Whole-Core Thermal Analysis of Prismatic Very High Temperature Reactor

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1. Introduction

A new method for thermal analysis of prismatic fuel blocks in a very high temperature reactor (VHTR) was developed [1] to overcome the demerits of computational fluid dynamics (CFD) and system calculations. The developed method solves three-dimensional heat conduction in prismatic fuel blocks like a CFD code. For the fluid, however, the method adopts one-dimensional conservation equations like a system code. Such a combination enables significantly reduced computational efforts with reasonable computational accuracy. In this paper, the new method has been applied to whole core of PMR200 [2] under full power operating conditions.

2. Core Design of PMR200

PMR200 has been pre-conceptually designed to have a 200 MW thermal power as one of the candidate reactor designs for a nuclear hydrogen production demonstration plant [2]. Fig. 1 shows the cross-sectional top view of the PMR200 core. The annular active core consists of 66 fuel assemblies which are surrounded by the central reflector assemblies and the side reflector assemblies. The height of one fuel block is 0.793m. 6 fuel blocks are stacked to form the active part of one fuel assembly, i.e., fuel column. Therefore, the total height of the active core is 4.758 m. As shown in Fig. 1, 66 fuel assemblies are composed of 42 standard fuel assemblies, 12 control fuel assemblies, and 12 reserved shutdown fuel assemblies. The coolant inlet and outlet temperatures are 490 and 950 ^{o}C, respectively. The bypass gap size is assumed to be 2 mm in this work.

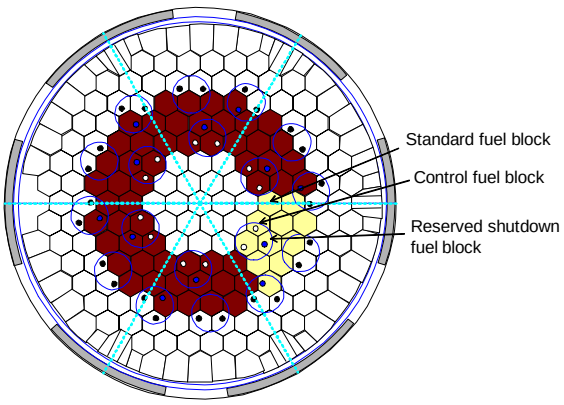

Fig. 1. Cross-sectional top view of PMR200 core.

3. Numerical Model & Boundary Conditions

Using the symmetry, 1/6 section of the active core of PMR200 (yellow part in Fig. 1) has been considered for the present analysis. Fig. 2 shows the considered domain. It includes 7 standard fuel assemblies, 2 control fuel assemblies, 2 reserved shutdown fuel assemblies, and 41 bypass gaps.

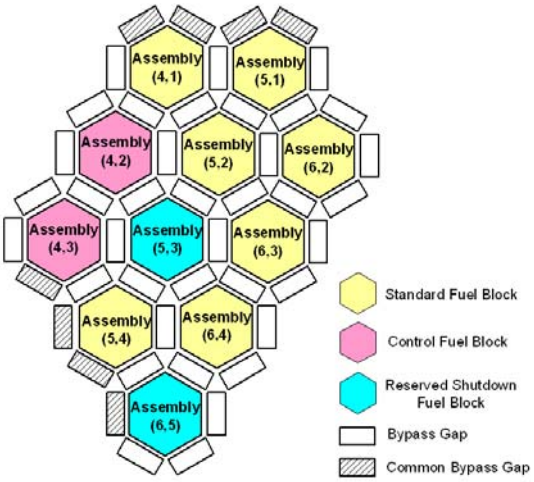

Fig. 2. Computation domain for the present analysis.

In the developed method, as described in the reference [1], a prismatic fuel block is modeled by the basic unit cells as shown in Fig. 3, which define computational grids for an analysis. The basic unit cells are arranged to simulate the entire fuel block. Each type of the fuel blocks (i. e., standard, control, and reserved shutdown fuel blocks) has different arrangement of the unit cells. Fig. 4 shows the unit cell arrangement for the reserved shutdown fuel block as an example. The numbers in Fig. 4 represent the corresponding types of the basic unit-cell. For example, 1 and 8 represent fuel compact and reserved shutdown hole, respectively.

Fig. 3. Basic unit cells used in the newly developed method.

The results by MASTER-GCR and GAMMA+ codes are used as boundary conditions. The MASTER-GCR code provides three dimensional power profiles for the present work. The steady-state result of the GAMMA+ code is adopted for the mass flow rate flowing into the each fuel assembly and the bypass gap.

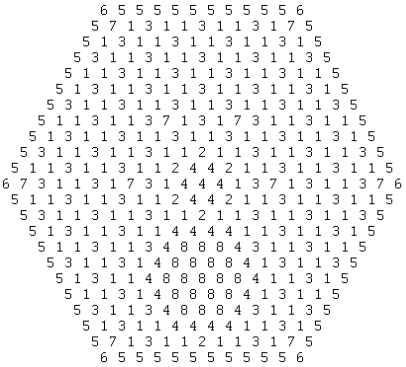

Fig. 4. Arrangement of the basic unit cells for reserved shutdown fuel block.

4. Results & Discussions

Fig. 5 shows the calculated maximum fuel temperatures for the individual fuel assemblies at the beginning of the cycle (BOC), the middle of the cycle (MOC), and the end of the cycle (EOC). The predicted hot spot fuel temperatures are 1154, 1189, 1204 ^{o}C at BOC, MOC, and EOC, respectively. Highest fuel temperatures are observed at the control fuel assemblies (i.e., Assembly (4,2) and Assembly (4,3)) located at the inner ring (See Fig. 2 for the location of the assembly.). Such an observation is well agreed with the previous study [3]. Lim and Kim pointed out the highest fuel temperature at the fuel blocks with control rod/reserved shutdown holes based on the GAMMA+ calculation with the detailed core model. This observation is confirmed by the recent CFD study by Kim et al. [4].

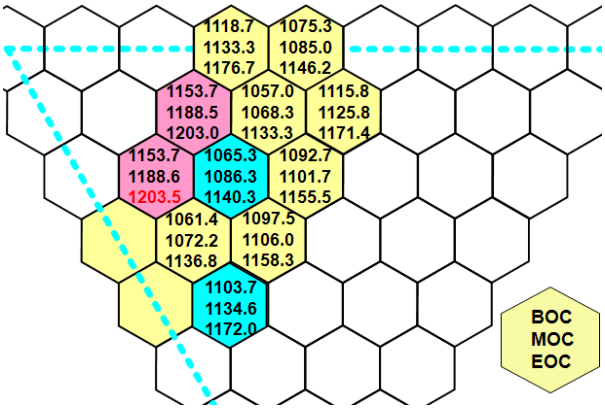

Fig. 5. Predicted maximum fuel temperatures for the individual fuel assemblies (unit: ^{o}C).

Table I compares the predicted maximum fuel temperatures at Assembly (6,2) with the existing CFD result [5]. A good agreement is found except the EOC condition. The difference at the EOC condition is ~15 ^{o}C. As shown in Fig. 6, the difference seems to be mainly due to the axial heat conduction through the non-fuel zone at the graphite plugs of the fuel blocks. Therefore, the graphite plug needs to be included for more accurate analysis. In addition, one of drawbacks of the present analysis is that convective heat transfer through control rod/reserved shutdown holes is not modeled. Future work will include such a phenomenon. Fig. 6 indicates that the results by the present analysis are reasonable in spite of such drawbacks.

Table I: Comparison of Maximum Fuel Temperature at Assembly (6,2) (unit: ^{o}C)

	Present	CFX [5]
BOC	1115.8	1113
MOC	1125.8	1127
EOC	1171.4	1157

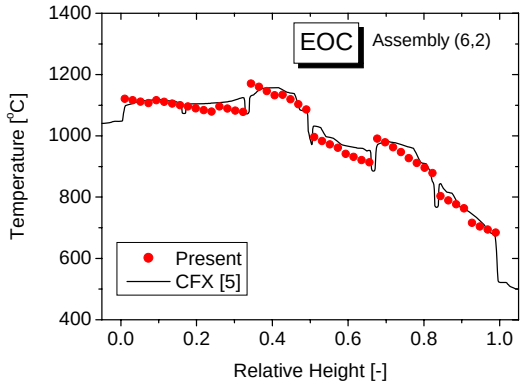

Fig. 6. Comparison of the predicted axial temperature profile at the fuel center with the existing CFD result.

5. Conclusions

Steady-state, whole-core thermal analysis of PMR200 has been made using the newly developed method. The results of the present analysis show that the developed method is applicable to whole-core thermal analysis of prismatic VHTR. However, more precise models (such as graphite plugs, control rod hole flow, etc.) are necessary to improve the accuracy of the calculation.

Acknowledgements

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