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# Thermal-Hydraulic Analysis of a Coupled Steady State for the OECD/NEA PBMR-400 Benchmark Problem by using the MARS-GCR / CAPP Codes

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## 1. Introduction

The scope of the OECD/NEA benchmark problem for the Pebble Bed Modular Reactor (PBMR) 400MWt [1] is to test the existing analysis methods for High Temperature Gas-cooled Reactors (HTGR) and to develop more accurate and efficient tools to analyse the neutronics and thermal-hydraulic behaviour for the design and safety evaluations of the PBMR. For these purposes, it includes defining appropriate benchmarks to verify and validate the new analysis methods in the computer codes.

The benchmark problem includes three steady state cases for phase I and six transient cases for phase II. Till now, both standalone calculations of the neutronics with fixed cross sections (Exercise 1) and the thermal-hydraulics with a given heat source (Exercise 2), and a coupled code calculation (Exercise 3) have been performed. Although the results of Exercise 1 and 2 have already been released by using MARS-GCR[2] and MASTER-GCR, respectively [3,4], at present, the MASTER-GCR code is replaced with the CAPP (Core Analyzer for Pebble and Prismatic type VHTRs) code [5] which has been newly developed for the HTGRs by KAERI. Therefore, this paper includes a description of the coupled calculation results with MARS-GCR and CAPP in Exercise 3, and a comparison with the results of Exercise 2. In addition, the results of Exercise 2 from the other participants are briefly compared with those of MARS-GCR.

## 2. System Model for Benchmark Problem

The general reactor layout and the coolant flow directions are based on a 2-D (r, z) geometry. The overall system model is almost identical to that of reference 4 with the exception of the stagnant helium and air gap model. According to the benchmark specification, neither mass flow nor convection should be calculated for these regions and the pressure of the helium and cavity air should be 9.0MPa and 0.1MPa, respectively. However, due to the heat loss to the environment, it is not possible to maintain a constant pressure in the isolated volume without a boundary volume. To satisfy this requirement, these stagnant fluid regions were considered as vacant volumes to prevent the pressure and temperature from changing due to the heat loss from the vessel wall. The heat transfer by conduction and radiation between the gaps, however, was modelled.

A constant thermal conductivity and specific heat of the heat structures were used except for the porous fluid region and the pebble core. In the porous regions, thermal properties were reduced according to their porosity. For example, if the porosity is 0.2, the thermal properties are reduced to 80%. In the pebble core, the effective thermal conductivity by the *Zehner-Schlünder* correlation was used instead of a reduced property. Also a contact conduction model of MARS-GCR was applied to the interfaces between adjacent heat structures to consider a pure conduction between the heat structures.

For the boundary condition of a heat sink, the isothermal condition of 20℃ is applied to the outer side of the reactor cavity cooling system (RCCS) wall.

## 3. Coupling Method of MARS-GCR and CAPP

Similar to the coupling method between MARS-GCR and MASTER-GCR, MARS-GCR and CAPP has been coupled with the explicit Dynamic Link Library (DLL). In the coupled code system, MARS-GCR is the main program and it calls in the DLL of CAPP if necessary. Among the interfaced variables, MARS-GCR provides CAPP with the time step, trip signal, control rod position and the temperatures of the moderator and fuel in each computational cell and then, the CAPP returns the feedback variables such as the total core power and local core power distribution from the provided information. Figure 1 shows the general concept of the code coupling.

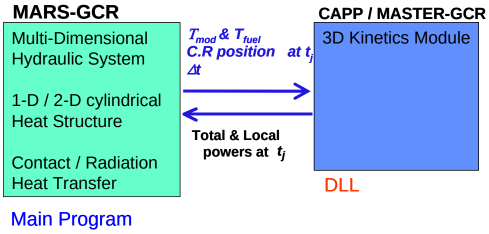


Figure 1. MARS-GCR/CAPP coupling concept

## 4. Result Comparison of Exercise 2

Prior to the discussion on the results of Exercise 3 coupled calculation, a comparison of the results of Exercise 2 with those from the other participants will be reviewed briefly. Exercise 2 of the benchmark problem is a thermal-hydraulic standalone calculation with a given heat source.

There are no significant differences in the global parameters such as the inlet / outlet temperatures, pressure drop and average temperatures of the fuel, moderator and helium in the pebble core. Moreover, radially-averaged axial profiles show a good agreement with most of the others[6]. However, the axially-averaged radial temperature profiles of MARS-GCR are different from the others. Figure 2 shows the comparison results of an axially-averaged radial fuel temperature profile in Exercise 2. Apparently, as shown in the figure, the temperature profile of MARS-GCR is much stiffer. A series of the THERMIX codes were used for a thermal-hydraulic calculation by other participants and so, the others except for MARS-GCR show a somewhat similar trend.

To investigate the effect of a pebble conduction, an additional calculation has been performed with a increased contact conductance by 30 times. However, it should be noted that this increased value is physically unreasonable because the contact area exceeds the total surface area of the pebbles in the cell. In this case, the profile of the axially-averaged fuel temperature is very close to the other results, especially, DELFT and Purdue University and it is also found that the axial profile is not strongly affected by a pebble conduction.

Consequently, it can be said that the radial temperature difference is mainly due to the heat flow difference by a pebble conduction and MARS-GCR underestimates it when compared with the other codes.

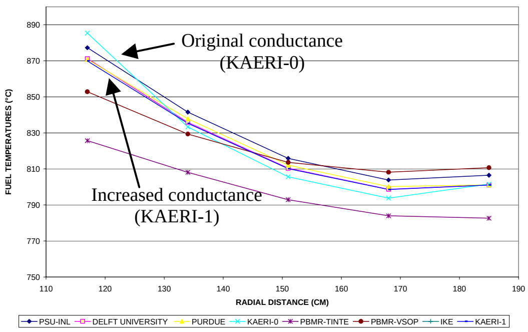


Figure 2. Comparison of averaged radial fuel temperature

## 5. Comparison of Exercise 2 and 3

At present, a preliminary coupled steady state analysis has been performed by using a steady state routine where CAPP solves an eigenvalue problem for a fixed power. In the steady state, MARS-GCR calls in the DLL of CAPP every 5 seconds for a calculation stability. The coupled calculation has been converged to a certain value within 20 seconds and terminated at 500 seconds.

The global parameters shown in Table 1 as well as the radially-averaged axial power distribution in Figure 3 are almost identical to those in Exercise 2. The axially-averaged radial power distribution, however, shows a little difference compared with Exercise 2. In Exercise 3, the power density in the outer core region is higher than that of Exercise 2 and slightly lower in the other core regions. This difference may result from the neutron cross section data because temperature dependent cross section data rather than fixed (temperature independent) cross section data is used in Exercise 3.

Table 1. Comparison of global T/H parameters (Exercise 2/3)

| Parameters | Exercise-2 | Exercise-3 |
|---|---|---|
| Helium inlet/outlet temperature (℃) | 500 / 899.2 | 500 / 899.2 |
| Pressure drop in pebble bed (kPa) | 273.4 | 273.1 |
| Average fuel temperature in core | 819.0 | 817.8 |
| Average moderator temperature in core | 802.3 | 801.2 |

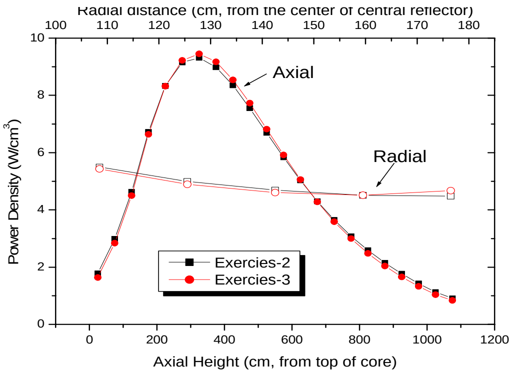


Figure 3. Comparison of averaged power density

## 6. Conclusion and Further Works

The T/H standalone and T/H-Neutronics coupled code calculations for the PBMR-400 OECD/NEA benchmark problem have been successfully performed with MAR-S-GCR/CAPP, but MARS-GCR underestimates the pebble conduction less than the other codes such as THERMIX. However, it seems that the overall results of both calculations are reasonable when compared with those of the other participants. Therefore, it is possible to prepare the transient benchmark calculations based on the coupled steady state result using the MARS-GCR/CAPP coupled code system.

## ACKNOWLEDGEMENTS

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## REFERENCES

[1] PBMR Coupled Netronics/Thermal Hydraulics Transient Benchmark the PBMR-400 Core Design, NEA/NSC/DOC Draft-V03, 2005.
[2] W. J. Lee, *et al.*, “Development of MARS-GCR/V1 for Thermal-Hydraulic Safety Analysis of Gas-Cooled Reactor System,” Nuclear Engineering and Technology, vol.37 no.6, 2005.
[3] 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.
[4] S. W. Lee, *et al.*, Thermal-Hydraulic Analysis of OECD Benchmark Problem for PBMR 400 using MARS-GCR, KNS Spring Meeting, May 2006.
[5] H. C. Lee, Neutronics and Coupled Calculation of OECD/NEA PBMR-400 Benchmark Problem with CAPP Code, PBMR-400 Core Design 3rd Workshop, Feb 2007.
[6] J. Han, *et al.*, Comparison of Participant Results for Steady Sate Thermal-Hydraulic Solution, PBMR-400 Core Design 3rd Workshop, Feb. 2007.