CAPP/GAMMA+ Coupled Transient Analysis for Very High Temperature Gas-cooled System

Seungsu Yuk*, Hong Sik Lim, Ji Su Jun, Tae Young Han
Korea Atomic Energy Research Institute, 111, Daedeok-daero, 989beon-gil, Daejeon, 34057, Korea
**Corresponding author: syuk@kaeri.re.kr*

1. Introduction

A very high temperature gas-cooled reactor (VHTR) can supply a large amount of high-temperature heat by operating at a higher temperature than existing commercial light water reactors. Korea Atomic Energy Research Institute (KAERI) is conducting research on the very high temperature system (VHTS) design technology that raises the coolant temperature at core outlet from 750 ℃ to 950 ℃ to supply the very high temperature heat required in various industries. However, the higher temperature reduces the thermal safety margin. To solve this problem, the core design must be done carefully [1] or an accurate numerical analysis method must be used.

This study was about the latter. In order to accurately analyze the transient problem of VHTS, a strategy of coupling a reactor physics analysis code CAPP and a thermo-fluid system code GAMMA+ was used. This was compared with the point kinetics (PK) method used in previous studies.

2. Methods and Results

This section briefly introduces the CAPP/GAMMA+ coupled code system. A VHTR-350, whose core outlet temperature is 950 ℃, is described and several transient scenarios for this reactor system are addressed.

2.1 CAPP/GAMMA+ Coupled Code System

KAERI has developed VHTR design codes, CAPP [2] and GAMMA+ [3]. CAPP is a neutronics code to calculate a neutron flux distribution in a block-type VHTR core. GAMMA+ is a thermo-fluid system code to predict a variety of thermo-fluid phenomena occurring in a VHTR.

The reactor physics properties and the thermo-fluid characteristics influence each other. Multiphysics analysis is required for accurate simulation. Fig. 1 shows CAPP/GAMMA+ coupled code system [4, 5] developed by KAERI. CAPP requires temperature distribution for neutron flux calculation. Meanwhile, GAMMA+ requires power distribution for thermo-fluid analysis. Data communication between two codes are performed by a server program INTCA. CAPP sends the power and neutron fluence distribution to GAMMA+ through INTCA. GAMMA+ sends temperature and some isotope number densities (H, O, N) to CAPP through INTCA. They synchronize the transient time via INTCA.

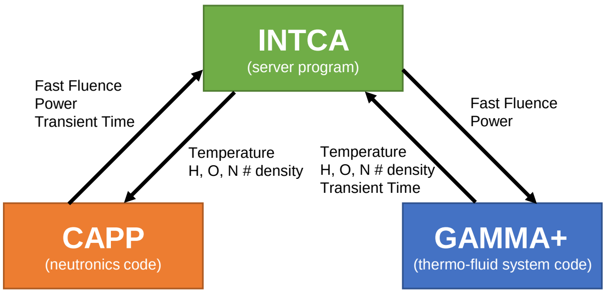
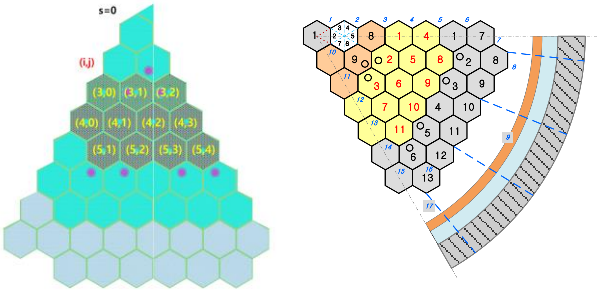


Fig. 1. CAPP/GAMMA+ coupled code system for transient analysis

2.2 VHTR-350: A Preliminary 950 ℃ VHTR Design

VHTR-350 is a conceptual VHTS (the coolant temperature at the core outlet is 950 ℃). The reactor design is based on the MHTGR-350 [6] and PMR-200 [7] design. The total thermal power is 350 MWt and the core coolant inlet/outlet temperature is 490/950 ℃. The radial fuel loading pattern was established so that the fuel temperature does not exceed the safety limit [1, 8]. A printed circuit heat exchanger (PCHE) was adopted for heat transfer to the secondary loop [9]. A natural circulation loop is installed outside the reactor pressure vessel (RPV) to finally release heat to the atmosphere. In an accident in which forced circulation is lost, residual heat from the core is transferred to the RPV by heat conduction, natural convection, and thermal radiation inside the RPV, and is transferred to the natural circulation loop by natural convection and thermal radiation outside RPV. Therefore, a completely passive cooling system was constructed in VHTR-350.

CAPP and GAMMA+ exchange data in the reactor core region. Therefore, core lattice matching between CAPP and GAMMA+ should be made. Fig. 2 shows the radial core model of VHTR-350 of CAPP and GAMMA+, respectively. In inner and outer reflectors and fuel regions, blocks of CAPP and GAMMA+ form a one-to-one correspondence. In the case of CAPP, the permanent reflectors are approximated to the set of hexagonal blocks. Since there is no power in this region and the temperature distribution is relatively flat, there is no significant issue for matching CAPP lattice and GAMMA+ lattice in the permanent reflector region.



(a) CAPP (b) GAMMA+

Fig. 2. VHTR-350 radial core models

2.3 Secondary Loop Temperature Transient

This and the next sub-sections show the numerical results of some transients in VHTR-350. In the first transient scenario, the coolant inlet temperature in the secondary loop is decreased by 50 ℃ for 10 seconds, and then increased by 50 ℃ for 10 seconds at 300 seconds. Fig. 3 and Fig. 4 show the numerical results of the CAPP/GAMMA+ coupled code system and GAMMA+ PK stand-alone code. As the coolant temperature decreases in the secondary loop, the temperature in the reactor core decreases and the power gradually increases due to the positive reactivity. As the power increases, the maximum fuel and moderator temperature increases. At 300 s, the secondary inlet temperature returns to the initial value. The reactor core temperature and the power level approach to the initial state. In the case of the coupled analysis, compared to the point kinetics method the power rise and the temperature rise are lower.

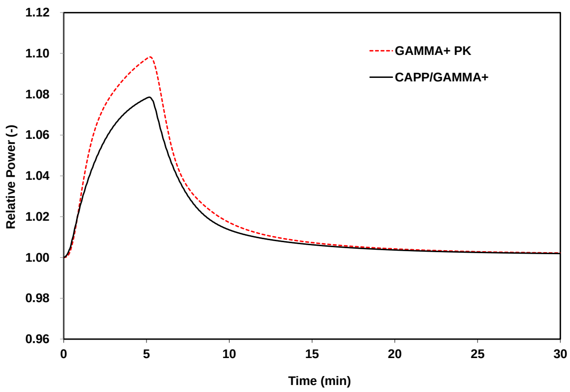


Fig. 3. Numerical results of secondary loop temperature transient in VHTR-350: Relative power.

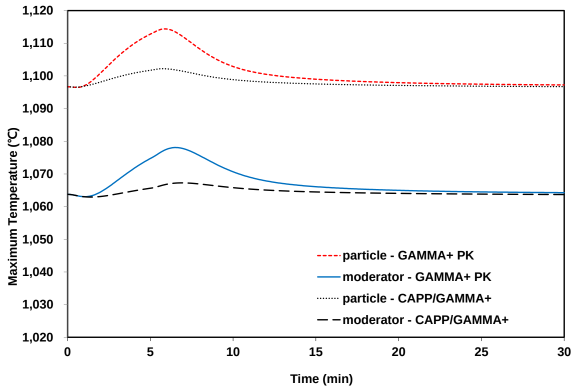


Fig. 4. Numerical results of secondary loop temperature transient in VHTR-350: Maximum temperature.

2.4 Secondary Loop Flow Rate Transient

In the second transient scenario, the secondary loop flow rate is increased by 20% for 0.1 sec, and then decreased again for 0.1 sec at 300 sec. Fig. 5 and Fig. 6 compare the results of CAPP/GAMMA+ coupled analysis and the GAMMA+ PK for this scenario. An increase in the secondary loop flow rate increases heat transfer through the intermediate heat exchanger, lowering the primary loop helium temperature and eventually cooling the reactor core. The resulting positive reactivity increases the reactor power. At 300 seconds, the secondary flow rate returns to the initial state, and the power and temperature return to the initial state. The fluctuation of the secondary loop flow rate is less affected than the first scenario, so the maximum temperature peak and power peak are also smaller. As in the first scenario, it can be seen that the coupling analysis shows lower power and temperature rise compared to the point kinetics method.

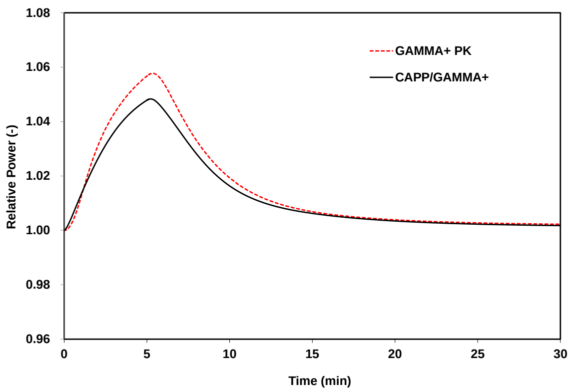


Fig. 5. Numerical results of secondary loop flow rate transient in VHTR-350: Relative power.

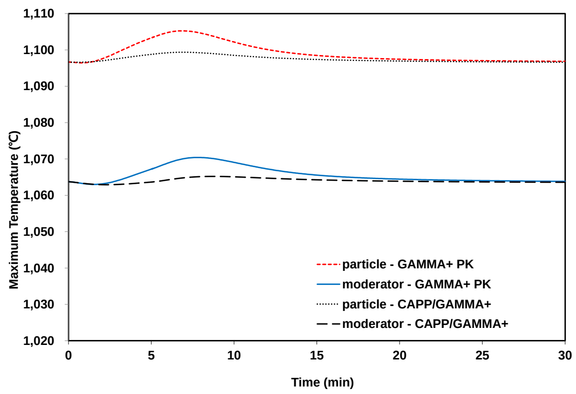


Fig. 6. Numerical results of secondary loop flow rate transient in VHTR-350: Maximum temperature.

3. Conclusions

In this paper, the transient problems of 950 ℃ VHTS was analyzed using the CAPP/GAMMA+ coupled code system and the numerical results were examined. As results of numerical analysis of temperature and flow rate fluctuation in the secondary loop, the coupling analysis predicted lower power and temperature rise than the conventional point kinetics method. Therefore, it is expected that the coupling analysis can secure a larger thermal safety margin than the conventional point kinetics method for 950 ℃ VHTS.

It is expected that the feedback between temperature and power distribution in the coupling analysis more accurately simulates the reactivity change than the reactivity coefficient used by the conventional point kinetics method which is assuming the core as a point. However, it is difficult to verify this because there are few experimental data for VHTR. In the future, this is a challenge to be addressed.

This paper dealt with the transient problem of VHTS due to the condition change of the secondary loop. The coupling strategy will be performed to analyze phenomena of accidents such as loss of forced circulation (LOFC) in the future work. The prediction of re-criticality due to the xenon will be considered for ATWS (anticipated transient without scram).

ACKNOWLEDGEMENTS

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