Coupling of THALES and FROST using MPI Method

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1. Introduction

The current safety analysis methodology for a CEA ejection accident based on numerous conservative assumptions with the point kinetics model results in quite adverse consequences. Thus, KNF is developing the multi-dimensional safety analysis methodology to enhance the consequences of the CEA ejection accident. For this purpose, three-dimensional core neutron kinetics code ASTRA, subchannel analysis code THALES, and transient fuel performance analysis code FROST are being coupled using message passing interface(MPI)[1]. For the first step, THALES and FROST are coupled and tested. This paper presents the coupling method between THALES and FROST and the simulation results with the coupled code system.

2. Methods and Results

The code coupling scheme including important thermal hydraulic parameters transferred between both codes are presented in Fig. 1. As a part of the validation of the coupled codes, the analysis results with the coupled codes under the same conditions, which are used in the CEA ejection accident analysis for the ShinKori units 3 and 4 FSAR[2], are compared with the FSAR.

2.1 Parameters Transferred

The thermal behavior in the fuel rod during the transient is calculated by FROST. It is transferred through CHASER to THALES[3]. The thermal hydraulic parameters including core coolant temperature are transferred from THALES to FROST. The fuel rod power, which is used in the calculation of thermal behavior in the fuel rod, is transferred to FROST by user-defined table. To calculate the transient heat flux on fuel rod surface, FROST uses coolant temperature and heat transfer coefficient calculated by THALES.

2.2 Coupling Scheme

A schematic data flow diagram of the coupled codes is presented in Fig. 1. FROST is linked to THALES via CHASER. For each time step in the transient analysis, CHASER collects the temperature data of the fuel rod calculated by FROST and transfers to THALES. THALES calculates the heat transfer coefficient based on transient fuel temperatures and coolant temperature in the core subchannel. The coolant temperature is then passed back to FROST via CHASER to be used in fuel rod temperature calculation. The data transfer between THALES and FROST is performed repeatedly by MPI method until the heat flux is converged within the convergence criteria given by user.

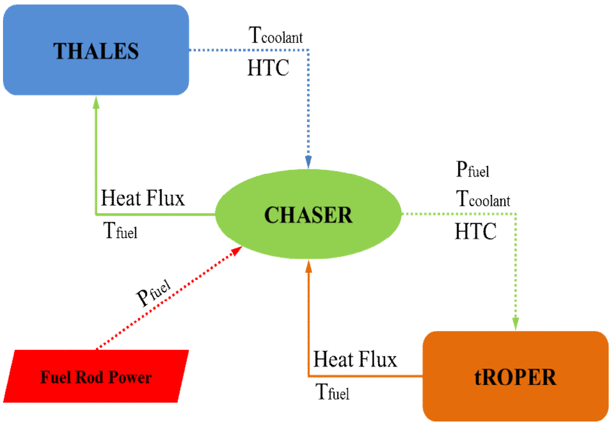

Fig. 1. Coupling schematic diagram

2.3 Validation of Coupled Codes

For the validation of the coupled codes, the single flow channel model with a single rod was tested. Rod input model based on PLUS7^{TM} fuel was used for FROST execution and corresponding single flow channel input model was also used for THALES execution. Since core neutron kinetic code ASTRA was not coupled in this study, the transient fuel rod power history data for the CEA ejection analysis of the ShinKori units 3 and 4 FSAR was used.

To validate the coupled codes, following initial conditions including power, flow rate, and pressure are used.

Table I: Initial conditions

	FSAR value	THALES-FROST
Power, [%]	140.5	140.5
Inlet coolant, temperature, [°F]	563.0	563.0
Inlet mass flow rate, [lbm/ ft^2-hr]	2.2043 x 10^6	2.2043 x 10^6
Inlet pressure, [psia]	2175.00	2175.32

The heat fluxes calculated by CHASER are presented in Fig.2. The overall behavior of heat flux was well predicted with CHASER except for the irregular pulses. It was caused by the change of flow regime at upper side of fuel rod due to the variation of thermal hydraulic conditions in flow channel.

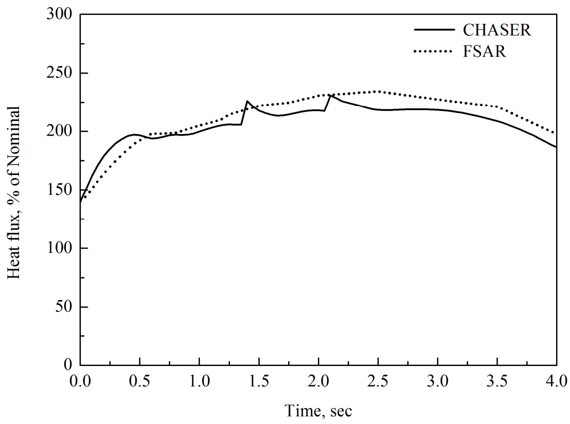

Fig. 2. Comparison of heat flux

The behavior of fuel temperature calculated by CHASER during a CEA ejection accident simulation is presented in Fig. 3. The fuel centerline and cladding surface temperatures at third node from the top are illustrated. Since the material properties of FROST are different from those of FSAR, the slope of fuel centerline temperature calculated by CHASER was lower than the slope of FSAR. CHASER estimated cladding surface temperatures relatively higher than those of FASR because the heat transfer coefficients calculated by CHASER are lower than those of FSAR. However, the results of CHASER calculation show that THALES and FROST codes are properly coupled.

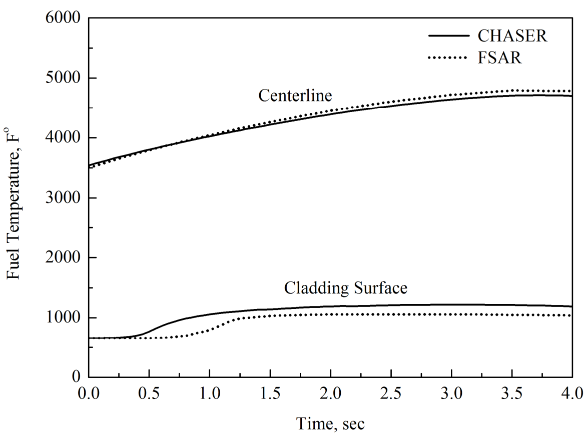

Fig. 3. Comparison of fuel rod temperature

The fuel and coolant temperature distributions with time during the transient are presented in Fig. 4. The coolant entering into the core is heated by fuel with axially increased power due to a CEA ejection, flow pattern in the flow channel changes from single-phase to two-phase. Therefore, the peak of fuel temperature occurs in the upper node that is far away from flow entrance. The maximum fuel centerline temperature is 4,712 ^{o}F at 3.75 seconds.

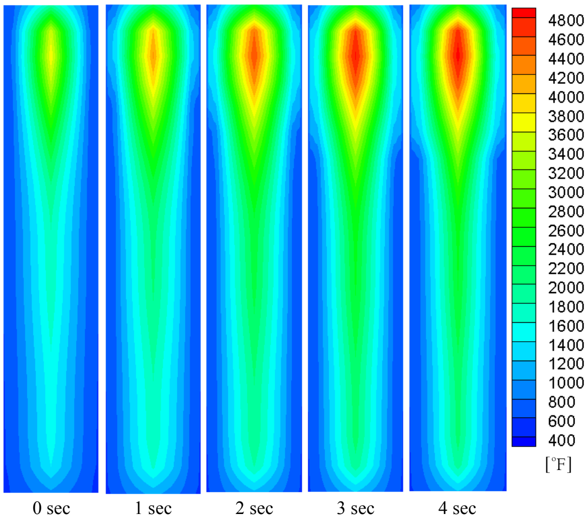

Fig. 4. Fuel and coolant temperature distributions with time

3. Conclusions

In this study, subchannel analysis code THALES and transient fuel performance code FROST were coupled using MPI method as the first stage of the development of the multi-dimensional safety analysis methodology. As a part of the validation, the CEA ejection accident was simulated using the coupled THALES-FROST code and the results were compared with the ShinKori 3&4 FSAR. Comparison results revealed that CHASER using MPI method predicts fuel temperatures and heat flux quantitatively well. Thus it was confirmed that the THALES and FROST are properly coupled.

In near future, ASTRA, multi-dimensional core neutron kinetics code, will be linked to THALES-FROST code for the detailed three-dimensional CEA ejection analysis.

REFERENCES

[1] Hongseok Lee, MPI Parallel Programming, ADBOOKS, 2010.
[2] ShinKori 3/4 Final Safety Analysis Report, Korea Hydro & Nclear Power.
[3] THALES Code Manual, KEPCO Nuclear Fuel, 2013.