Study on the Verification of Control Logic Code of NSSS for Integral Reactor

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1. Introduction

An integral reactor refers to a reactor in which major equipment, such as a core, steam generator, pressurizer, and reactor coolant pump, are placed in a single reactor pressure vessel. Unlike a large commercial reactor, there are no large pipes connecting major equipment, so it can eliminate leakage of reactor coolant. In addition, the passive safety concept is applied to mitigate accident by natural force in the event of an accident.

Since the core power, amount of coolant, and operation method are different from commercial reactors, a dedicated code is needed to simulate the integrated reactor and evaluate the control logic to determine the control coefficient used in the reactor regulating system and the reactor power cutback system.

Therefore, in this study, the control logic evaluation code for an integrated reactor was developed, and the results were compared with that of TASS/SMR-S.

2. Methods

2.1 Composition of RCS

The flow path of this integral reactor is described in Figure 1. The reactor coolant is heated at core region and flows through the hot region. The heated coolant is cooled at SG region and flows to the core region through cold region.

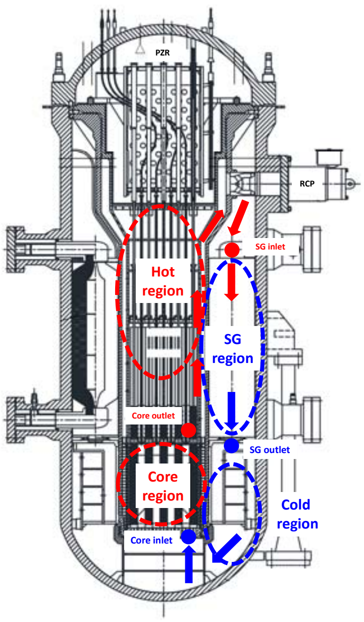

Fig. 1. RCS flow path

In order to simulate the RCS, this was largely divided into core region, hot region, steam generator region, and cold region as shown in Figure 2. The hot region means the upper part of the fuel alignment plate to the inlet of the reactor coolant pump, and includes all flow paths through which the temperature of the reactor coolant increases as it passes through the core.

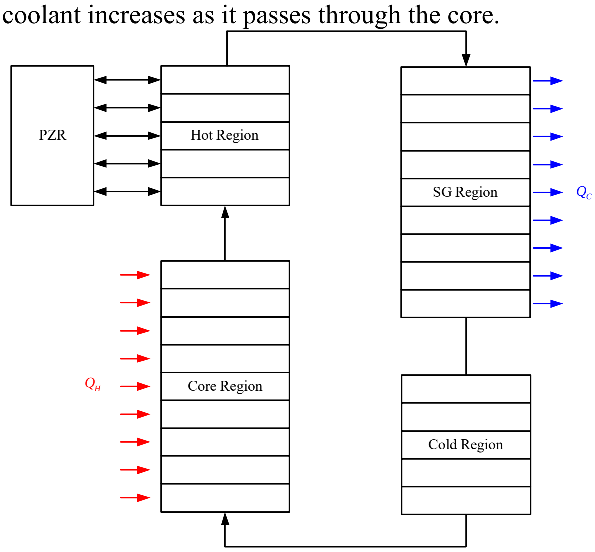

Fig. 2. RCS schematic diagram

The hot region includes upper guide structure (UGS), control rod assembly shroud assembly, UGS lower support plate, pressurizer surge region, etc. The cold region means the lower part of the steam generator to the core inlet, and includes a flow path through which the cooled reactor coolant flows through the steam generator. The cold region includes flow mixing header assembly (FMHA), flow skirt, and lower core support plate, etc.

2.2 Assumptions

- The flow path cross-section region of the control volume in each region is the same.
- One-dimensional flow.
- The heat generated from the core is provided to the reactor coolant with the constant heat flux.
- The heat flux from the reactor coolant (primary side) to the secondary side is uniform.
- The flow rate between the pressurizer and the hot region is distributed evenly to all control volumes of the pressurizer surge region.

- The heat from the core region and the heat between the pressurizer and the hot region are the same as the heat to the secondary side through the steam generator.
- Adiabatic in all regions except core and steam generator regions.
- The heat transfer between the reactor vessel and the reactor vessel assembly and the reactor coolant is ignored.
- The bypass flow rate of the core region and the steam generator region is ignored

2.3 Governing Equations

The continuity equation for each control volume is as follows.

$$\frac{\partial \rho}{\partial t}+\frac{1}{A}\frac{\partial W}{\partial x}=0$$

where ρ , A, and W mean the density and cross-sectional region of the control volume, and the mass flow rate through the control volume, respectively.

The energy conservation equation of the control volume with single phase is as follows.

$$\frac{\partial(\rho i)}{\partial t}+\frac{1}{A}\frac{\partial(Wi)}{\partial x}=\dot{q}'''$$

where i and $\dot{q}'''$ mean the enthalpy and the heat transfer rate between the pressurizer and the hot region, respectively.

2.4 Algorithm

The algorithm of this study is described in Figure 3. When calculation starts, geometry information are specified. Afterwards, the density, enthalpy, pressure, and flow rate of each control volume are entered as assumed values, and the continuity equation and the energy conservation equation are calculated.

The calculation along the reactor coolant pump (start) - steam generator region – cold region – core region – hot region - the reactor coolant pump (end) is conducted, and the difference between the start position and end position of the reactor coolant pump are compared. If this value is less than the designated value, the calculation proceeds to the next time step. Furthermore, to secure convergence in each calculation condition, the courant number is calculated for all control volumes and the value below 1 is checked.

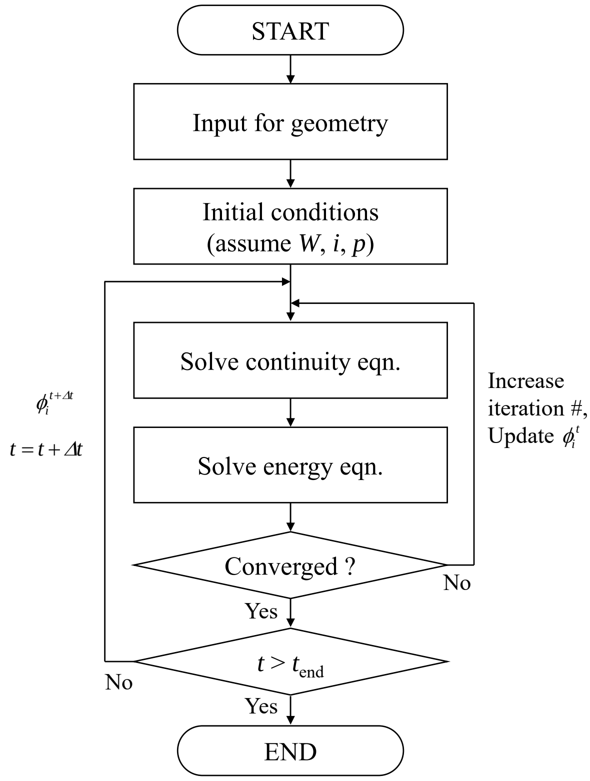

Fig. 3. Algorithm

3. Results

3.1 Core Inlet Point

Figure 4 shows the core inlet temperature variation with respect to time. The core inlet location is before core bypass. When the time reaches 100 seconds, the reactor power changes from 100% to 90%. The core inlet temperature starts to increase because of this integral reactor design characteristics. After the reactor power reaches 90%, the core inlet temperature converges to steady state condition. The reactor power starts to change from 90% to 100% at 1000 seconds (after reaching steady state). The core inlet temperature starts to decrease, and goes to the steady state temperature.

The results of the present work simulate that of TASS/SMR-S similarly in trend (red line). However, the temperature differences occurred. The temperature difference of steady state of 100% reactor power at core inlet is about 0.5°C. These results could be happened by the reasons as follows:

- The volume used in both program could be different.
- In the present work, the heat transfer rate from the RCP is neglected. This could cause the error.
- Furthermore, the time for reaching steady state of the core inlet temperature after reactor power change (100%→90% and 90%→100%) is estimated shorter than that of TASS-SMR-S. This may caused by the calculation of reactor pressure vessel structure. For

more precise simulation, the thermal mass of reactor pressure vessel shall be considered.

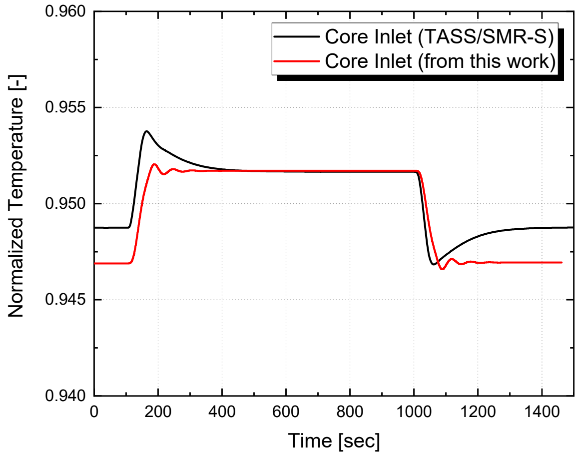

Fig. 4. Normalized temperature at core inlet point

3.2 Core Outlet Point

Figure 5 shows the core outlet temperature variation with respect to time. The core outlet location is after core bypass. The temperature trend is simulated similarly to the results at core inlet point (red line). After 1000 seconds, the reactor coolant temperature reaches the steady state slowly. This is because the thermal mass of reactor pressure vessel is not considered.

At 100% reactor power, the temperature difference between core inlet and core outlet at TASS/SMR-S is almost same as the temperature difference of this study. The total heat transfer rate from the fuel assembly to the reactor coolant in core region is almost the same.

3.3 SG Inlet Point

Figure 6 shows the SG inlet temperature variation with respect to time. The SG inlet location is before SG bypass. When the time reaches 100 seconds, the reactor power changes from 100% to 90%. The SG inlet temperature starts to decrease because of SMART design characteristics. After the reactor power reaches 90%, the SG inlet temperature converges to steady state. The reactor power starts to change from 90% to 100% at 1000 seconds. The core inlet temperature starts to decrease, and goes to the steady state temperature.

The results of the present work simulate that of TASS/SMR-S similarly in trend (red line). The temperature differences occurred. However this result seems to be allowable. The time for reaching steady state is still different. This seems to be the thermal mass problem.

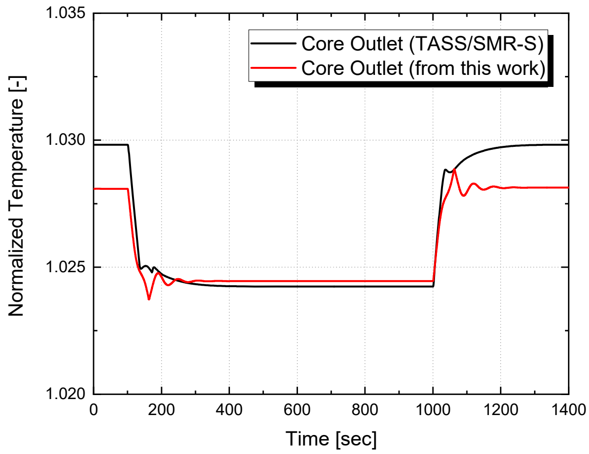

Fig. 5. Normalized temperature at core outlet point

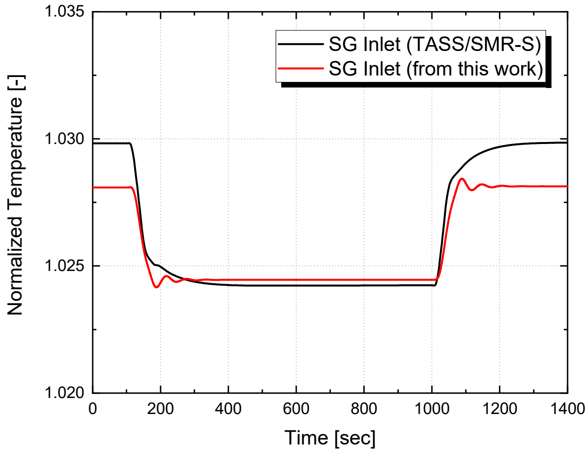

Fig. 6. Normalized temperature at SG inlet point

3.4 SG Outlet Point

Figure 7 shows the SG outlet temperature variation with respect to time. The SG outlet location is after SG bypass. The temperature trend is simulated similarly to the results at SG inlet point. After 1000 seconds, the reactor coolant temperature reaches the steady state slowly.

At the steady state of 100% reactor power, the temperature difference between SG inlet and outlet at TASS/SMR-S is the same as the results of this work.

In the present work, only the primary side of SG is calculated. The heat transfer rate from the fuel assembly to the reactor coolant and the heat transfer rate from the reactor coolant to the SG secondary side are assumed to be the same. The mass flow rate of the reactor coolant is the same at both core and SG region. Therefore, the enthalpy difference between inlet and outlet is almost the same at both core and SG region. In real situation, the primary and secondary side of SG are coupled, so that the calculation of both side of SG should be conducted simultaneously.

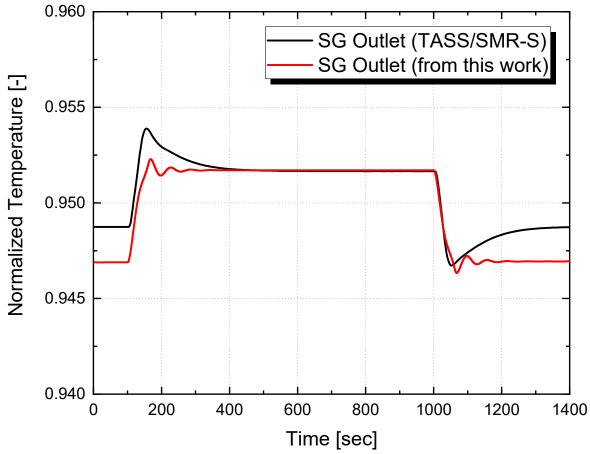

Fig. 7. Normalized temperature at SG outlet point

4. Conclusions

In this study, the calculations of RCS for validation are conducted. The maximum error of the temperature between TASS/SMR-S and this work is about 0.5°C. The trend is simulated similarly with the results of TASS/SMR-S. For more detailed simulation, the improvements of the program are needed as follows:

- The structure of reactor pressure vessel should be considered. (thermal mass calculation)
- The calculation for the secondary side of the steam generator is needed. (heat transfer rate from the primary side of SG to the secondary side of SG)
- The effect of RCS pressure will be checked.