Code Coupling for Multi-Dimensional Core Transient Analysis

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1. Introduction

The ejection of a control element assembly(CEA) with high reactivity worth causes the sudden insertion of reactivity into the core. Immediately after the CEA ejection, the nuclear power of the reactor dramatically increases in an exponential behavior until the Doppler effect becomes important and turns the reactivity balance and power down to lower levels. Although this happens in a very short period of time, only few seconds, the energy generated can be very significant and cause fuel failures.

The current safety analysis methodology which is based on overly conservative assumptions with the point kinetics model results in quite adverse consequences. Thus, KEPCO Nuclear Fuel(KNF) is developing the multi-dimensional safety analysis methodology to mitigate the consequences of the single CEA ejection accident.

For this purpose, three-dimensional core neutron kinetics code ASTRA, sub-channel analysis code THALES, and fuel performance analysis code FROST, which have transient calculation performance, were coupled using message passing interface (MPI).

This paper presents the methodology used for code coupling and the preliminary simulation results with the coupled code system (CHASER).

2. Methods and Results

The coupling of three codes has been performed using MPI method. As a part of the validation of the coupled code system, NEACRP three-dimensional PWR core transient benchmark problem was chosen and its results were compared with those of CHASER. Finally, as a preliminary calculation, a single CEA ejection accident of Shin-kori unit 3 was simulated using the coupled code system.

2.1 Coupling Scheme

The coupling scheme including the important kinetic and thermal hydraulic parameters transferred between codes is presented in Fig. 1. The kinetic parameter, nuclear power calculated by ASTRA, is transferred to FROST via CHASER. FROST calculates the rod temperature based on the kinetic data and generates the heat flux using the coolant temperature and heat transfer coefficient transferred from THALES. The thermal-hydraulic data including coolant temperature, heat transfer coefficient, and coolant density are transferred from THALES to ASTRA and FROST.

Thermal-hydraulic data, i.e. effective fuel average temperature, reactor coolant temperature and density, related with the effect of reactivity feedback in a core is passed to ASTRA, and then ASTRA calculates nuclear power considering Doppler and moderator feedbacks. In THALES, flow regime is determined through the heat flux and fuel rod surface temperature transferred by FROST. FROST calculates heat flux with the heat transfer coefficient and coolant temperature that are passed back from THALES. The data transfer between codes is performed repeatedly until the heat flux is converged within a criterion.

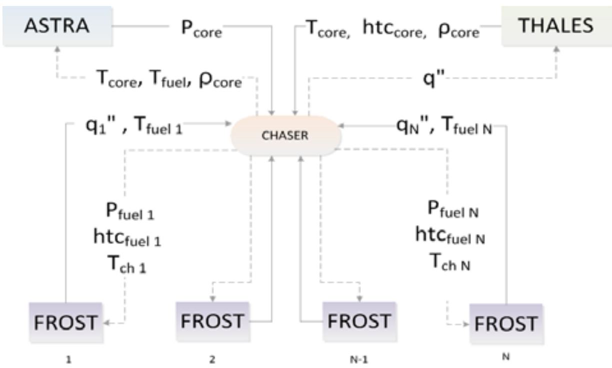


Fig. 1. Coupling Scheme of CHASER.

2.2 Validation of Coupled Codes

To assess the coupled code system, NEACRP three-dimensional PWR core transient benchmark problem[1] is simulated using CHASER. The hot zero power (HZP) case, most severe and challenging case C1 of this benchmark problem, was chosen for the validation of CHASER. The transient is initiated with 2,775W core power and the reactivity insertion of 1.22$.

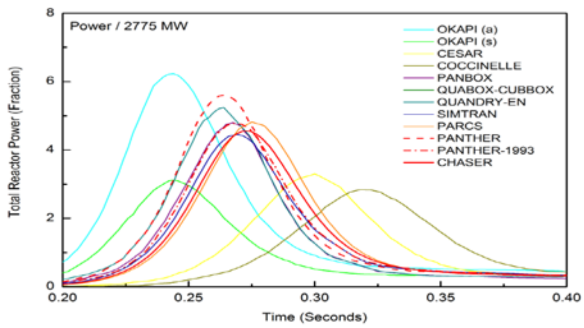


Fig. 2. Total reactor power with time (Case C1-HZP)

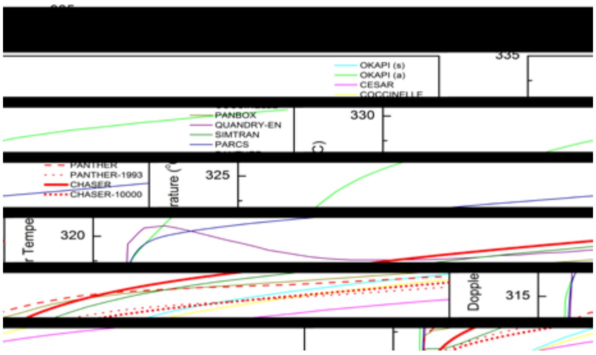


Fig. 3. Doppler temperature with time (Case C1-HZP)

Fig. 2 shows a little differences of the occurrence time of peak power and peak power level for each kinetics code in the interval from 0.2 to 0.4 seconds. The maximum powers seem very sensitive with respect to the computational strategy. Nevertheless, CHASER shows reasonable behavior during transient. As shown in Fig. 3, the Doppler temperature of CHASER is also similar to the values cited from reference data[1].

2.4 Preliminary Calculation of a Single CEA Ejection Accident

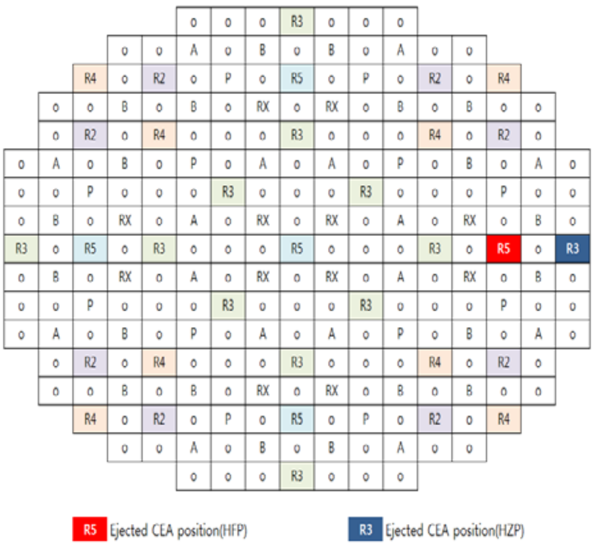
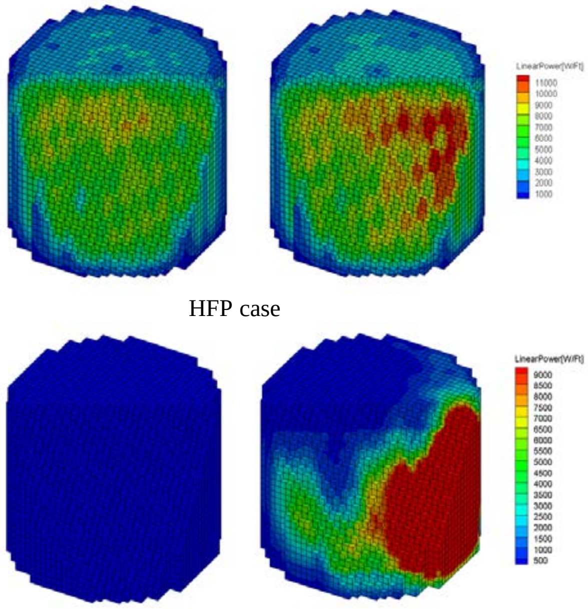


Fig. 4. Control rod pattern in a core and ejected rod location

The selected core for the preliminary application is APR1400-type nuclear power plant with a 16x16 assembly. The core geometry and control cluster locations are shown in Fig. 4. The radial nodes with 964 sub-channels for the full core and 26 axial nodes for each rod were considered during the analysis.

The preliminary calculation of a single CEA ejection accident consists of two cases, i.e. HFP and HZP cases. Before the CEA ejection is initiated, the reactor is assumed to be operating at 3983MWt for HFP case and 3983Wt for HZP case.

Immediately after a single CEA is ejected, local power increases rapidly in both cases, as shown in Fig. 5 and then fuel temperature rises. Therefore, a large negative reactivity is inserted into the core due to the Doppler feedback and it decreases reactor power in a low level.



HFP case

HZP case

Fig. 5. Local linear power after rod ejection

3. Conclusions

Multi-dimensional core transient analysis code system, CHASER, has been developed and it was applied to simulate a single CEA ejection accident. The multi-dimensional core power redistribution with Doppler and moderator temperature feedback effects was calculated. CHASER gave a good prediction of multi-dimensional core transient behaviors during transient.

In the near future, the multi-dimension CEA ejection analysis methodology using CHASER is planning to be developed. CHASER is expected to be a useful tool to gain safety margin for reactivity initiated accidents (RIAs), such as a single CEA ejection accident.

REFERENCES

[1] H. Finnemann, H. Bauer, A. Galati, R. Martinelli, Results of LWR Core Transient Benchmarks, Oct. 1993, OCED/NEA/NSC(93)25.