GAMMA+ Simulation of Phase 1 Exercise 2 of the OECD/NEA MHTGR-350 Benchmark

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1. Introduction

Sponsored by OECD/NEA, a benchmark study on the prismatic coupled neutronics/thermal fluids transient for the MHTGR-350 core was initiated in 2012 [1]. The benchmark consists of three phases, i.e., steady-state (Phase 1), transient-state (Phase 2) and depletion problems (Phase 3). Phase 1 has three exercises. Exercise 1 deals with neutronics stand-alone calculation whereas Exercise 2 focuses on thermo-fluid stand-alone calculation. The coupled simulation is defined in Exercise 3. Korea Atomic Energy Research Institute (KAERI) is participating in Phase 1 Exercise 2 using the GAMMA+ code [2].

The present paper summarizes the GAMMA+ model and results of Phase 1 Exercise 2 which contains the steady-state thermo-fluid simulation of the MHTGR-350 core.

2. Benchmark Specification

The radial layout of the MHTGR-350 core is shown in Fig. 1 and the main design parameters are provided in Table I. In order to simplify the calculation, the Reactor Cavity Cooling System (RCCS) is removed and the fixed temperature of 30 ºC is imposed at the outmost boundary except the bottom. Adiabatic conditions are assumed at the bottom boundary. Fixed 3-D power distribution is provided as a nuclear heat source.

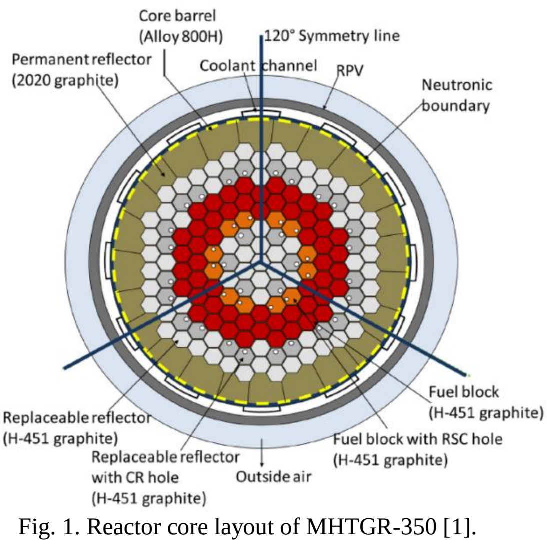

Fig. 1. Reactor core layout of MHTGR-350 [1].

Table I: Main Design Parameters of MHTGR-350 Core

	Values
Thermal power (MW_{th})	350
Coolant inlet/outlet temperatures (ºC)	259/687
System pressure (MPa)	7
Coolant flow rate (kg/s)	157.1
No. of fuel columns	66
Active core height (m)	7.93
Bypass flow gap size (mm)	2, 3.5
Crossflow gap size (mm)	0

Phase 1 Exercise 2 consists of the four subcases as shown in Table II. The four subcases are defined in order of increasing complexity by using the modeling of bypass flow and material properties.

Table II: Definition of Four Subcases of Phase 1 Exercise 2

Case	Bypass Flow	Material Properties
A	None	Fixed
B	Fixed distribution	Fixed
C	Fixed distribution	Variable
D	Calculated, based on given bypass gap sizes	Variable

3. GAMMA+ Model

Using symmetry shown in Fig. 1, 1/3 core model was used. Two different grid structures were applied for the fuel and replaceable reflector columns as shown in Figs. 2 and 3. In the case of coarse grid model, single hexagonal column has one cell tangentially. However, single hexagonal column is tangentially divided into six triangular cells in the case of fine grid model. All control rod channels are modeled individually whereas the coolant and bypass gap channels are grouped to reduce the number of the computational cells. The coolant channels are grouped in such a way that a single coolant channel is modeled for the single node of a fuel column (For example, 18 coolant channels in the same triangular region are grouped into one coolant channel in the case of fine grid model.). As for the bypass gaps between hexagonal blocks, they are grouped in 15 bypass gaps. The heat transfer through the air gap between the reactor pressure vessel and the outmost boundary is modeled with solid heat conduction and radiation. Fig. 4 shows the radiation paths between the core barrel and the reactor pressure vessel (RPV).

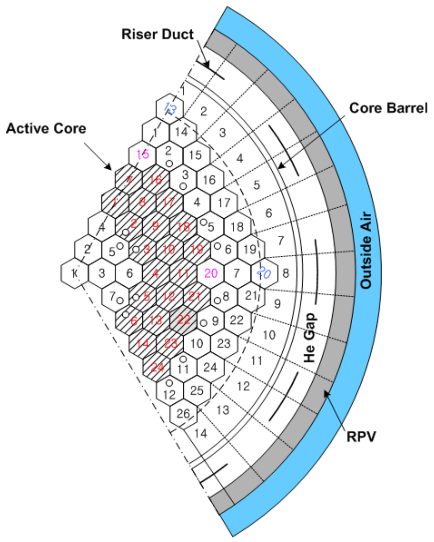

Fig. 2. Coarse grid nodalization for GAMMA+ simulation.

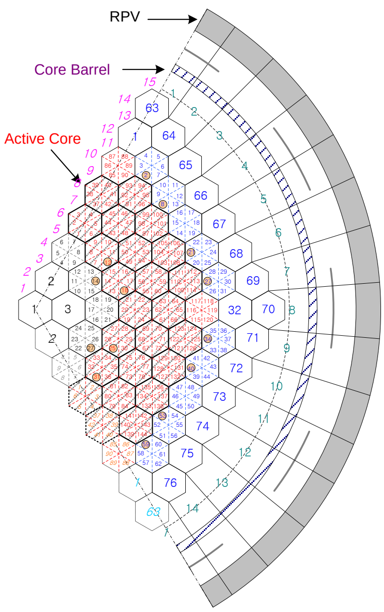

Fig. 3. Fine grid nodalization for GAMMA+ simulation.

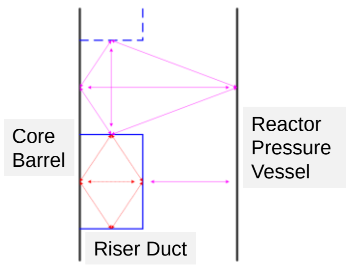

Fig. 4. Radiation paths between core barrel and RPV.

4. Results and Discussions

Table III shows the calculated global parameters for Cases A and B using two kinds of grid size models. It shows that the impact of the grid size on the temperatures is up to 69 °C. And it also shows that the temperatures of the fuel and moderator are increased with the bypass flow whereas the temperatures of the reflector, core barrel, and RPV are decreased with the bypass flow.

Table III: Effects of Grid Size on Global Parameters

	Coarse Grids	Fine Grids
Case A		
Max. fuel temp. [°C]	998	999
Aver. fuel temp. [°C]	643	612
Aver. moderator temp. [°C]	604	573
Aver. reflector temp. [°C]	425	450
Max. core barrel temp. [°C]	375	371
Max. RPV temp. [°C]	259	248
Case B		
Max. fuel temp. [°C]	1000	980
Aver. fuel temp. [°C]	671	634
Aver. moderator temp. [°C]	632	593
Aver. reflector temp. [°C]	312	381
Max. core barrel temp. [°C]	274	315
Max. RPV temp. [°C]	259	207

Figs. 5~8 shows the solid temperature distributions with fine grids. In order to show radial distribution, the temperatures are averaged for first inner ring (IR1), second inner ring (IR2), third inner ring (IR3), inner fuel ring (IF), middle fuel ring (MF), outer fuel ring (OF), first outer reflector ring (OR1), and second outer reflector ring (OR2). The temperature of the inner fuel ring is shown to be the highest. This is reasonable since the inner fuel ring has the highest power generation. The temperature of the middle fuel ring is slightly lower than that of the outer fuel ring due to smaller power generation. Comparable fuel temperature distributions are observed for Figs. 6~8. It means that the fuel temperatures are not significantly affected by the thermo-physical properties (Case B vs. Case C) and the modeling method of the bypass flow (Case C vs Case D).

In Fig. 5, the temperatures of the inner reflectors are seen to be close to the inner fuel. This is also reasonable due to no bypass flow condition. The temperatures of the inner reflectors are dramatically decreased at Figs. 6~8 due to the bypass flow through the inner reflector gaps. At Figs. 6~8, the higher temperatures of the reflectors are observed for closer location to the fuel.

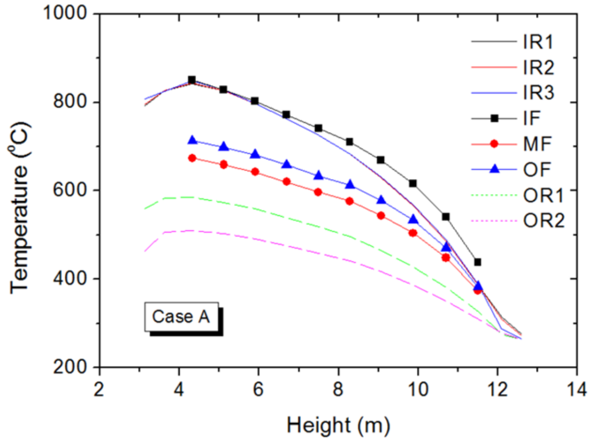

Fig. 5. Solid temperature distribution of Case A with fine grids.

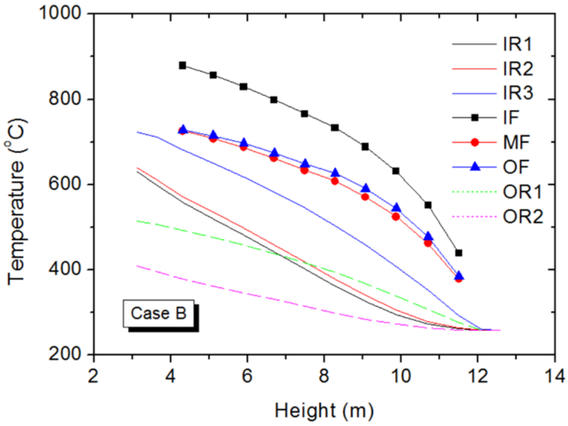

Fig. 6. Solid temperature distribution of Case B with fine grids.

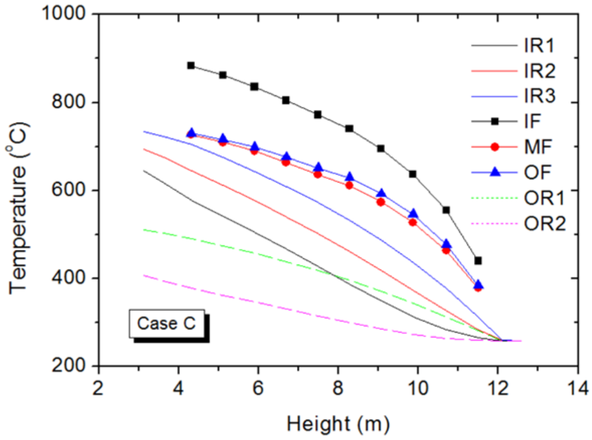

Fig. 7. Solid temperature distribution of Case C with fine grids.

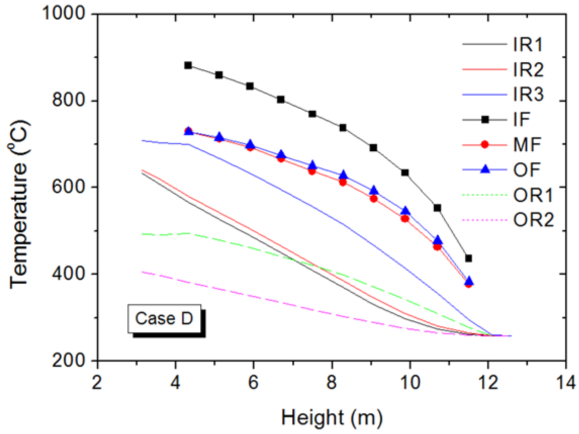

Fig. 8. Solid temperature distribution of Case D with fine grids.

5. Conclusions

In this work, the GAMMA+ modeling and calculation results were presented for Phase 1 Exercise 2 of the OECD/NEA MHTGR-350 benchmark. Four cases were considered with two different grid size models. The results of the GAMMA+ calculations were found to be reasonable. The results were submitted to the benchmark organizer. The international comparison is on-going and the final OECD/NEA publication will be issued later.

Acknowledgements

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REFERENCES

[1] J. Ortensi et al., OECD/NEA Coupled Neutronic/Thermal-Fluids Benchmark of the MHTGR-350 MW Core Design, Volume1: Reference Design Definition, 2015/1/15.

[2] H. S. Lim, General Analyzer for Multi-component and Multi-dimensional Transient Application, GAMMA+ 1.0 Volume II: Theory Manual, KAERI/TR-5728/2014, KAERI, 2014.