MHTGR-350 Coupled Steady-State Results using MCS and GAMMA+

Matthieu Lemaire[a], Hyunsuk Lee[a], Nam-il Tak[b], Hyun Chul Lee[b], Deokjung Lee[a*]
[a]*Ulsan National Institute of Science and Technology, 50, UNIST-gil, Ulsan, 689-798, Republic of Korea*
[b]*Korea Atomic Energy Research Institute, 150, Deokjin-dong, Yuseong-gu, Daejeon, 305-353, Republic of Korea*
[*]*Corresponding author: deokjung@unist.ac.kr*

1. Introduction

The MHTGR-350 benchmark was approved for international participation in 2012 by the Nuclear Energy Agency [1][2]. The benchmark contains various problems (neutronics, thermo-fluid, depletion and coupled calculations) and the resulting code-to-code comparison will aim at improving the reactor analysis tools used for the design and safety evaluation of prismatic modular reactors. In this paper, some preliminary results for the Phase-1 exercise-3 (P1-Ex3) steady-state exercise are obtained by using the MCS Monte Carlo code developed at UNIST [3] and the GAMMA+ thermo-fluid code developed by KAERI [4].

2. Methods and Results

2.1 Definition of the Exercise

P1-Ex3 of MHTGR-350 benchmark is a steady-state exercise requiring coupled neutronics and thermo-fluid simulations of End-of-Equilibrium-Cycle MHTGR-350. The actual core geometry is shown in Fig. 1 and some of MHTGR-350 characteristics are summed up in Table 1 [5]. P1-Ex3 comprises two subcases, Ex3a where the bypass flow between fuel blocks is a fixed parameter and Ex3b where it is a calculated parameter.

2.2 MHTGR-350 modelling

MCS is a Monte Carlo core simulation code for reactor physics analysis. The MCS model is a full-core model where the permanent reflector is simplified using a hexagonal representation as shown in Fig. 2. There are 271 hexagonal radial meshes which contain 66 fuels blocks, 97 replaceable reflector blocks and 108 permanent reflector blocks. In axial direction, there are 14 layers consisting of 10 layers containing fuel regions and two layers for upper and lower reflector regions. Control rods are inserted one active core layer deep in columns 33 shown in Fig. 2. Homogenized macroscopic 26-group neutron cross-sections are given for the 660 fuel blocks, inner/outer reflectors, and the control rods.

GAMMA+ code is a system/safety analysis code for high-temperature reactors. The GAMMA+ model is presented in Fig. 3. Using the core symmetry, only 1/3 section is modeled. Single fuel columns are modeled by six triangular cells. In the case of replaceable reflector columns, either hexagonal or triangular cells are used. The control rod channels are modeled individually but the coolant and bypass gap channels are grouped to reduce the number of the computational cells. The coo-

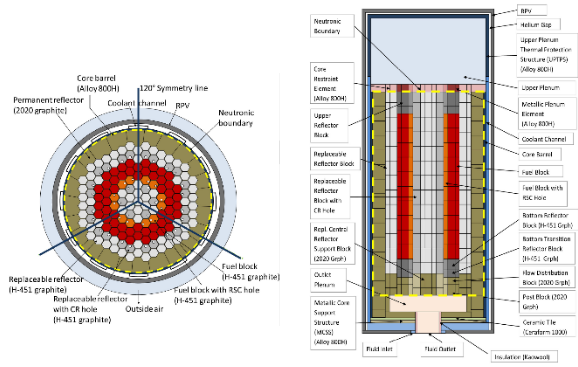

Fig. 1. MHTGR-350 core geometry

Table 1. MHTGR-350 characteristics

Thermal power (MW)	350
Average power density (MW/m^3)	5.93
Average UO2 enrichment (wt%)	15.5
Packing fraction of TRISO particles	0.35
Primary coolant	helium
Outlet coolant pressure (MPa)	6.39
Total coolant flow rate (kg/s)	157.1
Core inlet temperature (°C)	259
Core inlet temperature (°C)	687

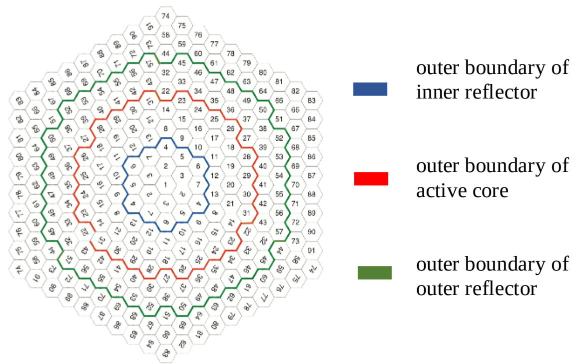

Fig. 2. MCS radial mesh

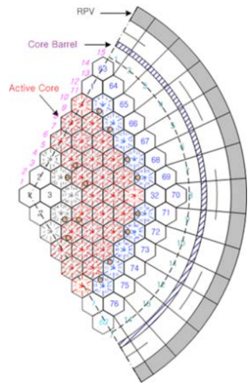

Fig. 3. GAMMA+ radial mesh

-lant channels are grouped in such a way that a single coolant channel is modeled for the triangular region of a fuel column. Axially, one cell is assigned for each fuel block.

2.3 Coupling Scheme

A loosely-coupled scheme is implemented with a client/server architecture. MCS and GAMMA+ codes act as client programs and a third-party server, INTCA, controls the coupled calculations by receiving requests from the two client codes and sending commands to them. The control algorithms of INTCA are explained in detail in [4].

A coupled step unfolds as follows. On the one hand, MCS calculates the power densities and sends them to GAMMA+. The power density data is used as heat source in GAMMA+. On the other hand, GAMMA+ calculates the temperature of the core components (e.g., fuel, moderator, and reflector) and sends them to MCS. The temperature data is used to evaluate nuclear cross-sections in MCS. Since the meshes of GAMMA+ and MCS are different, both axially and radially, each code uses its own naming convention for the variables. Mapping between the variables of the two codes is conducted by INTCA.

At each coupled step, the Xenon135 equilibrium number densities in each fuel block are also calculated by MCS using the Inline Equilibrium Xenon method [6]. The Xenon135 number densities are used along with the GAMMA+ temperature feedback to evaluate the nuclear cross-sections at each coupled step.

2.4 Preliminary Results for P1-Ex3b

The convergence during 500 coupled steps of the axial profile of power density and fuel temperature is presented on Fig. 4 and Fig. 5 respectively (layer 1 = bottom active core layer, layer 10 = top active core layer). The maximum of power density is reached for axial layer 8, which is reasonable given the fact that the helium cools the MHTGR-350 core from top to bottom and 3 control rods are inserted in layer 10.

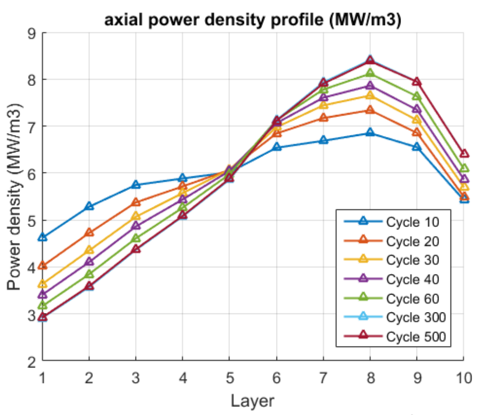

Fig. 4. Power density radially-averaged axial profile at different coupled step

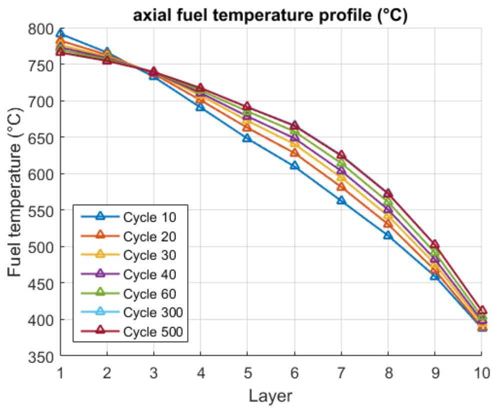

Fig. 5. Fuel temperature radially-averaged axial profile at different coupled step

Table 2 presents additional converged parameters.

Table 2. Global calculated parameters for P1-Ex3b

Keff	1.05916
Axial offset	0.267
Pressure drop across core (kPa)	23.5
Total bypass flow (kg/s)	17.95
Maximum fuel temperature (°C)	1167
Average fuel temperature (°C)	641

3. Conclusions

In this paper, preliminary coupled steady-state results for the OECD/NEA MHTGR-350 neutronics/thermo-fluids benchmark problems were presented. The numerical simulation showed reasonable results. Complete results for P1-Ex3 using the MCS/GAMMA+ coupled code system will be submitted to the MHTGR-350 benchmark committee in the near future.

REFERENCES

[1] G. Strydom, Epiney SA. RELAPS-3D Results for Phase I (Exercise 2) of the OECD/NEA MHTGR-350MW Benchmark. Proceedings of the ICAPP' 12 Conference, Chicago, Illinois, USA, June 24-28, 2012.

[2] Ortensi J et al. OECD/NEA coupled neutronics/thermal-fluids benchmark of the MHTGR-350MW core design. Volume I: reference design definition and Volume II: definition of the steady-state exercise. Draft date: 1/15/2015.

[3] Lee H, Kim W, Zhang P, Khassenov A, Jo Y, Lee D. Development Status of Monte Carlo Code at UNIST. Transactions of the Korean Nuclear Society Spring Meeting, Jeju, Korea, May 11-13, 2016.

[4] Tak NI, Lee HC, Lim HS, Han TY. CAPP/GAMMA+ code system for coupled neutronics and thermo-fluid simulation of a prismatic VHTR core. Annals of Nuclear Energy 2016; 92, pp. 228-242.

[5] ARIS (Advanced Reactors Information Systems). General Atomics' Prismatic Modular High-Temperature Gas-Cooled Reactor. Online: http://aris.iaea.org/

[6] Yang F, Wang G, Yu G, Wang K, Chen Z. Implementation of Inline Equilibrium Xenon method in RMC code. Proceedings of the PHYSOR 2016 Conference, Sun Valley, Idaho, USA, May 1–5, 2016