Development of the CAPP code for the Analysis of Block Type VHTRs

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1. Introduction

Korea Atomic Energy Research Institute (KAERI) is developing the HELIOS/CAPP code system for the analysis of a very high temperature gas cooled reactors (VHTRs). The functionalities for the analysis of the pebble type VHTRs was implemented and verified in the previous works[1,2].

In this paper, the extension of the functionalities of the CAPP code for the analysis of the block type VHTRs is presented and some verification results are also presented.

2. Methods and Results

2.1 Neutron Flux Solver

The multi-group neutron diffusion equation is solved based on the block nodalization and the finite elements shown in Fig. 1. The fuel or reflector block is divided into six triangular prisms radially and each of them is axially divided into several homogeneous zones. A triangular prismatic finite element is assigned for each homogeneous zone. Four types of the triangular prismatic finite elements shown in Fig. 1 can be chosen depending on the order of the element function order. Four types of core model can be used : one sixth, one third, half, and full core model. Rotational symmetry condition is imposed on the internal boundary of the core models except for the full core model.

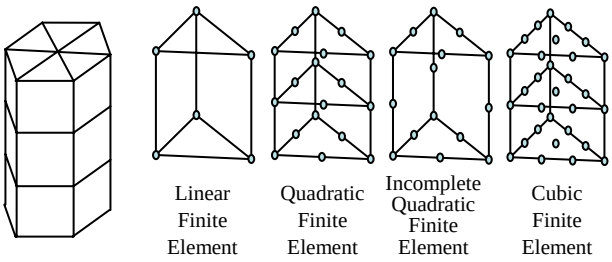

Fig. 1. Block nodalization and the finite elements.

2.2 Steady State Thermo-Fluid Equation Solver

Six representative coolant channels per fuel column as shown in Fig. 2 are modeled for coolant temperature calculation. The coolant mass flow rate for each coolant channel is determined by assuming that the total mass flow rate of the fuel column given by the user is distributed in the proportion of the flow area. Each coolant channel is axially divided into several coolant channel cells and each coolant cell is attached to each homogeneous zone in Fig. 1. The axial coolant temperature distribution in a coolant channel is calculated by the energy balance equation assuming that the heat generation in each homogeneous zone contributes to the increase of the coolant temperature of the corresponding coolant cell. The moderator temperature is calculated by using the two-dimensional conduction model for the fuel element shown in Fig. 2 for each coolant channel cell. The average/maximum fuel temperature is calculated by using the spherical one-dimensional conduction model for a TRISO particle with the average/maximum fuel compact temperature as the boundary condition.

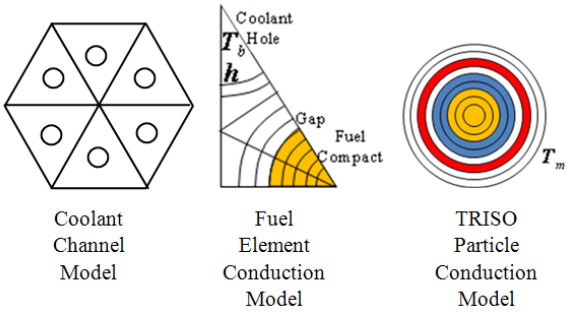

Fig. 2. Thermo-fluid models for the fuel columns.

The temperature distribution in the graphite reflector blocks surrounding the fuel blocks is calculated by solving 3-dimensional conduction equation in the reflector blocks based on the finite difference method. Each homogeneous zone in Fig 1 corresponds to the finite difference nodes. Similar assumptions as in the previous work for the pebble type VHTRs[3] are used for the reflector temperature calculation. The Temperature distribution at the surface of the top reflector and the outer reflector given by the user is used as an external boundary condition. Adiabatic condition at the surface of the bottom reflector is also used as an external boundary condition. In the active core region, the average moderator temperature is assigned to the conduction nodes as an internal boundary condition. The outlet coolant temperatures are assigned to the conduction nodes in the bottom reflector of the fuel column as an internal boundary condition by assuming that the heat loss through the conduction in that region is negligible compared with the heat transfer through the coolant flow.

2.3 Cross Section Representation

The cross sections are represented as a function of burnup, moderator temperature, and fuel temperature as

in Eq. (1). The first term of the RHS of the Eq. (1), $\sigma_{xg}^{j,ref}$, is the cross-section at the reference temperature state. The second and the third term, $\Delta\sigma_{xg}^{j,T_m}$ and $\Delta\sigma_{xg}^{j,T_f}$, are the increment of the cross-section due to the moderator temperature and fuel temperature variation, respectively.

$$\sigma_{xg}^{j}\left(b,T_m,\sqrt{T_f}\right)=\sigma_{xg}^{j,ref}\left(b\right)+\Delta\sigma_{xg}^{j,T_m}\left(b,T_m\right)+\Delta\sigma_{xg}^{j,T_f}\left(b,\sqrt{T_f}\right) \quad (1)$$

2.4 Micro Depletion Solver

Micro depletion calculation is performed for each homogeneous zone in Fig. 1 by using the one-group cross-sections and the one-group flux determined by the neutron flux solver. The same nuclide chain solver as in the previous work for the pebble bed type VHTRs[1] was used for depletion calculation.

2.5 Verification Results

Figure 3 compares the multiplication factors and power distributions for a two-dimensional PMR200[4] core loaded only with the fresh fuel blocks with a packing fraction of 23.5%. The reactor is at the reference temperature state(T_m=1000K and T_f=1000K). The reactivity error is 246pcm and the maximum power density error is 1.62%.

Table 1 compares the infinitive multiplication factor values at various temperature states for the fuel block of PMR200 reactor with a packing fraction of 23.5. The cross section table set for the CAPP code was generated from the HELIOS calculation at the reference temperature state. For the HELIOS branch calculation, 700K and 1300K were used as the moderator temperature variation points and 700K and 1500K was used as the fuel temperature variation points. The HELIOS/CAPP results were obtained by performing CAPP 0-D calculation with the table set.

Figure 4 compares the infinitive multiplication factor values during the single block depletion calculation for the fuel block of PMR200 reactor at the reference temperature state. Fifteen actinide nuclides and eight fission product nuclides were explicitly treated in the CAPP code depletion calculation. The maximum error is less than 200 pcm.

3. Conclusions

In this paper, the functionality extension of the CAPP code for the analysis of the block type VHTRs and some verification results was presented. Verification results showed a good accuracy of the HELIOS/CAPP code for the 2-D PMR200 core at BOC. More verification results including 3-D depletion calculation results for the PMR200 reactor will be presented in the conference.

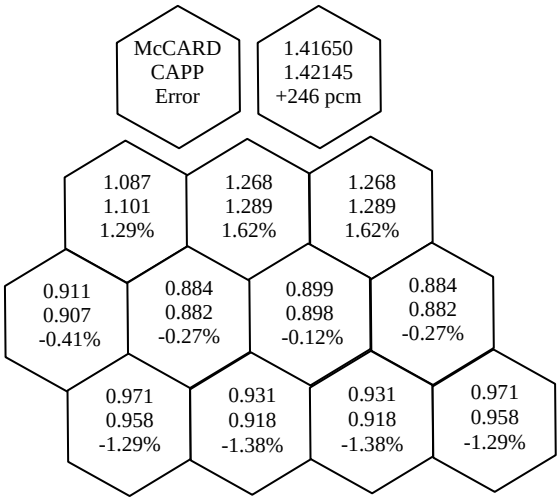

Fig. 3. Multiplication factor and power distribution for the 2-D PMR200 core.

Table 1. Comparison of k_{inf} for the PMR200 fuel block.

T_m [K]	T_f [K]	HELIOS k_{inf}	HELIOS/CAPP Δ ρ [pcm]
700	700	1.48479	-6
700	900	1.46617	+23
1000	1200	1.43989	+49
1300	1300	1.43138	+41
1300	1500	1.41890	-14

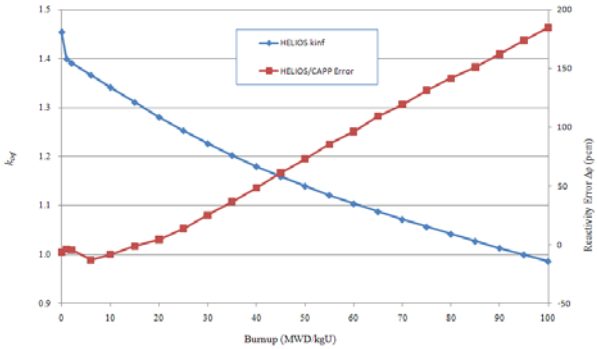

Fig 4. Infinitive multiplication factor and its error during the single block depletion calculation.

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