Preliminary Transient Analysis Using GAMMA+ Code for MSRE System

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1. Introduction

After two big accidents of Chernobyl and Fukushima, the nuclear community has been focusing on the safety issue more. The Generation IV (Gen-IV) type reactors emerged to enhance safety and reliability. The Molten Salt Reactor (MSR) is one of the Gen-IV reactors[1]. The fuel mixture of the MSR is molten during a normal operation. The fission products and noble metals are separated and processed during the normal operation. Therefore, the potential risk related with the severe accident is less than other reactor types. MSR concept was developed and tested in 1950~1960[2].

The numerical analysis tool has been developed actively from ~2010. He[3] applied a TRACE code to the MSR system. Singh et al.[4] published the reproduced results from MSRE analysis results[2] using recent digital method. Korea Atomic Energy Research Institute (KAERI) has been upgrading the GAMMA+ code to apply MSR system[5]. In the present paper, the preliminary analysis for the MSRE transient state has been conducted and the results were compared with the data in the reference papers.

2. Methods and Results

The fuel in MSR system circulates in the primary loop. Therefore, the analysis code needs to consider additional phenomena compared to solid fuel core system. The heat generation in the core top, bottom region and primary loop pipe might be included to investigate the temperature distribution properly. The dynamic of the freezing valve component is necessary to drain the molten salt during reactor shutdown. KAERI has chosen the GAMMA+ code to conduct transient analysis of MSR.

2.1 GAMMA+ MSR Model

GAMMA+ code has been developed to solve transient phenomena in the gas cooled system initially. As non-LWR reactor type is attracting more interest recently with enhanced safety, the GAMMA+ code is implementing the additional modules for Sodium cooled Fast Reactor (SFR) and Molten Salt Reactor (MSR). MSR has unique characteristic compared to other reactor types. The fuel type is not solid but fluid. The fluid fuel continuously circulates the primary loop. Therefore, the point kinetics for delayed neutron should differ with a conventional solid fuel type reactor. The GAMMA+ code adopt 4 type reactor kinetics in Fig. 1.

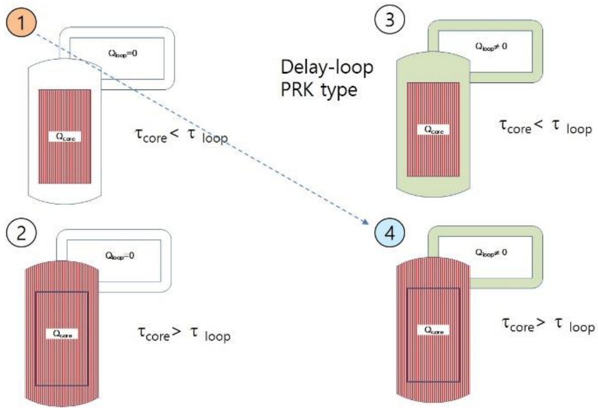


Fig. 1. MSR reactor kinetics model of GAMMA+

Each of equation corresponding to 1~4 is written below.

$$\frac{dP}{dt} = \frac{\rho-\beta_{eff}}{\Lambda}P + \sum_{i=1}^{6}\lambda_i C_i \quad (1)$$

$$\frac{dC_i}{dt} = \frac{\beta_i}{\Lambda}P - \lambda_i C_i - \frac{C_i}{\tau_c} + \frac{C_i(t-\tau_l)}{\tau_c}e^{-\lambda_i\tau_l} \quad (2)$$

$$\beta_{loss} = \sum_{i=1}^{6}\frac{\beta_i\lambda_i}{\lambda_i+\frac{1}{\tau_c}\left(1-e^{-\lambda_i\tau_l}\right)} \quad (3)$$

for 1 and 2

$$\frac{dP}{dt} = \frac{\rho-\beta_{eff}}{\Lambda}P + \sum_{i=1}^{6}\lambda_i C_i \quad (4)$$

$$\frac{dC_{c,i}}{dt} = \frac{\beta_i}{\Lambda}P - \lambda_i C_{c,i} - \frac{C_{c,i}}{\tau_c} + \frac{V_l}{V_c}\frac{1}{\tau_l}C_{l,i}(t-\tau_l) \quad (5)$$

$$\frac{dC_{l,i}}{dt} = -\lambda_i C_{l,i} - \frac{C_{l,i}}{\tau_l} + \frac{V_c}{V_l}\frac{1}{\tau_c}C_{c,i} \quad (6)$$

for 3 and 4

The precursors generated in the core decay during circulating in the primary loop. The residual precursors re-enter into the core. Therefore, the point kinetics of MSR should include those delayed term. Type 1 and 2 include the delayed term. Type 2 is the same as Type 1, but the outer regions of the graphite core have some fraction of the fission power.

Guo et al. introduced new concept for delayed neutron [6]. The concentrations of the precursors are calculated in both the core and the primary loop. Type 3 and 4 adopt this model. Type 4 is the same as Type 1, but the outer regions of the graphite core are included as core fission zone.

To assess the reactor kinetics model of GAMMA+, MSRE system constructed in 1964 is considered in the present study in Fig 2. The reactivity accidents are compared with the results from the several previous reports.

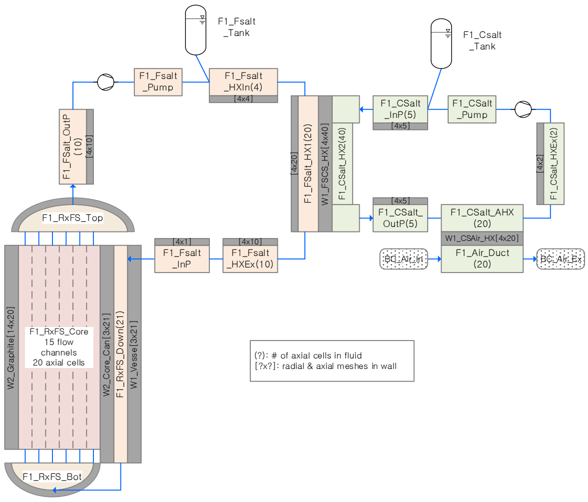


Fig. 2. GAMMA+ MSRE model[5]

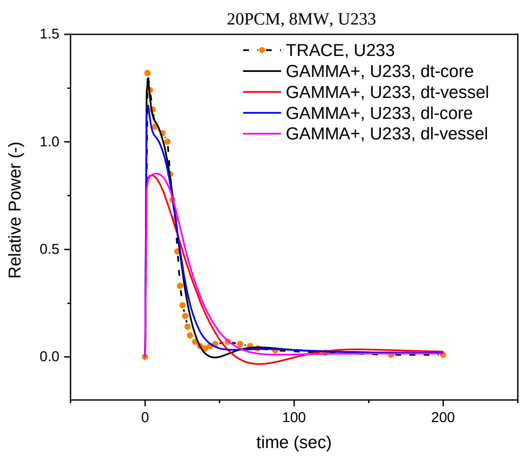
2.2 Reactivity Insertion Accident

The reactivity insertion accident cases are written in Table I.

Table I: Reactivity Insertion Accident Cases

	Reactivity Insertion[PCM]	Operating Power[MW]
Case1	20	8
Case2	10	8
Case3	10	5
Case4	10	1

Fig. 3 represents 20PCM insertion for 8 MW operation of U233 and U235. The terms ‘dt-core’, ‘dt-vessel’, ‘dl-core’ and ‘dl-vessel’ correspond the number from 1 to 4 in Fig. 1. The calculated results by GAMMA+ were compared with the results obtained by TRACE code simulation[3]. Regardless of the reactor kinetics model, the core options show similar results compared to the results of TRACE.



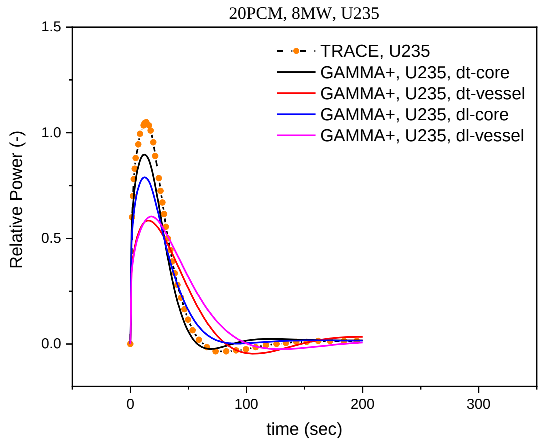
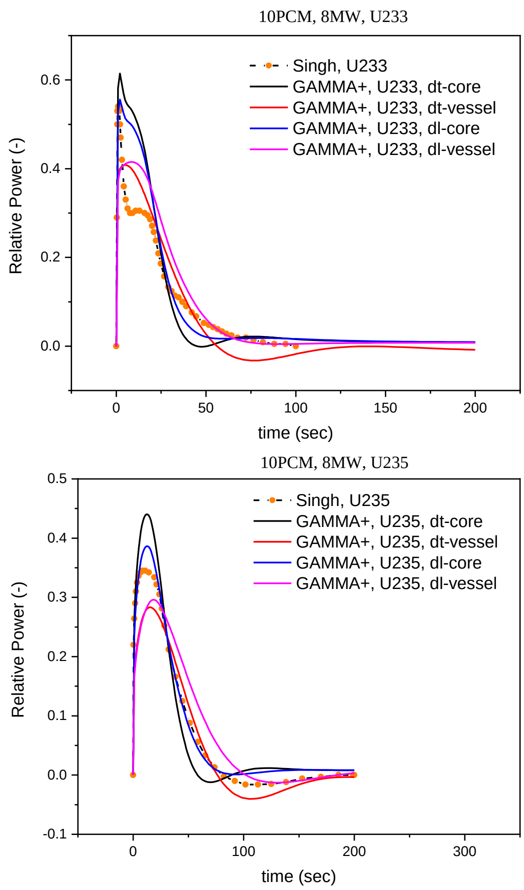
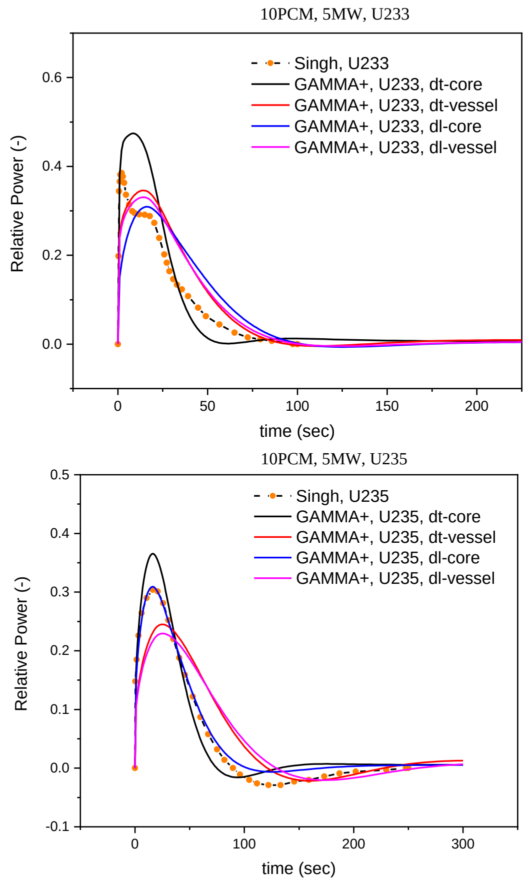


Fig. 3. 20PCM insertion for 8MW power(Left : U233, Right :U235)

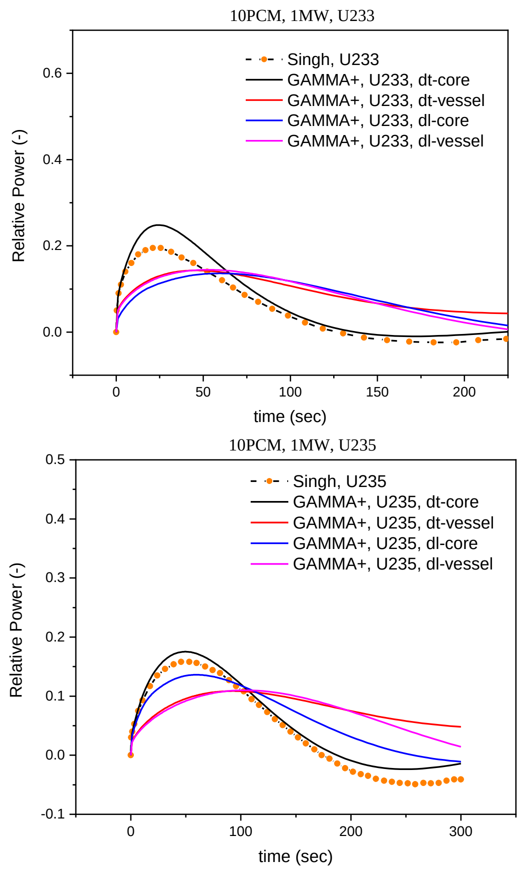
The results of the 10 PCM insertion accidents for 1, 5 and 8MW are plotted in Fig. 4. The data were compared with the results of Singh et al.[4]. Because there is only fission power in the core by the reference paper, the results by the core model are closer to the reference results. However, the power fractions in the real system may be distributed in some region outside the graphite core, the actual results would be located between the core and the vessel model.



(a) 10PCM, 8MW(Left : U233, Right : U235)



(b) 10PCM, 5MW(Left : U233, Right : U235)



(c) 10PCM, 1MW(Left : U233, Right : U235)

Fig. 4. 10PCM insertion for 1, 5 and 8MW power(Left : U233, Right :U235)

3. Conclusions

The GAMMA+ code has been updating to simulate MSR reactor. The molten fuel circulates continuously in the primary loop. The modelling strategy is different from the other reactor types. Therefore, the code verification and validation should be well established. In the present paper, the reactivity insertion accidents were analyzed and compared with the reference papers. The GAMMA+ simulated the reference paper reasonably. The point kinetic models of the GAMMA+ may be modified and improved in the future.

Acknowledgements

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