Study on Single CEA Withdrawal Event in a Typical SMR using 3-Dimensional Core Simulation Methodology

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1. Introduction

The study on single control element assembly withdrawal (SCEAW) event in a typical small modular reactor (SMR) was conducted based on the 3-dimesional core simulation to understand the phenomena after the event occurs and to figure out the amount of thermal margin decrease without an appropriate core protection system.

The SMR assumed in this paper is capable of soluble boron-free core and load following operation. Therefore, the reactivity worth of single control element assembly (CEA) may be larger and the power dependent insertion limit (PDIL) may be deeper than current commercial NPP. Also, it was assumed that reactor trip due to the deviation of CEA position would not occur, conservatively. These assumptions can increase the amount of reactivity insertion and the distortion of power distribution when SCEAW event occurs, which has a significant impact on thermal margin decrease.

All design data used in this paper are assumed values and best estimated.

2. Methods and Results

2.1 CHASER Code System

The methodology for 3D core transient analysis using the CHASER code system has been developed by KNF [1]. The main flow chart of CHASER code system is shown as Figure 1. ASTRA calculates pin power using the 1/4 assembly-wise radial node and 26 axial layers at first within every time step. It is transferred to FROST which calculates heat flux at the fuel outer surface. It is transferred to the THALES to calculate coolant temperature, density and heat transfer coefficient. They are transferred to the ASTRA and the FROST. These three codes calculate the several iterated calculations within each time step until the convergence conditions. CHASER determine whether the results of ASTRA, FROST and THALES reach the convergence conditions based on the heat flux.

2.2 CHASER-SPACE Code Coupling

CHASER can apply to only short-term transient that thermal-hydraulic behaviors are negligible because it does not reflect changes of TH conditions. To expand the applicability of CHASER, coupling between CHASER and SPACE codes has been performed in Reference [2].

The linkage between CHASER and SPACE is a direct coupling of the two codes on a synchronous time-step basis. The thermal-hydraulic (TH) conditions calculated by SPACE are passed to CHASER, and CHASER performs a calculation for the detailed core power and heat flux. The heat flux is then passed back to the SPACE model, and is used for the next time step.

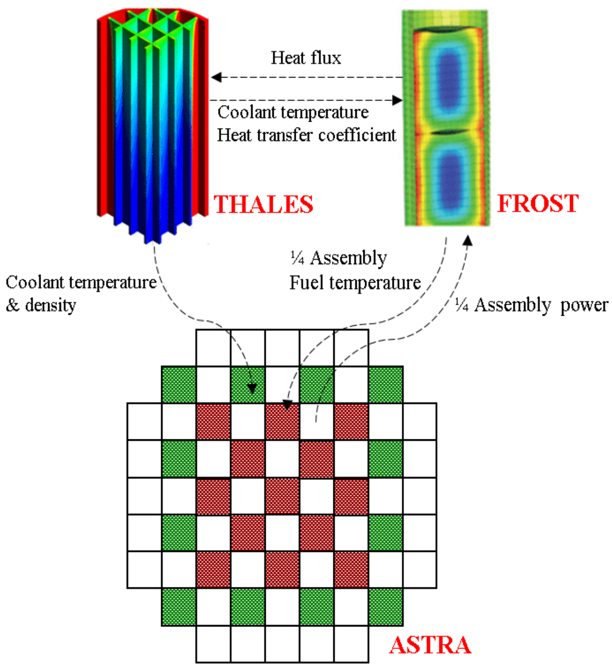

Fig. 1. Main flow chart of the CHASER code system

2.3 DNBR Evaluation

The minimum DNBR evaluation is conducted after CHASER or CHASER-SPACE calculation. The time dependent pin power is passed to SPACE (Hot rod model) and used to calculate fuel surface heat flux during transient. Afterwards, THALES calculates minimum DNBR with the transferred heat flux. Especially in the case of CHASER-SPACE calculation, the time dependent TH conditions are added to calculate minimum DNBR.

2.4 Analysis Results

The results of analysis using CHASER and CHASER-SPACE code systems were compared. It was assumed that the single CEA was fully withdrawn around 240 seconds.

Figure 2 and 3 show core average power and coolant temperature behavior, respectively. The core average power of CHASER-SPACE was evaluated lower than CHASER. In CHASER simulation, constant value of core inlet temperature is assumed as boundary condition. Whereas in CHASER-SPACE simulation, increase of core inlet temperature is applied, so the negative reactivity insertion induced by moderator feedback is relatively larger than that of CHASER.

Figure 4 and 5 show the departure from nucleate boiling ratio (DNBR) result which is the percentage of DNBR decrease compared to initial DNBR for each assembly. The DNBR in the most limiting assembly (G7) of CHASER and CHASER-SPACE decreased by 74.7% and 72.4%, respectively. The reason why DNBR decreased less in CHASER-SPACE is because of the difference in the core average power.

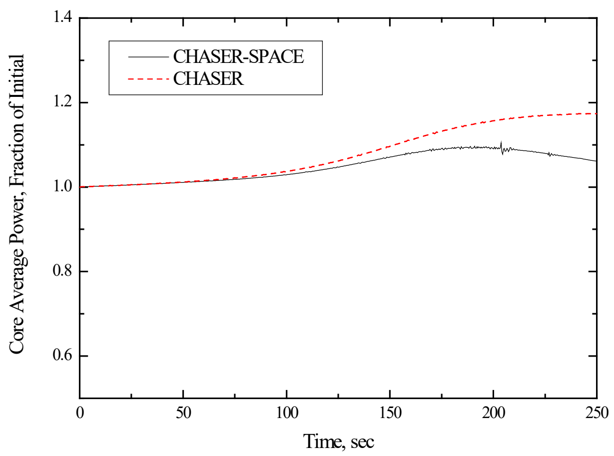

Fig. 2. Core Average Power vs. Time

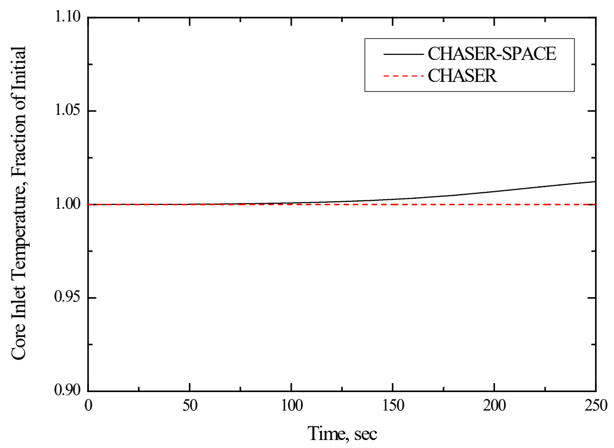

Fig. 3. Core Inlet Temperature vs. Time

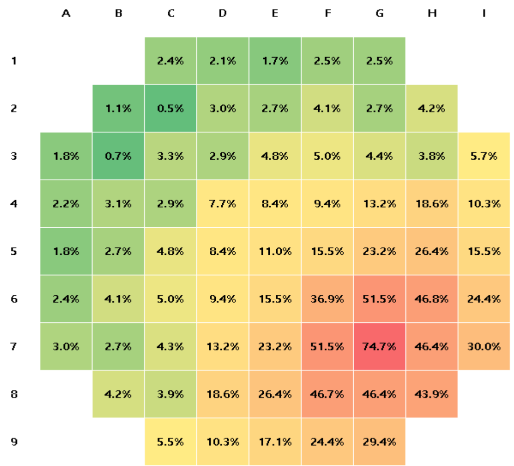

Fig. 4. Percentage of DNBR decrease compared to initial DNBR for Each Fuel Assembly (CHASER)

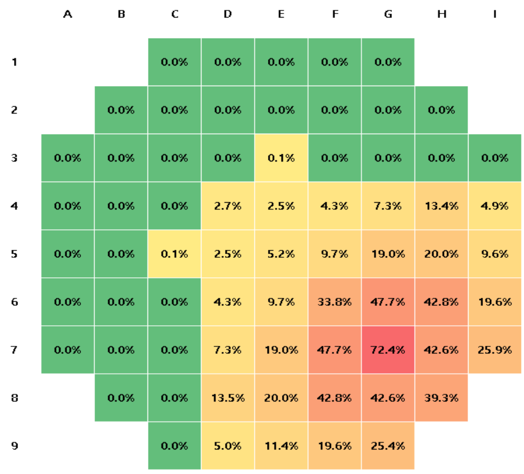

Fig. 5. Percentage of DNBR decrease compared to initial DNBR for Each Fuel Assembly (CHASER-SPACE)

3. Conclusions

The study on SCEAW event in a typical SMR was conducted using the 3D core simulation system. In both of CHASER and CHASER-SPACE, it was evaluated that the DNBR of the most limiting assembly decreased by more than 70% compared to the initial DNBR without appropriate reactor trip to protect SCEAW event.

Additionally, since this analysis was performed based on best-estimated methodology, the amount of DNBR decrease can be increased if additional conservative assumptions is applied.

REFERENCES

[1] S. K. Sung and J. W. Park et al., CEA Ejection Accident Analysis Methodology based on 3-Dimensional Core Simulation for APR1400, Topical Report by KNF, June 2021.

[2] J.W. Park and G.T. Park et al., Development of safety analysis code system based on 3-Demensional Core Simulation, The Eleventh Korea-Japan Symposium on Nuclear Thermal Hydraulics and Safety, November 2018.