensional and 3-dimensional interfaces. And 3-dimensional convection and diffusion terms are implemented in the momentum equation. The hydrodynamic components of a 3D module consist of 3-dimensional array of volumes and the internal junctions connecting these volumes. The MARS 3D module is enabled to predict a more realistic and accurate thermal hydraulic phenomena.

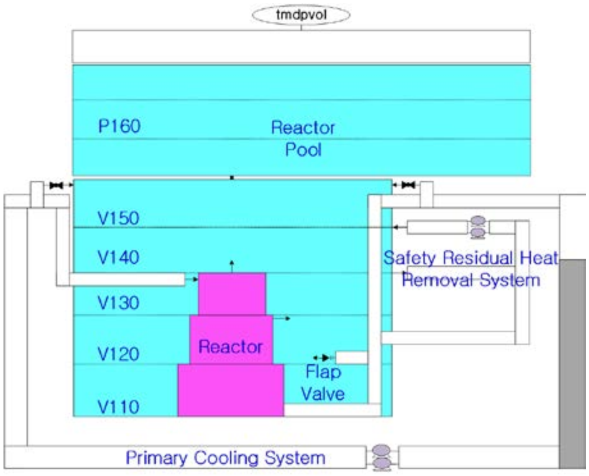

Fig. 1. Simplified nodalization of the KJRR.

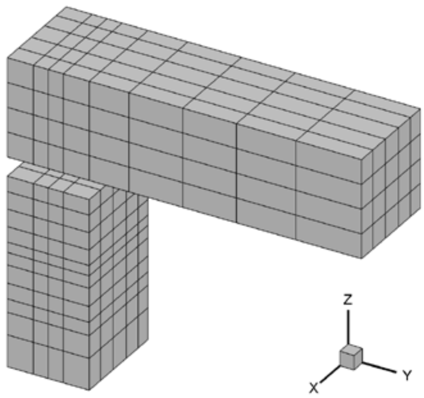

Fig. 2. 3-dimensional model of the reactor pool.

2.2 Modeling

Figure 1 shows the simplified nodalization of a 1-dimensional model for KJRR. The analyzed system includes the reactor, PCS, SRHRS and pool. Pool is divided into less than 10 volumes according to the interfaces with the connected fluid system.

In this study, the pool is only modeled as 3-dimensions as shown in Fig 2. The grids in a 3-dimensional model are defined considering the area and heights of connections to the pool. There are dummy volumes in the pool which represent the reactor and piping system. The fluid system connected to the 3-dimensional pool is identical to the 1-dimensional model.

3. Result and discussion

The thermal hydraulic behavior in the pool is investigated in a loss of electrical power (LOEP) accident. When the LOEP occurs, the reactor is tripped instantly as the control rods drop into the core, and the PCS pumps coast down. Then, SRHRS pumps start to cool the core further by forced convection for a certain period of time. After the SRHRS pumps stop, the flow direction in the core is switched to the upward direction and the decay heat is removed by natural convection. There is no difference in thermal hydraulic behavior between the 1-dimensional model and the 3-dimensional model before natural convection cooling mode. So the results in the natural convection mode are discussed here.

The natural convection flow rates at the reactor plenum are the same but temperatures are not. Fig. 3 shows the temperature changes in the 1D and 3D models from the beginning of natural convection cooling to 24hours. In the 1D model, the temperature at the reactor plenum rises rapidly with time. However, the temperature increases gradually in the 3D model. The enhanced temperature in the core plenum results in the higher fuel temperature. This means that the core cooling performance is lower. In the 1D model, decay heat is not sufficiently removed, which leads to fuel temperature increase.

The different temperature trends come from different flow path in the pool. In the 1D model, most of warm coolant exiting the reactor flows into the flap valves after mixing with the pool water only between top of the reactor and flap valves (V120 and V130 in Fig 1). Coolant flowing into the flap valves is still cold at the beginning of opening valves. But the temperature of the coolant increases rapidly as shown in Fig 3, since temperatures of the V120 and V130 have increased.

On the other hand, the coolant rises up to the top of the pool in 3-dimensional analysis. Fig 4 shows the temperature distributions with time after flap valves are opened. Grey color indicates the reactor which is dummy volume in the 3-dimensional pool model. As the warm coolant from the reactor rises as shown in Fig 4, the pool is heated up from the top of the pool. After enough time, the temperature increases in the lower part of the pool, especially near the flap valves. And the temperature at the reactor plenum increases. Therefore, it takes more time to increase the temperature at the reactor plenum, compared to 1-dimensional analysis, since the flow of coolant by natural convection is mixed with the pool of much larger volume of the pool.

4. Conclusions

3-dimensional natural convection in the pool of KJRR has been analyzed in the loss of electric power

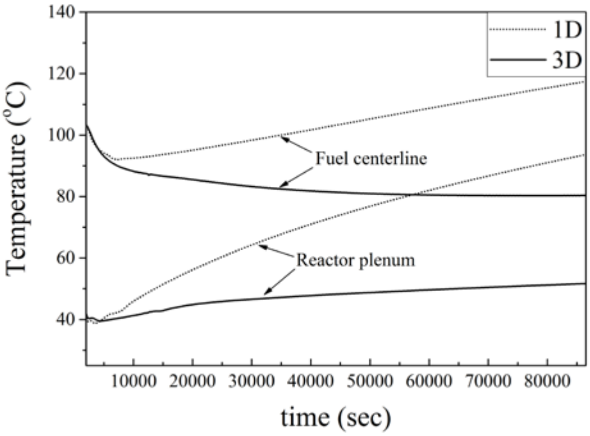

Fig. 3. Comparison of coolant and fuel temperatures between the 1D and 3D models.

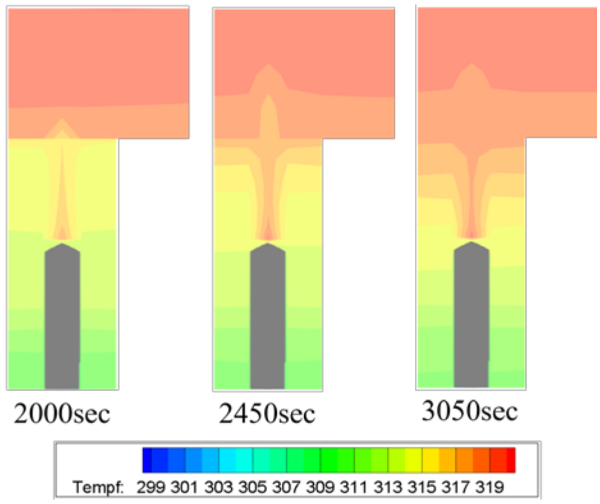

Fig. 4. Temperature distributions with time in the 3-dimen sional pool model of KJRR with time.

using MARS-KS. The thermal hydraulic results are compared with those calculated from the 1-dimensional model. In conclusion, the 1-dimensional model provides much more conservative results during natural circulation cooling phase in a view of fuel temperature.

A big difference of core cooling performance is expected during long term cooling phase between the 1-dimensional model and 3-dimensional model.

Acknowledgement

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[1] MARS-KS, Code Manual Input Requirements, KINS, 2015