Cycle Average Peak Fuel Temperature Prediction Using CAPP/GAMMA+

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1. Introduction

The General Atomics proposed that the design limit of the fuel temperature under normal operating conditions should be a cycle-averaged maximum value [1]. Nonetheless, the existing works of Korea Atomic Energy Research Institute (KAERI) only calculated the maximum fuel temperature at a fixed time point, e.g., the beginning of cycle (BOC) just because the calculation capability was not ready for a cycle average value. In order to obtain a cycle average maximum fuel temperature without rigorous efforts, a neutronics/thermo-fluid coupled calculation is needed with depletion capability. Recently, a CAPP/GAMMA+ coupled code system has been developed and the initial core of PMR200 was analyzed using the CAPP/GAMMA+ code system [2]. The GAMMA+ code [3] is a system thermo-fluid analysis code and the CAPP code is a neutronics code [4].

In this work, a cycle average maximum fuel temperature has been calculated using CAPP/GAMMA+ code system for the equilibrium core of PMR200.

2. CAPP/GAMMA+ Code System

Fig. 1 shows the CAPP/GAMMA+ coupling scheme. A server program named INTCA was developed 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.
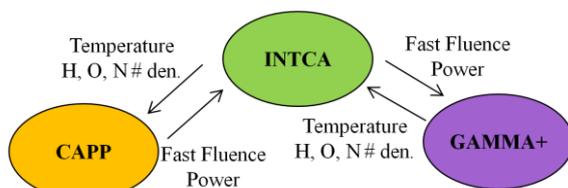
Fig. 1. GAMMA+/CAPP coupling scheme.

3. PMR200 Analysis

PMR200 was selected as a reference core in this work. PMR200 [5] is a 200 MWth prismatic very high temperature reactor (VHTR) pre-conceptually designed by KAERI. Fig. 2 shows the layout of the PMR200 core. The main design parameters of PMR200 are provided in Table I.
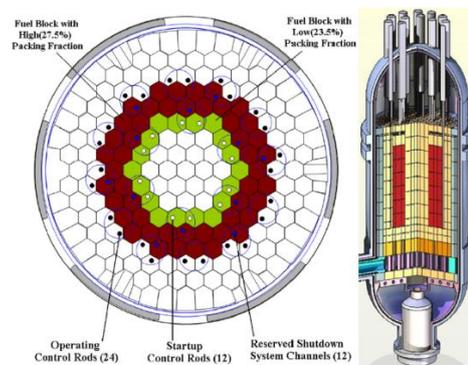
Fig. 2. Layout of PMR200 core.

Table I: Major Design Parameters of PMR200 Core

Parameter	Nominal value
Thermal power (MW)	200
UO_2 enrichment (w/o)	12.0
Coolant inlet temperature (^{o}C)	490
Coolant outlet temperature (^{o}C)	950
Coolant flow rate (kg/s)	83.2
Primary coolant pressure (MPa)	7
No. of fuel columns	66
Kernel diameter (μm)	500
TRISO fraction in compacts (%)	27.5/23.5
Ave. power density (MW/m^3)	5.67
Height of active core (m)	4.758

Fig. 3 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.

In the present coupled calculation, the critical control rod positions were searched at every burnup step of the equilibrium cycle of PMR200 from BOC (beginning of cycle) to EOC (end of cycle). Once the converged multiplication factor of the core was obtained, the

control rod positions were adjusted based on the multiplication factor obtained to make the reactor critical. After a criticality of the reactor was achieved at a burnup step, the depletion calculation was performed for the next burnup step.
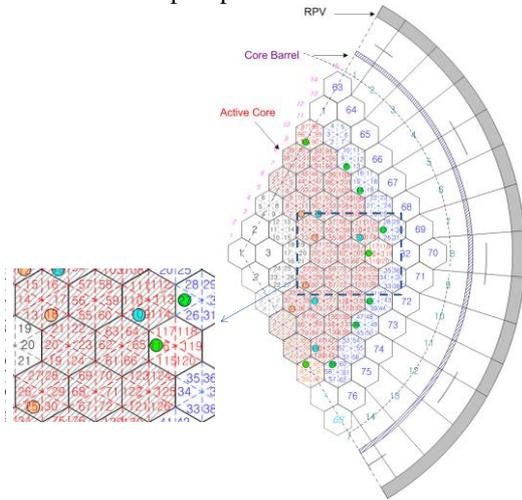
Fig. 3. GAMMA+ nodalization for PMR200.

4. Results and Discussion

Fig. 4 shows radially-averaged axial power density profile at BOC, MOC (middle of cycle), and EOC, respectively. At BOC, the axial power is almost symmetric but the axial power is strongly skewed toward the top of the core at MOC and EOC due to the combined effect of the control rod movement and the burn out of the burnable poison in the fresh fuel.

Figs. 5-7 show the radial temperature profiles at BOC, MOC, and EOC, respectively. For BOC and MOC, the fuel temperature of the inner ring is higher since the power density of the inner ring is higher. Figs. 5 and 6 obviously show that the inner ring has the peak power density and the peak temperature. In particular, Fig. 6 shows the existence of the steep gradient of the power density, which results in the steep temperature gradient. Fig. 7 shows that the temperature profile of EOC is relatively flat due to the flat power density profile.
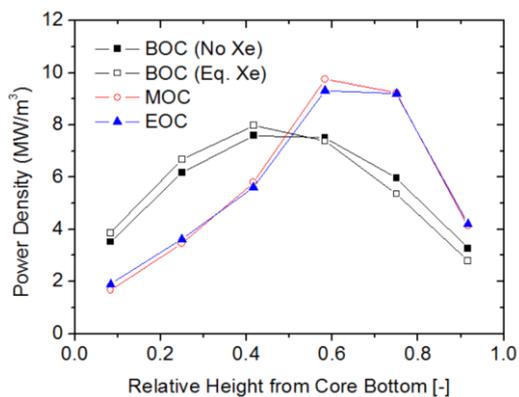
Fig. 4. Radially-averaged axial power density profile.
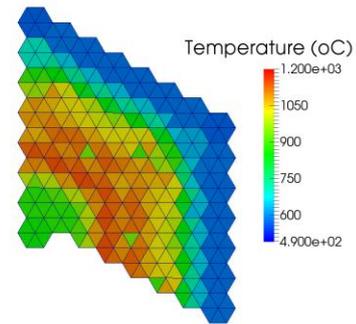
Fig. 5. Radial temperature distribution at the bottom layer of the active core at BOC (Eq. Xe).
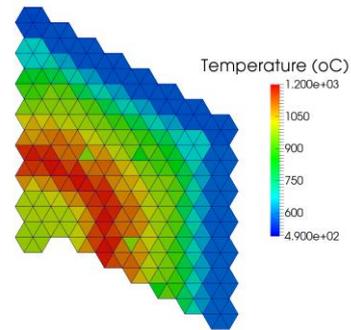
Fig. 6. Radial temperature distribution at the bottom layer of the active core at MOC.
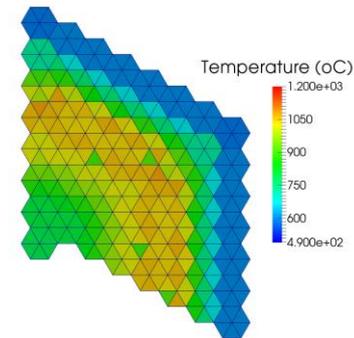
Fig. 7. Radial temperature distribution at the bottom layer of the active core at EOC.

Fig. 8 shows the maximum fuel temperature history with the burnup. The maximum fuel temperature at BOC is 1248 ^{o}C. The maximum fuel temperature goes down and rises up to 1372 ^{o}C, which is the peak value. After the effective full power day (EFPD) of 300 days, the maximum fuel temperature decreases to below 1200 ^{o}C. The cycle average peak fuel temperature was calculated to be 1181 ^{o}C, which is below the design target of 1250 ^{o}C. The average kernel temperature was used to evaluate the cycle average peak value.
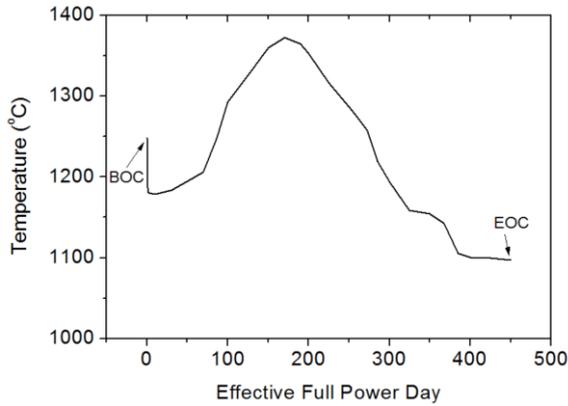
Fig. 8. Maximum fuel temperature history during the equilibrium cycle.

5. Conclusions

The CAPP/GAMMA+ coupled calculation was carried out for the equilibrium core of PMR 200 from BOC to EOC to obtain a cycle average peak fuel temperature. The peak fuel temperature was predicted to be 1372 ^{o}C near MOC. However, the cycle average peak fuel temperature was calculated as 1181 ^{o}C, which is below the design target of 1250 ^{o}C. A further study should focus on the capability of pin-by-pin fuel temperature prediction for an accurate value of the cycle average fuel temperature.

Acknowledgements

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