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Quasi-static Analysis of VHTR Core using Neutronics/Thermo-fluid Coupled CAPP/GAMMA+ Code System

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Abstract – *CAPP and GAMMA+ code are mainly used in quasi static analysis of VHTR. CAPP code calculate power density, fast fluence and send to GAMMA+ code. On the other hand, GAMMA+ code calculate temperature of core component and send to CAPP code. Recently, CAPP/GAMMA+ coupled code system is being developed to improve efficiency by adopting advantages of both codes. The purpose of this paper is to demonstrate the capability of the CAPP/GAMMA+ coupled code system for quasi static analysis of slow transient. In this paper, quasi static analyses were performed for slow transients of a very high temperature reactor using neutronics/thermos-fluid coupled CAPP/GAMMA+ code system.*

I. INTRODUCTION

Computer code systems for the analysis of very high temperature reactor (VHTR) core are being developed at Korea Atomic Energy Research Institute (KAERI). DeCART2D code is a lattice physics code for few-group cross-section generation in two-step neutronics analysis procedure [1]. CAPP code is a 3-dimensional (3-D) core simulation code for core physics analysis and simulation [2]. GAMMA+ code is a system/safety analysis code for thermos-fluid and system transient [3].

Recently, CAPP/GAMMA+ coupled code system was developed for neutronics/thermos-fluid coupled analysis of VHTR core and the coupled analysis of equilibrium cycle depletion calculations were demonstrated [4,5,6]

The purpose of this paper is to demonstrate the capability of the CAPP/GAMMA+ coupled code system for quasi static analysis of slow transient. In this paper, quasi-static analyses were performed for slow transients of a very high temperature reactor using neutronics/thermos-fluid coupled CAPP/GAMMA+ code system. Steady state was assumed for neutron flux and thermos-fluid analyses while transient state was assumed for fission product analysis, especially, iodine-xenon chain. The numerical simulation for several slow transient scenarios showed reasonable results. The quasi-static analysis of the coupled code system can be used for operation strategy study of VHTR system.

II. COUPLED QUASI-STATIC ANALYSIS OF PMR-200 CORE

Some slow transient scenarios were simulated using the coupled code system. Steady state was assumed for neutron flux and thermos-fluid analyses while transient state was assumed for fission product analysis, especially, iodine-xenon chain. PMR-200[7] was used as the reference reactor for the analyses.

1. CAPP/GAMMA+ Code System

The CAPP code is a 3-D core simulation code for reactor physics analysis of VHTR core and the GAMMA+ code is a system/safety analysis code for VHTR. Figure 1 shows the CAPP/GAMMA+ coupled code system. The coupling of the two codes is implemented based on client/server architecture. INTCA is a server which controls the coupled calculation and the CAPP code and GAMMA+ code are clients in this system. The connections between the server and the clients are established via socket communication during run time. 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 to evaluate the thermal conductivity of the graphite material. On the other hand, GAMMA+ calculates the temperature of the core components (e.g., fuel, moderator, and reflector) and sends them to CAPP. The temperature data are used to evaluate nuclear cross-sections in CAPP.

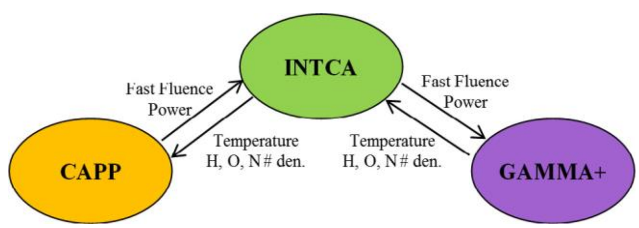


Fig. 1. CAPP/GAMMA+ coupled code system.

The computational cells of the CAPP and GAMMA+ codes do not necessarily match exactly because the GAMMA+ code uses either hexagonal or triangular radial cells while the CAPP code uses triangular radial cells. So, mappings between the variables in the two codes are required and INTCA provide the mapping between the two codes.

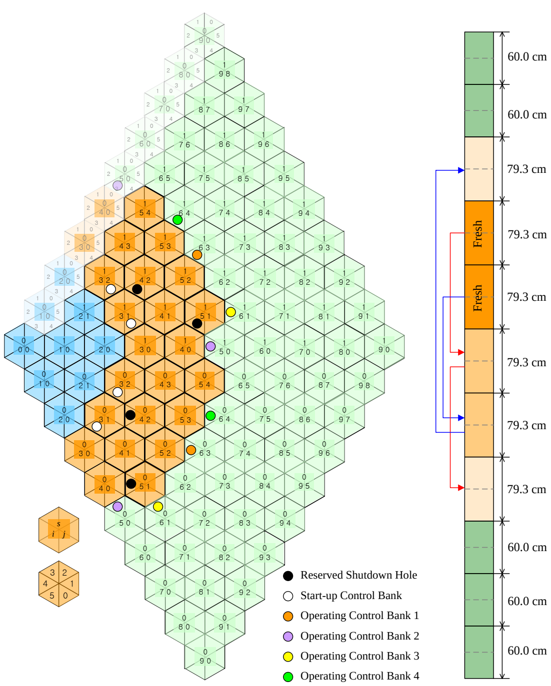
INTCA controls the two codes by receiving the requests from the two codes and sending the commands to them. The control algorithms of the three codes are explained in detail in references 4 and 6.

2. CAPP Model for PMR-200

Figure 2 shows the CAPP nodalization for the reactor core of PMR-200. One third of the core was modeled with a rotational symmetry. There are four reserved shutdown holes and four start-up control rod holes in the 1/3 sector of the active core region and the holes are empty during operation. There are eight operating control rods in the 1/3 sector of the side reflector region. It was assumed that the banks are inserted without overlapping, which means that the n^{th} bank starts to move after the $(n-1)^{th}$ bank is fully inserted. They are grouped into four control banks as shown in Figure 2(a). All the blocks are divided into six triangles radially and two zones axially. Only axial shuffling of the fuel blocks is adopted for refueling as shown in Figure 2(b).

3. GAMMA+ Model for PMR-200

Figure 3 shows the GAMMA+ nodalization for the PMR-200 core. Due to symmetry, 1/3 section of the core was considered. Single fuel column was modeled by six triangular cells. In the case of reflector columns, either hexagonal or triangular cells were adopted. The coolant and bypass gap channels were grouped to reduce the number of the computational cells while all the control rod channels were individually modeled. For example, single coolant channel was modeled for the triangular region of fuel column. That is, 18 coolant channels in the same triangular region were grouped into one coolant channel. In terms of the axial aspect, one cell was assigned for each fuel block.



(a) Radial configuration (b) Axial configuration
Fig. 2. Core configuration of PMR-200 for CAPP.

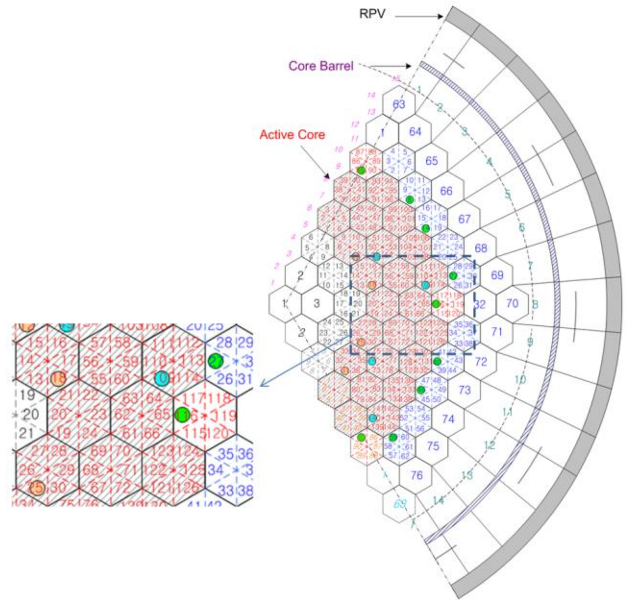


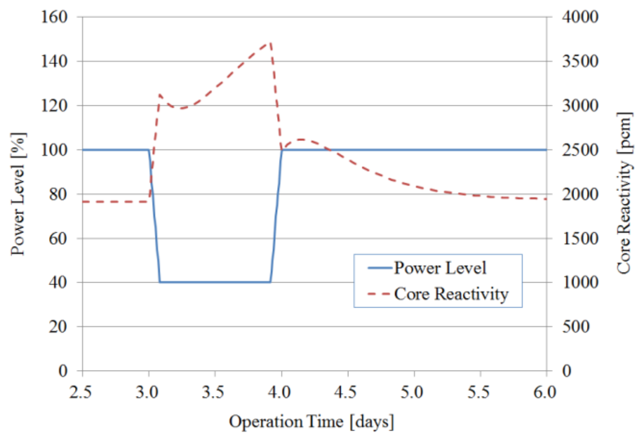
Fig. 3. PMR-200 reactor configuration for GAMMA+.

III. RESULTS

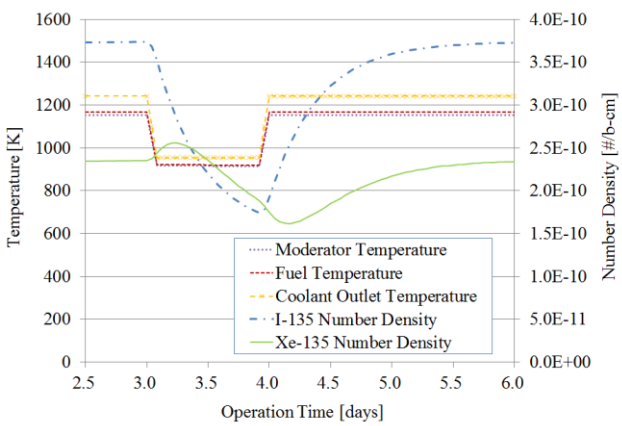
Some slow transient scenarios were simulated using the coupled code system. It was assumed that the transient was initiated at the BOC (3 EFPD) equilibrium Xe condition of the equilibrium cycle of PMR-200.

The first simulation is reactivity search during slow power transient. Figure 4(a) shows the target power history and the reactivity. In this simulation, it was assumed that the reactor power changes from 100% to 40% in 2 hours and the lowered power level remains constant for 20 hours and then the power level goes up to 100% in 2 hours as shown in Figure 4(a). It was also assumed that the coolant flow level remains constant at the nominal value during the transient. As a result, the core-averaged temperatures and the fission product number densities change as shown in Figure 4(b). The temperature drop due to the power level change causes reactivity rise and Xe build-up due to power drop decreases the reactivity. The reactivity increases as the Xe decays out. The temperature rise caused by the power increase lowers the reactivity. The Xe concentration decreases due to the increased power level right after the power increase and then it goes eventually to the equilibrium lever. This behavior of Xe increases the core reactivity right after the power increase and eventually lowers the reactivity to an initial value. However, this scenario is a fictitious one because the reactor power is not an independent control parameter but a dependent variable resulting from the change of independent control parameters such as control rod positions.

The second simulation is the critical control rod position search during slow power transient. The target power lever is the same as that in the first scenario. Figure 5 shows the critical rod positions during the transient searched by the coupled code system. It means that we can get the power history shown in Figure 4(a) if we move the control rods as shown in Figure5.



(a) power level and core reactivity



(b) Temperatures and number densities

Fig. 4. Coupled simulation results for scenario 1.

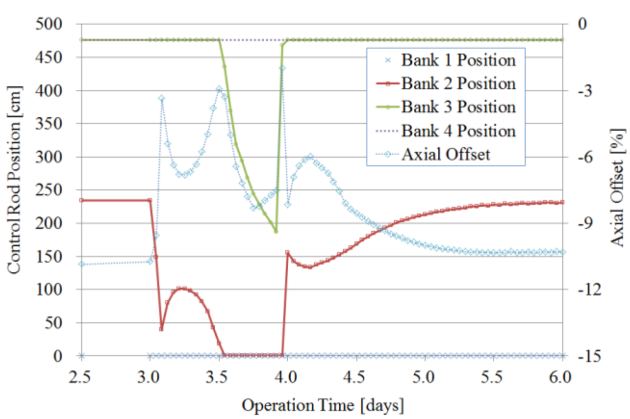
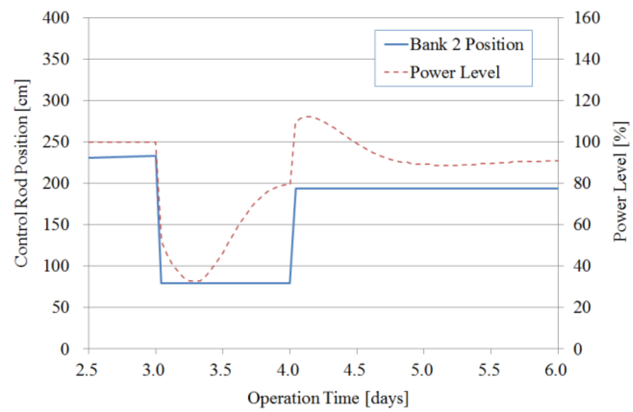
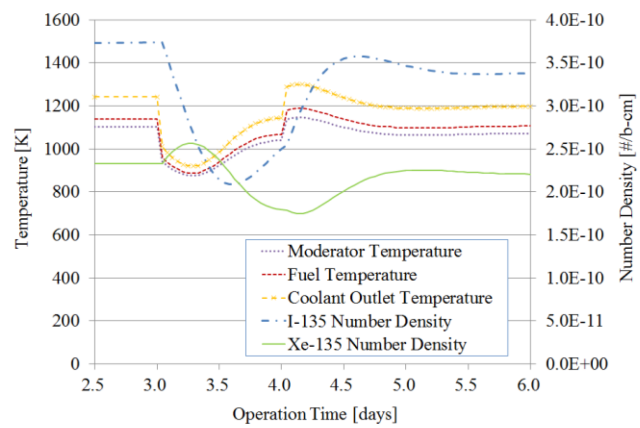


Fig. 5. Critical control rod positions.

The third simulation is the critical power level search for a given control rod movement history. Figure 6(a) shows the movement history of bank 2 and the power level history due to the movement of the control rod. In this scenario, bank 1 is fully inserted and bank 3 and 4 are fully withdrawn during the simulation. Figure 6(b) shows the history of the temperatures and the fission product number densities.



(a) Control rod movement and power level



(b) Temperatures and number densities

Fig. 6. Coupled simulation results for scenario 3.

IV. CONCLUSIONS

Quasi-static analyses were performed for slow transients initiated at the BOC equilibrium Xe condition of the equilibrium cycle of PMR-200 using the neutronics/the-rmos-fluid coupled code system CAPP/GAMMA+. The numerical simulation for several slow transient scenarios showed reasonable results. The quasi-static analysis of the coupled code system can be used for operation strategy study of VHTR system. More detail performance parameters and analysis test for quasi-static analysis of the coupled code system is expected in following research.

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