Assessment of Three-Dimensional Effect on Reactor Fuel Assembly Simulation using CUPID and MARS-KS Codes

Yun-Je Cho[a*], Han-Young Yoon[a], Ik Kyu Park[a], Seung Jun Lee[a], Jae-Ryong Lee[a]
[a]*Korea Atomic Energy Research Institute, 111 Daedeok-daero, 989 Beon-gil, Yuseong-gu, Daejeon 305-600*
[*]*Corresponding author: yjcho@kaeri.re.kr*

1. Introduction

The nodalization with two fluid channel and three groups of fuel rods are widely used for the modeling of a reactor core in the safety analysis using a system Thermal-Hydraulics (TH) code. In this nodalization, the fluid channels are modeled with the averaged fuel assembly channel and hot fuel assembly channel while the fuel rods are modeled with three groups: the averaged fuel rods, hot fuel rods, and the hottest fuel rod. Different levels of power are input into the three groups of fuel rods by using the results of reactor core analysis. In this paper, the effect of the conventional nodalization and three-dimensional (3D) simulation using the CUPID [1] code on the reflood PCT are evaluated.

2. Calculation Setup

2.1 Conventional MARS-KS Nodalization

In the safety analysis, a reactor core is usually modeled with two fluid channels and three groups of fuel rods. One fuel assembly is modeled as a hot fuel assembly, and the other assemblies are modeled as averaged fuel assemblies. Therefore, the ratio of the flow area between the hot and averaged fuel assemblies is almost same to the total number of assemblies in the reactor core. The cross flow junctions are connected between two channels at each elevation.

On the other hand, the fuel rods are modeled with three groups of heat structures. The averaged fuel assembly and hot fuel assembly have different group of fuel rods, and one hottest fuel rod is additionally inserted in the hot fuel assembly. The power input for each fuel rod group is calculated from a reactor core analysis, and the hot fuel assembly has about 140 – 150% of the power in the averaged fuel assembly. The hottest fuel rod has 150 – 175% of the power in the averaged fuel assembly.

2.2 Test Calculation Case

To evaluate the effect of the nodalization and 3D simulation under the reflood condition, RBHT test geometry and its test condition were applied [2]. RBHT has the rectangular test channel with 49 fuel rods, which have almost identical shape to the real geometry, as shown in Fig.1. The length and outer diameter of the fuel rod are 3.6576 m and 9.45 mm, respectively.

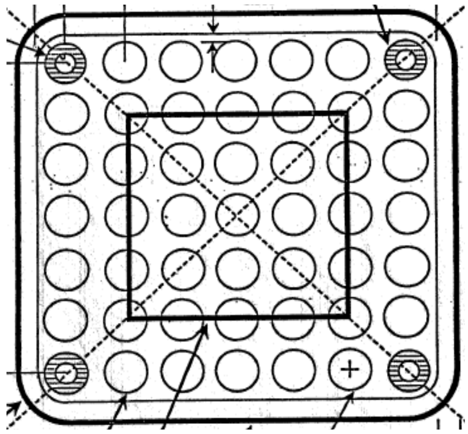


Fig. 1. Test channel of RBHT facility

The axial power distribution has linear shape function and the radial power distribution is uniform. However, in this paper, a conceptual calculation case is additionally prepared using a radially non-uniform power distribution. The initial and boundary conditions for the test calculation case are summarized in Table I.

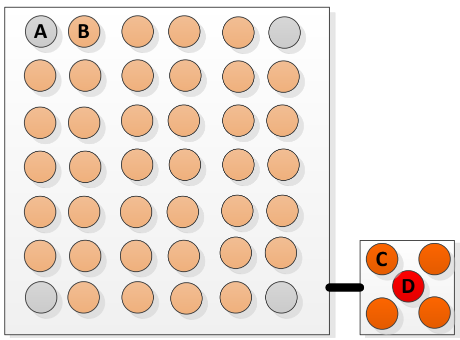
Table I: Initial and boundary condition

Pressure	Rod LHGR	Injection rate	Inlet subcooling
275.8 kPa	1.53 kW/m	15.24 cm/s	53.3 K

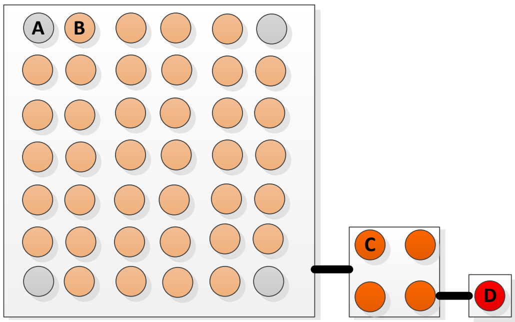
*LHGR: Linear Heat Generation Rate

2.3 MARS-KS Nodalization and CUPID Grid Generation

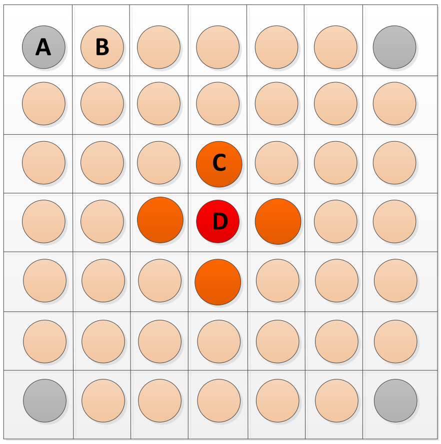
A simple one-dimensional (1D) nodalization, multi-channel nodalization for the MARS calculation and 3D computational grid for the CUPID calculation are prepared to evaluate the effects of nodalization and 3D simulation as shown in Fig. 2.



(a) MARS two-channel nodalization



(b) MARS three-channel nodalization



(c) CUPID 3D grid

Fig. 2 Nodalization and grid generation

1D nodalization for MARS and 1D grid for CUPID are basically identical. To model the two-channel approach the 45 fuel rods are located in the large fluid cell, which model the averaged fuel assembly, while 4 hot fuel rods and one hottest fuel rod are located in the separate fluid channel, which model the hot fuel assembly, as shown in Fig. 2 (a). Three-channel nodalization is also attempted by independently model the small fluid channel where the hottest fuel rod is located as shown in Fig. 2 (b). In the case of 3D grid for the CUPID calculation, 7x7 grids for the cross section of the fluid channel are generated so that the each fuel rod is connected to separate fluid cell as shown in Fig. 2 (c).

2.4 Non-Uniform Power Distribution Input

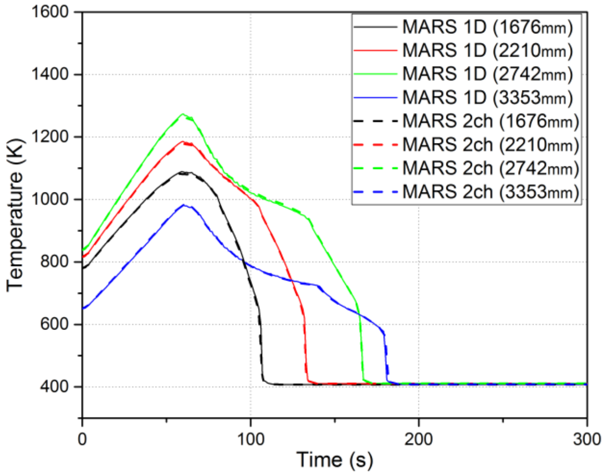
In addition to the uniform power distribution in a radial direction, the non-uniform case is calculated because the effect of multi-channel nodalization and 3D grids can be more significant in the radially asymmetric case. Maintaining other initial and boundary conditions identical to the uniform power distribution case, the power inputs to the hot fuel rods and the hottest fuel rod are increased up to 145% and 172% of the averaged power, respectively. In Fig.2, the notations in the fuel rods A, B, C, and D indicate the unheated rods, averaged fuel rods, hot fuel rods, and the hottest fuel rod, respectively.

3. Calculation Results

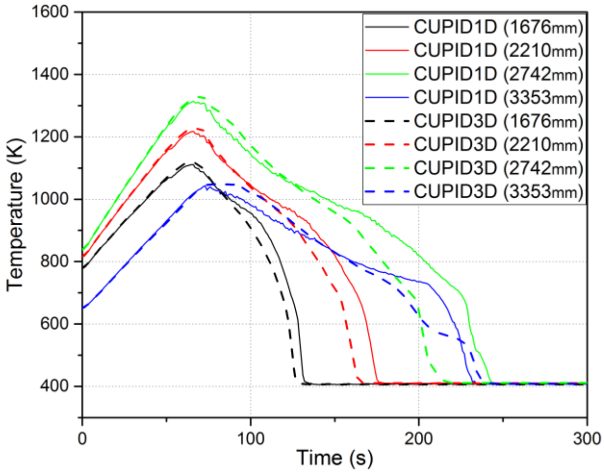
3.1 Uniform Power Distribution Case (Baseline case)

In the calculation results with the radially uniform power distribution, the effect of multi-channel nodalization in the MARS calculation is negligible as shown in Fig. 3 (a). The CUPID calculation results shows that the 3D calculation predicted slightly faster decrease of fuel rod temperature after the peak value because of a lateral mixing effect.

Comparing the CUPID calculation results to the MARS calculation results, CUPID predicted slightly higher fuel rod temperatures as shown in Fig. 3 (b). This discrepancy implies that CUPID and MARS may have partially different physical models for the reflood calculation.



(a) MARS calculation result



(b) CUPID calculation result

Fig. 3. Calculation results for uniform power distribution case

3.2 Non-Uniform Power Distribution Case

As described in Section 2.4, three different powers were used to model the radially non-uniform power distribution. To evaluate the effect of 3D calculation using CUPID comparing to the MARS calculation results, the CUPID calculation results were compensated by using the baseline calculation result described in the previous section.

Fig. 4 shows the comparison results among the calculation results using MARS with 2-channel and 3-channel nodalizations, and CUPID 3D calculation result. The fuel rod temperatures at 2.742 mm height are compared where the peak cladding temperature (PCT) occurs.

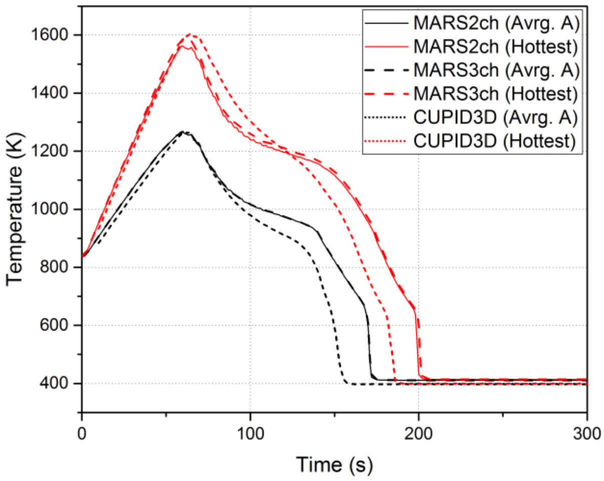


Fig.4. Calculation results for non-uniform power distribution case

As shown in Fig. 4, PCTs occur at 60 s when the temperature of averaged fuel rod is about 1267K. The temperatures of the hottest fuel rod in the MARS calculations using 2-channel nodalization, and 3-channel nodalization, and CUPID 3D calculation are 1562K, 1586K, and 1602K, respectively. In the calculation results with MARS 3-channel nodalization and CUPID 3D grid, the fluid temperature around the hottest fuel rod is higher than the fluid temperature in the hot assembly channel. Thus, the temperatures of the hottest fuel rod in the calculation results using MARS 3-channel nodalization and CUPID 3D grid are also higher than that in the MARS 2-channel nodalization.
The calculation result of CUPID showed the faster decrease of fuel rod temperature after the peak as shown in Section 3.1 because of the same reason. However, the PCT in the CUPID calculation is higher than the MARS calculation results using 2-channel nodalization and even 3-channel nodalization. The reason of trend might be assessed with additional model sensitivity tests.

5. Conclusions

The effect of MARS nodalization and 3D calculation on the reflood calculation was investigated using the RBHT test geometry and its test conditions. Unlike the conventional 2-channel nodalization, a higher PCT was predicted when the separate fluid cell was modeled for the hottest fuel rod. With the same reason, the 3D calculation result using CUPID also showed the higher PCT than the PCT in the MARS calculation with 2-channel nodalization.

In the future, the cause of discrepancy in the calculation results between the MARS and CUPID in the uniform power distribution case will be assessed by performing additional model sensitivity.

ACKNOWLEDGMENTS

This work was supported by National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIP).

REFERENCES

[1] J. J. Jeong, et al., The CUPID code development and assessment strategy, Nuclear Engineering and Technology, Vol. 42, No. 6, 2010.
[2] L. E. Hochreiter, et al., RBHT data and analysis report reflood heat transfer experiments, The Pennsylvania State University, 2007.