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# Improvement of Steady-State IHTS Modeling with GAMMA+

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## 1. Introduction

The GAMMA+ (General Analyzer for Multi-component and Multi-dimensional Transient Application) 1.0 (Rev01/Mod00) version has been further updated from the original GAMMA code, by implementing additional features for applying to the VHTR design and safety analyses: multi-dimensional fluid flow and heat conduction in a spherical coordinate, two-phase flow dynamics, detailed core heat conduction to which a particle-coupled fuel conduction are coupled, and pool boiling bath. GAMMA+2.0 version is that extended to Micro Gas-Cooled Reactor (MMR), Liquid-Metal Reactor (LMR), Molten-Salt Reactor (MSR), and Space Power Reactor (SPR). This version contains a generalized heat pipe model, a compensating tank model, stratified flow dynamics, modified point reactor kinetics, and a modeling feature for heat exchangers such as PCHE, as well as the capability to perform Neutronics/Thermo-fluid coupled transient analysis (CAPP/GAMMA+) for a prismatic-core VHTR [1].

As part of this process [2], it is planned to conduct a safety analysis reflecting the recently updated (2024) safety analysis methodologies and modeling. A prerequisite for the safety analysis is the steady-state analysis, and this study describes the steady-state analysis of the Intermediate Heat Transport System (IHTS).

## 2. Methods and Results

The SALUS (Small Advanced Long-cycled and Ultimate Safe SFR), currently being developed by KAERI, has the characteristic of being able to operate without the need for nuclear fuel replacement for about 20 years. One of the heat transfer systems in the SALUS, the intermediate heat transfer system, consists of two independent loops. Each loop is composed of pipes, an intermediate heat exchanger, a steam generator, an expansion tank, an electro-magnetic type pump, a steam trap, and valves as shown in Fig. 1.

The purpose of the studies is code verification and validation, intending to compare GAMMA+'s analysis results with those of MARS-LMR. Identical initial values, modeling, and nodalization have been applied (Fig. 2).

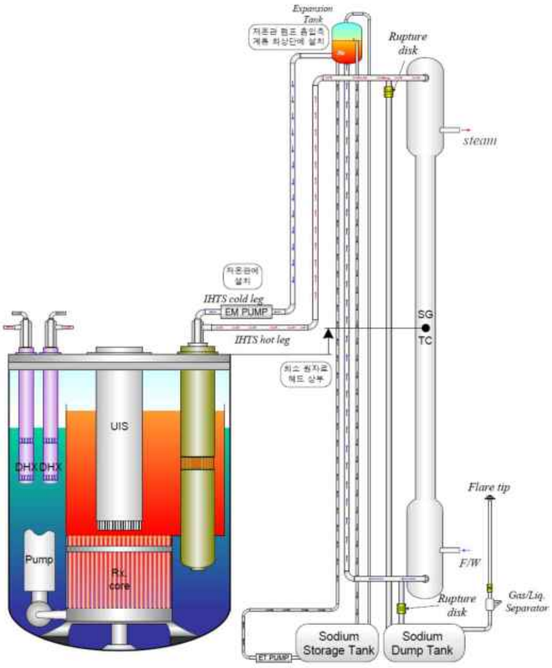

Fig. 1. IHTS arrangement requirements

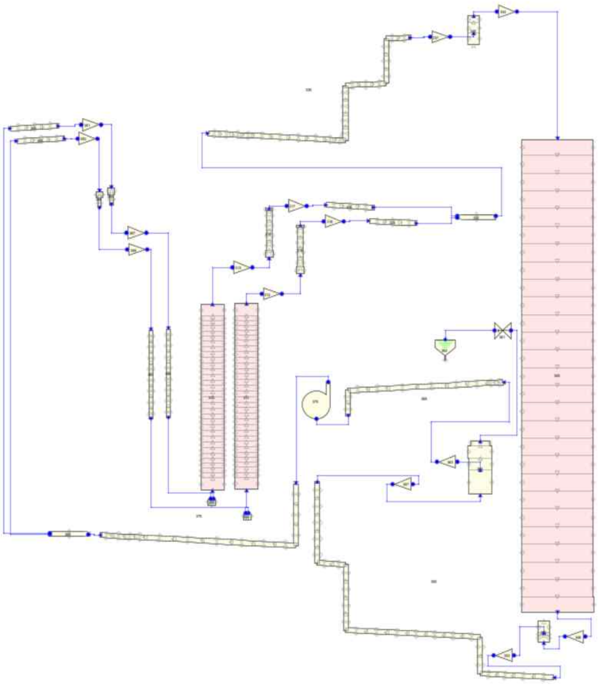

Fig. 2. 1-D Modeling and Nodalization of IHTS

### *2.1 Two-phase Modeling evaluation*

Due to flow instability issues, it became necessary to further evaluate the two-phase flow in the GAMMA code. To address this, an evaluation of the maximum time step among the numerical analysis methods in the GAMMA code was conducted. The learning outcomes, as shown in Figures 3 to 5, confirmed the convergence and trends of the results related to two-phase flow depending on the time step. Based on this, an appropriate time step was determined, and this value was used in subsequent results (ex. sensitivity study of nodalization etc.).

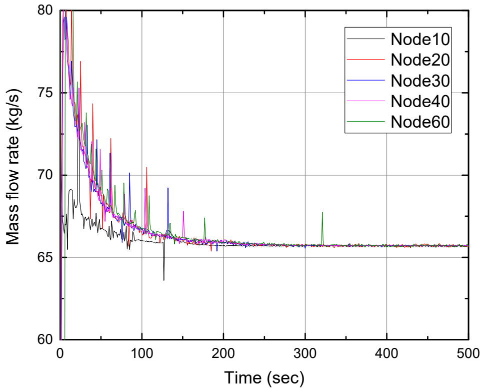

Fig. 3. Variation of Steady-State Mass flow rate with Number of Nodes

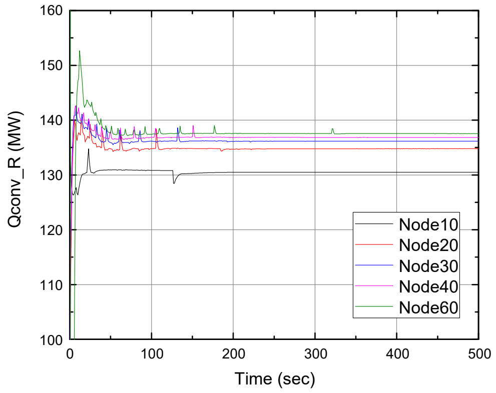

Fig. 4. Variation of Steady-State Heat Transfer with Number of Nodes

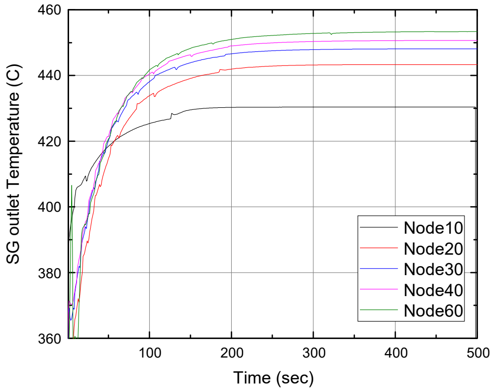

Fig. 5. Variation of Steady-State Outlet Temperature with Number of Nodes

### *2.2 Pressure distribution in IHTS*

In the previous GAMMA+ analysis modeling, a significant difference was observed between the operating pump head and the rated pump head used to satisfy the same pressure distribution conditions within the system, compared to the results from MARS-LMR. Since the same modeling and initial values were used, we could predict that the differences should be similar. Therefore, factors that could influence the operating pump head value within the IHTS system were examined. As a result, the modeling was modified to align with the GAMMA code for the branch and cross flow junction of the MARS-LMR model. After modifications, the magnitude of the operating head and rated head is approximately 3 meters. This magnitude has been confirmed to be similar to the analysis results from MARS-LMR.

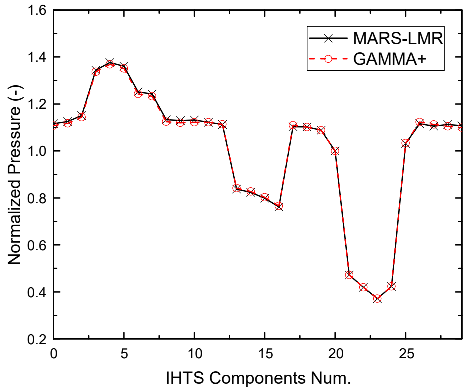

Fig. 6. Pressure distribution between MARS-LMR and GAMMA+

### *2.3 Steady-state results of IHTS*

Reflecting the improvements from the existing modeling, steady-state analysis for the IHTS was conducted as shown in Figures 7 to 10. When compared with MARS-LMR results, the differences in temperature, pressure, flow rate, and heat transfer rate at the inlet/outlet locations of the IHX and SG were observed to be -0.8 to -0.1%, -0.4 to 0.8%, 0.0%, and -1.9 to 5.1%, respectively. Additionally, efforts were made to minimize the flow variation on the Steam generator tube side where two-phase flow exists, allowing for a comparative analysis of SG modeling with MARS-LMR. These calculated steady-state results will be used in the upcoming comprehensive system integration and safety analysis for the SALUS reactor.

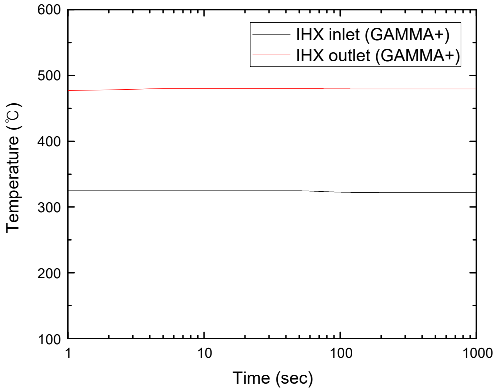

Fig. 7. Steady-state temperature in IHX

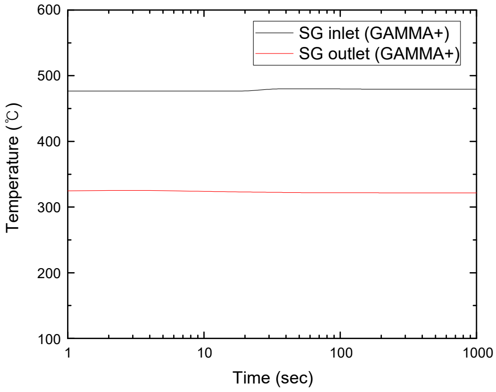

Fig. 8. Steady-state temperature in SG

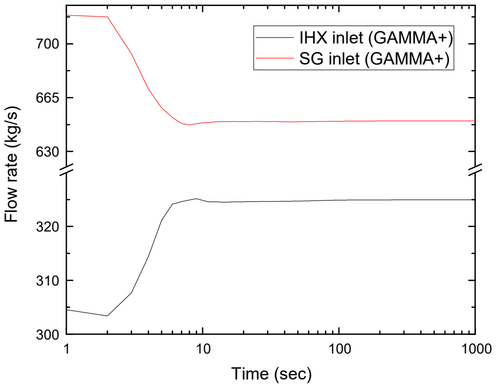

Fig. 9. Steady-state flow rate of IHTS

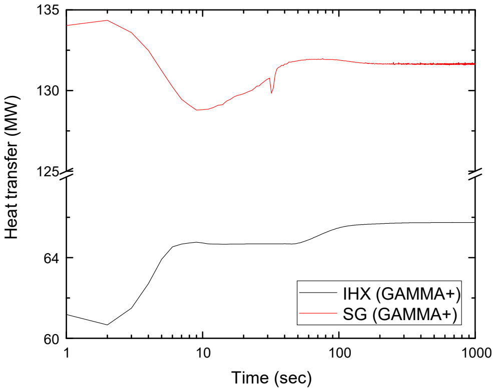

Fig. 10. Steady-state heat transfer of IHX and SG

## 3. Conclusions

In this study, to enhance the reliability of the safety analysis results, GAMMA+ modeling improvements were performed. As a result, the pressure gradient difference within the IHTS system was matched similarly to the MARS-LMR code. By minimizing flow changes in two-phase flow, it was possible to add a modeling evaluation for the steam generator as a single device. Based on this research, system integration and safety analysis for the entire SALUS reactor system are planned to be conducted in the future.

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