Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 7-8, 2015

Steady-State Core Temperature Prediction Based on GAMMA+/CAPP Coupling

Nam-il Tak,* Hyun-Chul Lee and Hong-Sik Lim
Korea Atomic Energy Research Institute, 111, Daedeok-daero 989 Beon-gil, Yuseong-gu, Daejeon 305-353, Korea
**Corresponding author: takni@kaeri.re.kr*

1. Introduction

The GAMMA+ code [1] is a system thermo-fluid analysis code under development at Korea Atomic Energy Research Institute (KAERI) for an analysis and design of a very high temperature reactor (VHTR). In spite of sizable applications of the GAMMA+ code for the thermo-fluid analysis and design of a prismatic VHTR, the existing works are limited to stand-alone calculations. In the stand-alone calculations, information from the neutronic analysis (e.g., reactor power density profile) was considered only once i.e., when the calculations get started.

For the neutronic analysis and design of a VHTR, the CAPP code [2], which is also under development at KAERI, is used.

The main objective of this paper is to investigate the capability of GAMMA+ and CAPP coupling and to examine the results of the coupled analysis.

2. GAMMA+/CAPP Coupling

Fig. 1 shows the GAMMA+/CAPP coupling scheme. A server program named INTCA is used to control the coupling of GAMMA+ and CAPP. The CAPP code calculates the power density and the fast fluence and sends them to GAMMA+. The power density data are used as heat source in GAMMA+. The fast fluence is used for evaluating the conductivity of graphite material. On the other hand, GAMMA+ calculates core temperatures (e.g., fuel, moderator, and reflector) and sends them to CAPP. The temperature data are used to evaluate nuclear cross-sections in CAPP. At the current stage, the data exchange of the atomic number densities shown in Fig. 1 is not used yet. These data will be used for the accident conditions such as water-ingress.

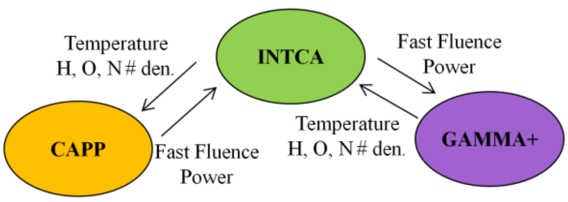

Fig. 1. GAMMA+/CAPP coupling scheme.

Fig. 2 illustrates the mapping of the computational cells of the GAMMA+ and CAPP codes. There exists some degree of flexibility in the choice of computational cells for GAMMA+ and CAPP since different computational cells (radially as well as axially) can be used for GAMMA+ and CAPP. The GAMMA+ code uses hexagonal or triangular cells while the CAPP code uses triangular cells. The mapping of GAMMA+ and CAPP computational cells is implemented at the server code, INTCA.

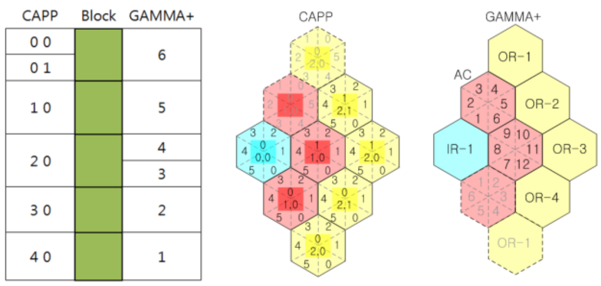

Fig. 2. Example of mapping of computational cells of GAMMA+ and CAPP.

3. PMR200 Analysis

PMR200 was selected as a reference core in this work. PMR200 [3] is a 200 MWth prismatic VHTR pre-conceptually designed by KAERI. Fig. 3 shows the layout of the PMR200 core. The main design parameters of PMR200 are provided in Table I.

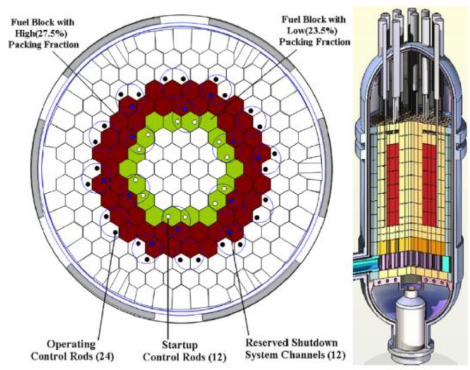

Fig. 3. Layout of PMR200 core.

Table I: Major Design Parameters of PMR200 Core

Parameter	Nominal value
Thermal power	200 MW
Coolant inlet temperature	490 ^{o}C
Coolant outlet temperature	950 ^{o}C
Coolant flow rate	83.2 kg/s
Primary coolant pressure	7 MPa
No. of fuel columns	66
Height of active core	4.758 m

Fig. 4 shows the GAMMA+ nodalization for PMR 200. Single fuel column was modeled by six triangular cells. In the case of reflector columns, either hexagonal or triangular cells are adopted. The coolant and bypass gap channels are grouped while all the control rod channels are individually modeled. Single triangular region of fuel column contains 18 coolant channels.

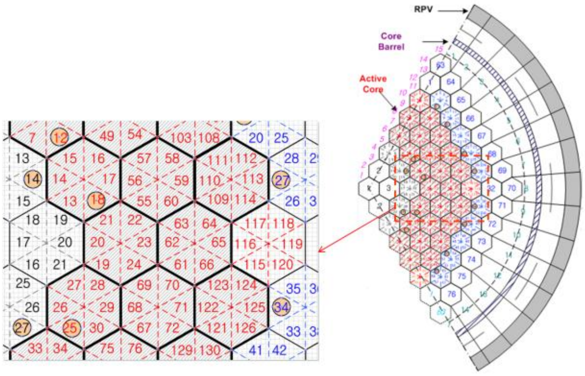

Fig. 4. GAMMA+ nodalization for PMR200.

Fig. 5 shows the predicted power density profile by GAMMA+/CAPP coupling. It clearly shows the evolution of the power density profile with the coupling. The data exchange was set up with the interval of 50 sec. At the beginning of the calculation, a constant power density was assumed. After the first coupling, the power density profile was changed to sinusoidal shape. After the second coupling, the power density profile was skewed toward the top. The power density profile of the fourth coupling was found to be almost same as that of the final 11th coupling. After 11th coupling, the coupling was ended.

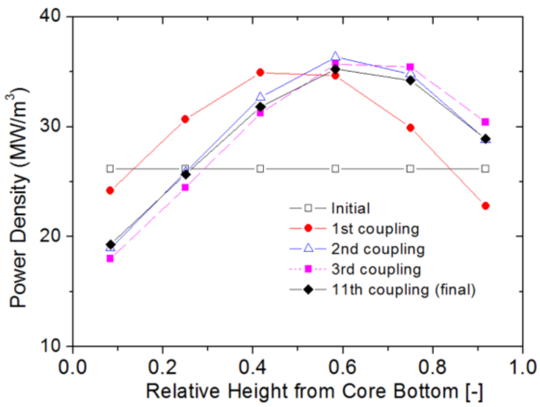

Fig. 5. Evolution of predicted power density profile with coupling (inner core).

Fig. 6 shows the predicted temperature profile by GAMMA+/CAPP coupling. It also clearly shows the evolution of the temperature profile with the coupling. The evolution is made by the change of a heat source supplied by the CAPP code.

Figs. 7 and 8 show the predicted power and temperature profiles based on GAMMA+/CAPP coupling. Since the inner ring of the power density is higher than the others, the fuel temperature of the inner ring is the highest.

The calculated hot spot fuel temperature is 1280 ^{o}C which is slightly higher than the design limit of 1250 ^{o}C. Therefore, the modification of the design is required for PMR200.

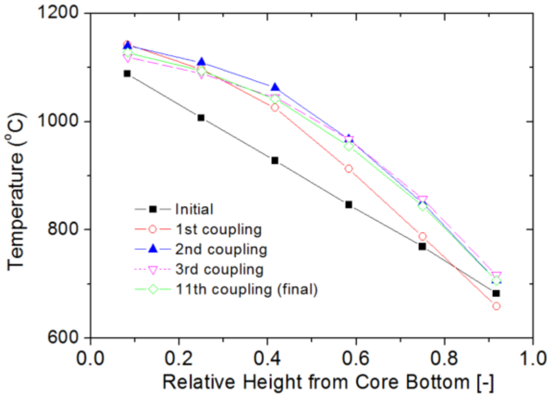

Fig. 6. Evolution of predicted fuel temperature profile with coupling (inner core).

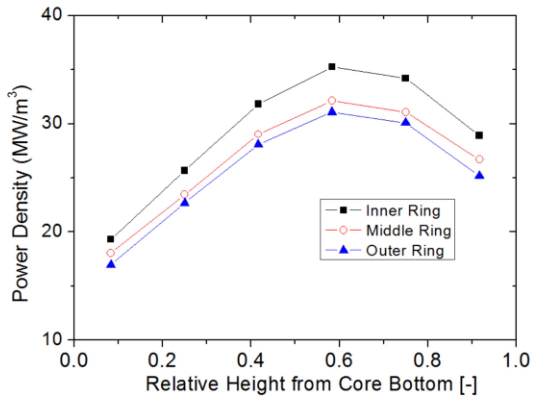

Fig. 7. Predicted power density profile based on GAMMA+/CAPP coupling.

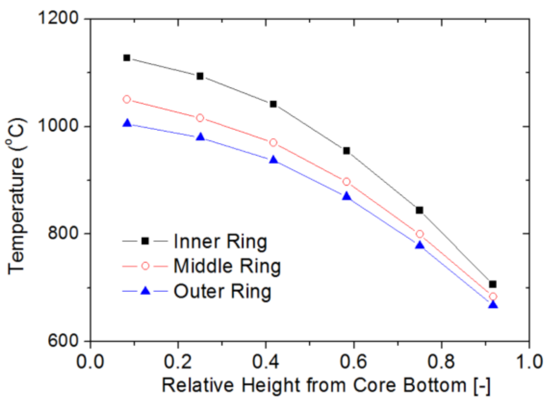

Fig. 8. Predicted fuel temperature profile based on GAMMA+/CAPP coupling.

4. Conclusions

Based on the coupling of GAMMA+ and CAPP, the steady-state core temperature was investigated in this work. It is found that the communication of data was successful. And the results of the GAMMA+ and CAPP coupling are found to be reasonable. The design modification of PMR200 is required to satisfy the design limit for the hot spot fuel temperature.

Acknowledgements

This work was supported by Nuclear R&D Program of the NRF of Korea grant funded by the Korean government (Grant code: NRF-2012M2A8A2025679).

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