Transactions of the Korean Nuclear Society Autumn Meeting
Goyang, Korea, October 24-25, 2019

A Feasibility Study on Transient Analysis of a Block-type HTGR Core

Seungsu Yuk*, Jeong-Hun Lee, Hong Sik Lim, and Chang Keun Jo
Korea Atomic Energy Research Institute, 111, Daedeok-daero 989beon-gil, Yuseong-gu, Daejeon, 34057, Korea
**Corresponding author: syuk@kaeri.re.kr*

1. Introduction

As the hydrogen economy has come to the fore, high temperature gas-cooled reactor (HTGR) is drawing attention as a way to produce a large amount of hydrogen. Korea Atomic Energy Research Institute (KAERI) has paid attention to the potential of HTGR and has been developing the design technologies of HTGR. Among them, a reactor physics analysis code CAPP [1] and a thermal-fluid system analysis code GAMMA+ [2] are the main computer codes for the HTGR design.

In recent years, the study on the CAPP code has been focusing on the transient analysis for a block-type HTGR [3]. It described well the HTGR characteristics for reactivity insertion accidents. CAPP stand-alone transient analysis showed reasonable accuracy compared to CAPP/GAMMA+ coupled transient analysis [4].

On the other hand, the GAMMA+ code adopted the point kinetics method to predict the reactor power during the transient calculation. This method does not accurately calculate the power distribution of the reactor core. Therefore, it would provide some deviation for problems of change in power distribution.

This paper presents a comparison of CAPP transient and GAMMA+ transient for a block-type HTGR core. The transient calculations were carried out with several reactivity increase scenarios, and the feasibility of the transient analysis was discussed.

2. Transient Analysis Methods for HTGR Core

This section introduces two codes, CAPP and GAMMA+, which perform transient analysis of a block-type HTGR core.

2.1 CAPP Transient

The CAPP code is a reactor physics analysis code for HTGR. CAPP can calculate power distribution in the reactor core by solving three-dimensional, multi-group neutron diffusion equation. CAPP also provides a simplified thermal-fluid analysis for considering thermal feedback effect. Some appropriate assumptions induce a simplified energy balance equation for the coolant and heat conduction equations for fuel, moderator, and reflector in a HTGR core. CAPP extended the functionality to the transient analysis in the previous study [3] and was compared to CAPP/GAMMA+ coupled transient analysis [4].

2.2 GAMMA+ Transient

The GAMMA+ code is a thermal-fluid system analysis code, which is used for analyzing various thermal-fluid phenomena of HTGRs. It solves the multi-dimensional governing equations for fluid and solid simultaneously. Therefore GAMMA+ can perform more accurate thermal-fluid calculations than the thermal-fluid analysis via CAPP. The verification study was performed for multi-dimensional heat transfer in a block-type HTGR [5].

GAMMA+ uses the point kinetics method which ignores the spatial power distribution and considers only the change in power level over time. The point kinetics parameters are obtained from the CAPP steady-state calculation.

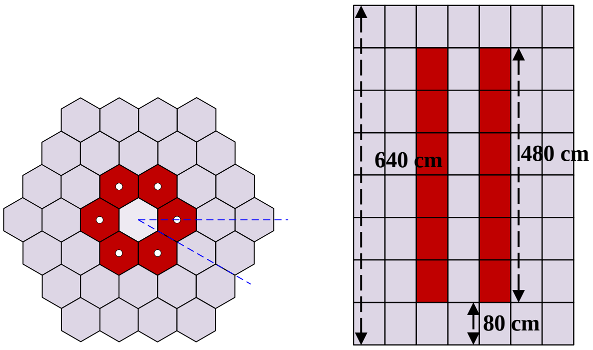
3. Numerical Results

To test the transient analysis via CAPP and GAMMA+, a mini HTGR core problem [4] was considered. This problem was based on the MHTGR-350 core design [6]. Figure 1 shows the geometry of the mini HTGR core and Table I is a list of design parameters of the mini HTGR core. In addition, there are six controls rods which move along the control rod holes with the same axial position. It is used to control the excess reactivity.

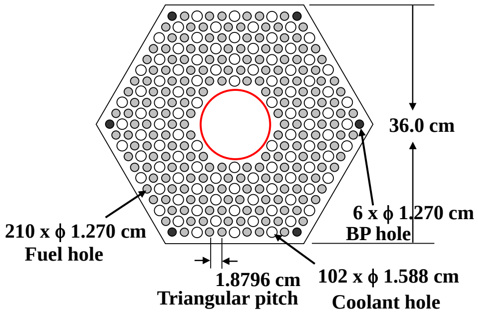
Table I: Design Parameters of a Mini HTGR Core

	Values
Thermal power (MW_{th})	19.0909
Coolant inlet temperature (°C)	259
Total coolant mass flow (kg/sec)	8.57
Number of fuel columns	6
Number of inner reflector columns	1
Number of outer reflector columns	30
Active core height (cm)	480.0
Bypass flow gap size (mm)	0
Crossflow gap size (mm)	0

The initial condition of the transient problems is the critical state, which were obtained by the critical control rod tip position search via CAPP. The mini HTGR achieved the criticality when the control rod tip position was 413.34 cm above the bottom.



(a) Plane Geometry (b) Axial Geometry



(c) Fuel Block Geometry

Fig. 1. Configuration of a mini HTGR Core.

3.1 Case 1: Decrease of Coolant Inlet Temperature

The first transient scenario is that the coolant inlet temperature decreases 50 °C for 0.1 sec. It induces the decrease of the overall temperature of the core and the increase of the reactivity. Figure 2 shows the comparison results of transient analysis for case 1. Power level slightly increases for about 200 sec and it is saturated. On the other hand, the core average temperature of fuel, moderator, and coolant slightly decrease for about 200 sec and they are saturated. The numerical results obtained by GAMMA+ agree well with those obtained by CAPP transient.

3.2 Case 2: Increase of Coolant Mass Flow Rate

The second transient scenario is that the total coolant mass flow rate increases by 10% for 1.0 sec. It induces the decrease of the overall temperature of the core and the increase of the reactivity as case 1. Figure 3 shows the comparison results of transient analysis for case 2. Power level and core average temperature slightly change for 100 sec. Different from the analysis for case 1, power level has a peak and each core average temperature has a small valley before it is saturated. The numerical results obtained by GAMMA+ agree well with those obtained by CAPP transient as case 1.

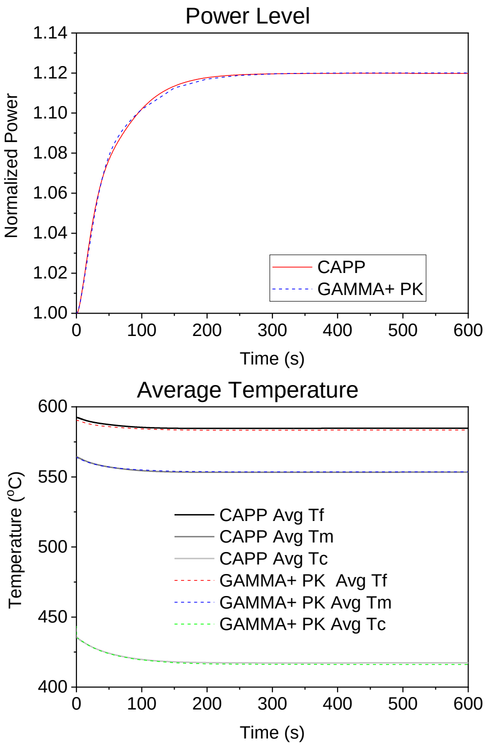


Fig. 2. Power level and core average temperature of case 1: decrease of coolant inlet temperature (Tf: fuel temperature, Tm: moderator temperature, Tc: coolant temperature).

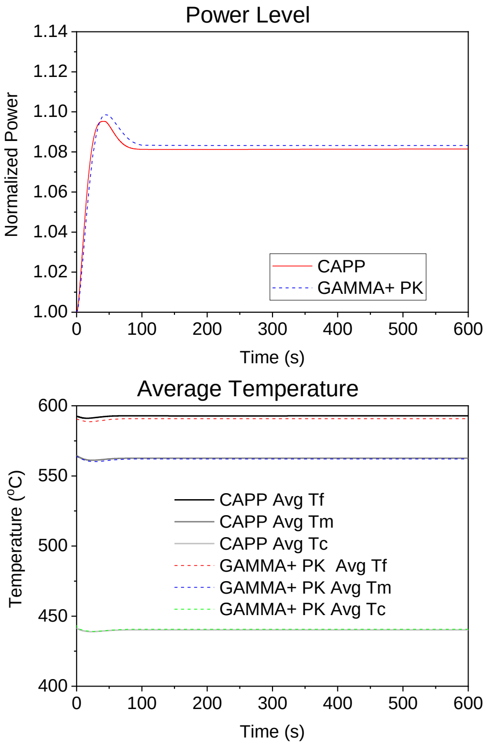


Fig. 3. Power level and core average temperature of case 2: increase of coolant mass flow rate.

3.3 Case 3: Control Rod Ejection

The third transient problem is a control rod ejection accident. All control rod tips are at the same height. From the critical state, all control rods start to be ejected at 0.0 sec with a constant speed and are stopped at 0.1 sec when 1.5$ reactivity is inserted. Figure 4 shows the numerical results of the transient analysis via CAPP and GAMMA+ for case 3. Because of the large reactivity insertion in a short time, power level changes quickly. The fuel, moderator and coolant temperature change slowly compared with the power level. The fuel temperature increases first, and then others increase. The numerical results of CAPP and GAMMA+ transients show similar graph shapes. However, the difference between them is larger than those in the previous cases. It is due to the different model of control rod movement. CAPP can describe the control rod movement explicitly, but GAMMA+ considers the control rod movement as the change of reactivity in the point kinetics equation.

3.4 Case 4: Control Rod Withdrawal

The fourth transient problem is a control rod withdrawal accident. The scenario is similar to the third problem except for the control rod moving speed. All control rods start to be withdrawn at 0.0 sec with a constant speed and are stopped at 200.0 sec when 1.5$ reactivity is inserted. Figure 5 shows the numerical results of the transient analysis via CAPP and GAMMA+ for case 4. The power level change is slower than that of case 3 because the reactivity insertion per unit time is smaller than that of case 3. The negative feedback due to temperature rise largely offsets the positive reactivity by control rod withdrawal. After the control rods stop (200.0 sec), the power level decreases and it is saturated. As the case 3, the numerical results of CAPP and GAMMA+ transients show similar graph shapes. However, the difference between them is larger than those in the case 1 and case 2. The power level graph in Figure 5 makes it look as if GAMMA+ uses the insertion of larger reactivity.

4. Conclusions

In this study, several transient scenarios for a block-type HTGR core were analyzed using CAPP and GAMMA+, respectively and compared with each other. The results of the calculation show that CAPP and GAMMA+ agree well for small reactivity change and change in coolant status. Because the change of spatial power distribution is small for such scenarios, the point kinetics method is appropriate. On the other hand, the results of GAMMA+ transient are different from those of CAPP transient for large reactivity change and control rod movement. Because it changes the spatial power distribution significantly, the point kinetics method would be difficult to simulate the scenario accurately.

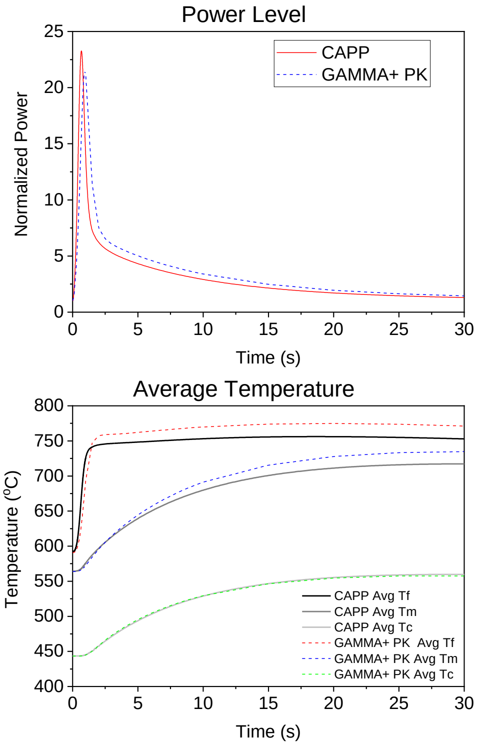


Fig. 4. Power level and core average temperature of case 3: control rod ejection.

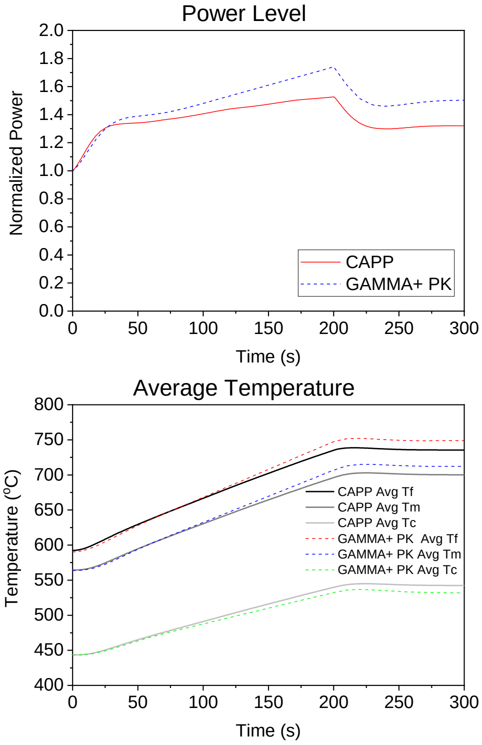


Fig. 5. Power level and core average temperature of case 4: control rod withdrawal.

This work presented the feasibility study of GAMMA+ transient for a block-type HTGR core. To improve the accuracy for control rod ejection or withdrawal problems, more accurate model describing control rod movement is necessary. Developing such a model without change of the point kinetics solver will be one of further studies. On the other hand, the application these transient codes to more realistic core is another obvious direction for the further studies.

Acknowledgements

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (No. 2017M2A8A1014757).

REFERENCES

[1] H. C. Lee, C. K. Jo, and J. M. Noh, Development of CAPP Code Based on the Finite Element Method for Analysis of VHTR Cores, Proceedings of HTR2008, Washington, DC, USA, September 28–October 1, 2008.

[2] H. S. Lim, General Analyzer for Multi-component and Multi-dimensional Transient Application, GAMMA+ 1.0 Volume II: Theory Manual, KAERI/TR-5728/2014, Korea Atomic Energy Research Institute, 2014.

[3] S. Yuk, J. Y. Cho, and C. K. Jo, Development of the CAPP Code for Transient Analysis of a Block-Type VHTR Core, Proceedings of HTR2018, Warsaw, Poland, October 8–10, 2018.

[4] S. Yuk et al., CAPP/GAMMA+ Coupled Code System for Transient Analysis of a Block-Type HTGR Core, Proceedings of M&C2019, Portland, Oregon USA, August 25-29, 2019.

[5] S. N. Lee, N. Tak, and H. S. Lim, Verification of GAMMA+ for Multi-Dimensional Heat Transfer in a Prismatic Core, Transactions of the Korean Nuclear Society Spring Meeting, Jeju, Korea, May 17–18, 2018.

[6] J. Ortensi et al., Benchmark of the MHTGR-350 MW Core Design. Volumes I and II, NEA/NSC/R(2017)4, Nuclear Energy Agency, 2017.