Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 10-11, 2007

A Steady State Neutronics Solutions to the OECD/NEA PBMR-400 Coupled Benchmark Problem by using the MARS-GCR/CAPP Code

Hyun Chul Lee*, Seung Wook Lee, Jae Man Noh, Jae Jun Jeong
Korea Atomic Energy Research Institute, 150 Deokjin-Dong, Yuseong, Daejeon, Korea, lhc@kaeri.re.kr

1. Introduction

The OECD/NEA PBMR-400 neutronics/thermal-hydraulics benchmark problem was recently proposed to test the existing analysis methods for high temperature gas-cooled reactors (HTGRs) and to develop more accurate and efficient tools to analyze the neutronics and thermal-hydraulic behavior for the design and safety evaluations of the PBMR [1]. There are three cases in the steady state phase (Phase I). They are the neutronics stand-alone case with fixed cross sections (Exercise 1), the thermal-hydraulics stand-alone case with given heat source (Exercise 2), and the neutronics/thermal-hydraulics couple case (Exercise 3), which is the initial condition for the cases in the transient state phase (Phase II).

In our previous work [2], we tried to use the hex-z solver of the MASTER code for the neutronics solutions of exercise 1. However, we observed a large azimuthal dependency of the neutronics solution which was additionally introduced by the zigzag core/reflector boundary in the hex-z model. In this paper, we present the neutronics solutions of the newly developed CAPP (Core Analyzer for Pebble and Prismatic type VHTRs) code[3] to exercise 3 as well as exercise 1.

2. Methods and Results

2.1 CAPP code Model and Coupling Method

The CAPP code has two solvers. One is a finite difference method (FDM) solver with flexible geometry treatment and the other is a finite element method (FEM) solver with many kinds of finite elements (FEs) such as triangular FE, rectangular FE, triangular prismatic FE, and rectangular prismatic FE. All the results in this paper were obtained by using the FDM solver with an r-z geometry.

Single diffusion coefficient (SDC) was used in the benchmark calculation though the direction dependent diffusion coefficients (DDDCs) were given for the top and the side void regions in the problem specifications. The axial diffusion coefficient and the radial diffusion coefficient were used for the top void region and the side void region, respectively, since the axial leakage is much more important than the radial one in the neutron balance at the top void region and vice versa at the side void region. This approximation was found to be very accurate for this benchmark problem [4]. The DDDC is not implemented in the CAPP code since much more advanced method with an SDC based on the equivalence theory is going to be used in the CAPP code to treat the void regions.

The CAPP code was coupled with the MARS-GCR code [5] through a dynamic link library (DLL). In the coupled code, MARS-GCR is the main program and CAPP is called as a subroutine in the DLL. Figure 1 shows the coupling of the two codes.

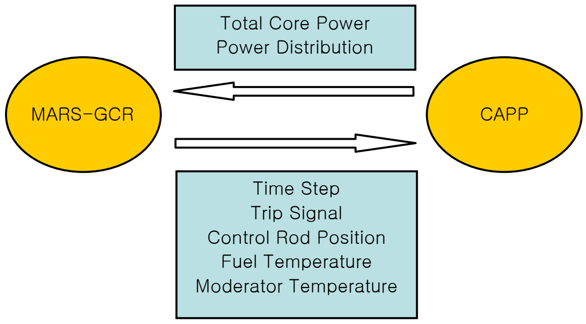

Figure 1. MARS-GCR/CAPP Coupling

2.2 Results of Exercise 1

Table 1 shows the spatial convergence of the effective multiplication factor for exercise 1. Each material zone defined in the problem specification was divided into $N_r \times N_z$ sub-meshes. With 40x20 sub-meshes, 1.00463 of an effective multiplication factor was obtained. Figure 2 shows the power density profile for exercise 1 with 40x20 sub-meshes.

Table 1. Spatial convergence of k_{eff}

N_z \ N_r	5	10	20	40
5	1.00440	1.00462	1.00468	1.00469
10	1.00435	1.00457	1.00463	1.00464
20	1.00433	1.00456	1.00461	1.00463

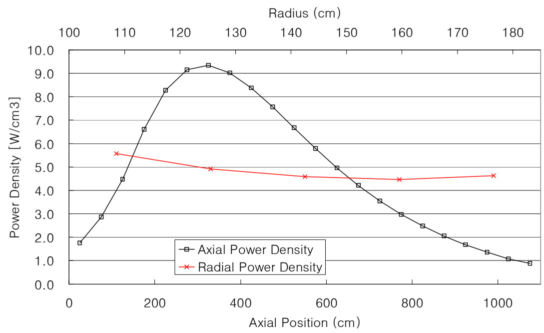

Figure 2. Power Profile for the Exercise 1.

Figure 3 compares the effective multiplication factors submitted by the participants of the benchmark problem

[6]. The effective multiplication factor of the CAPP code is very similar to those of the DALTON code, the TOPS code and the PARCS code. However, there are large k_{eff} differences among the participants. The cause of the large differences is not clear yet.

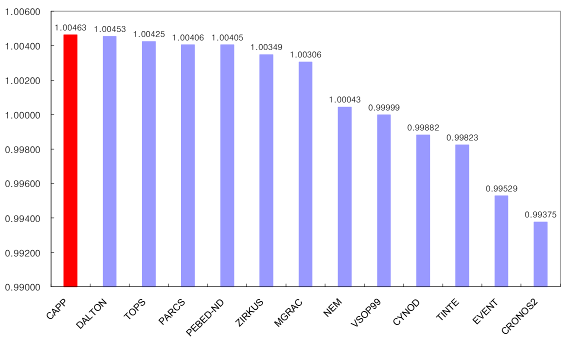

Figure 3. Comparison of effective multiplications

2.3 Results of Exercise 3

To save computation time, 5x5 sub-meshes were used in the coupled calculation for the exercise 3, which introduced only a 23pcm k_{eff} error when compared to the 40x20 sub-mesh calculation in exercise 1.

Figure 4 shows the power distribution for the exercise 3 coupled case. Figure 5 compares the effective multiplication factors submitted by the participants of the benchmark problem [7]. The effective multiplication factor of the CAPP/MARS-GCR coupled code is very similar to that of the PARCS/THERMIX-DIREKT while it has about 650pcm and 1250pcm differences

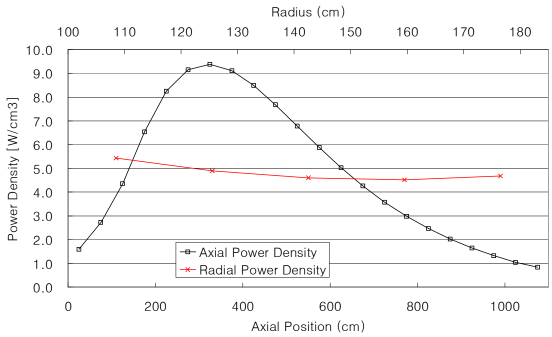

Figure 4. Power Profile for the Exercise 3.

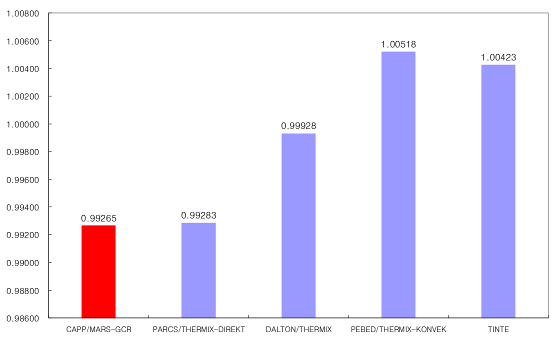

Figure 5. Comparison of effective multiplication factors

from those of the DALTON/THERMIX and the PEBED/THERMIX-KONVEK respectively though they gave similar effective multiplication factors in exercise 1. It means that the differences in the effective multiplication factors are ascribed to the differences in the analysis models of the thermal-hydraulic codes.

3. Conclusion

In this paper, we presented the neutronics solutions of the CAPP/MARS-GCR coupled code system for exercise 1 and exercise 3 of the OECD/NEA PBMR400 Benchmark Problem. A good agreement with the PARCS, DALTON, PEBED, and TOPS codes was observed for exercise 1 but we observed relatively large differences in k_{eff} from these codes except for the PARCS code, which is ascribed to the differences in the analysis models of the thermal-hydraulic codes. More thorough investigation should be made to clarify this point.

ACKNOWLEDGEMENTS

This work has been performed as a part of the Nuclear R&D Program supported by the Ministry of Science and Technology (MOST) of the Republic of Korea.

REFERENCES

[1] PBMR Coupled Netronics/Thermal Hydraulics Transient Benchmark the PBMR-400 Core Design, NEA/NSC/DOC Draft-V03, 2005.

[2] H. C. Lee, *et al.*, "A Neutronics Solution to the OECD/NEA/NSC PBMR-400 Stand Alnoe Steady State Benchmark Problem by using the Hex-Z Solver of the MASTER Code," KNS Spring Meeting, May 2006.

[3] H.C. Lee, *et al.*, "Comparison of Two-Step Diffusion Solutions and Monte Carlo Solutions to a Doubly Heterogeneous PBMR-400 Problem," M&C+SNA2007, Joint International Topical Meeting on Mathematics & Computation and Supercomputing in Nuclear Applications, Monterey, California, April 15-19, 2007, on CD-ROM (2007).

[4] Abdelkrim Sekhri *et al.*, "OECD PBMR 400MW Benchmark : Updated steady state OSCAR-4 results and proposed thermal-hydraulic coupling", OECD/NEA/NSC PBMR Coupled Neutronics/Thermal Hydraulics Transient Benchmark - THE PBMR-400 CORE DESIGN Third Workshop, 1-2 Feb. 2007.

[5] S. W. Lee, *et al.*, Thermal-Hydraulic Analysis of OECD Benchmark Problem for PBMR 400 using MARS-GCR, KNS Spring Meeting, May 2006.

[6] J. Han, *et al.*, "Comparison of Participant Results for Steady State Neutronics Solution," OECD/NEA/NSC PBMR Coupled Neutronics/Thermal Hydraulics Transient Benchmark - THE PBMR-400 CORE DESIGN Third Workshop, 1-2 Feb. 2007.

[7] J. Han, *et al.*, "Comparison of Participant Results for Coupled Neutronics & Thermal – Hydraulics," OECD/NEA/NSC PBMR Coupled Neutronics/Thermal-Hydraulics Transient Benchmark - THE PBMR-400 CORE DESIGN Third Workshop, 1-2 Feb. 2007.