

# Application of Multi-Dimensional Core Transient Analysis for RCP Locked Rotor Accident

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## 1. Introduction

A single reactor coolant pump (RCP) locked rotor (LR) accident could be caused by seizure of the upper or lower thrust-journal bearings. Following the seizing of a shaft, the core coolant flow rate rapidly decreases to its value corresponding to 3 RCPs operating. In case of APR1400 plant, RCP trip is assumed to be occurred right after reactor trip. This assumption results in continuous core flow reduction during transient. This coolant flow rate reduction causes an increase of the coolant temperature/quality and may result in some fuel pins experiencing departure from nucleate boiling (DNB). This accident is protected by the low RCS flow reactor trip which activated in a very short time.

KNF/KHNP currently uses the LR methodology using SPACE (safety and performance analysis code for nuclear power plants) [1]. The method consists of core power calculation with point kinetics model and hot pin behavior calculation with the detailed fuel model. The point kinetics model with conservative assumptions makes more severe results compared to realistic core power behavior. Therefore, it is required to use 3D kinetics model at the core power calculation. Recently, the topical methodology of CEA ejection accident analysis for APR1400 plant has been submitted, which uses CHASER (a coupling code for 3-dimensional core analysis) [2] developed by KNF, and approved by KOREA institute of nuclear safety (KINS) [3].

This paper presents the application of the LR analysis methodology based on CHASER 3D kinetics model for core power calculation instead of using SPACE point kinetics model. In the present study, the current hot pin behavior calculation logic using SPACE code is not changed to maintain the conservatism of the current hot pin calculation. All the evaluations are simulated for an APR1400 plant with PLUS7<sup>TM</sup> fuel.

## 2. Methods and Results

### 2.1 Coupling Scheme and Calculation Flow Chart

This methodology consists of two steps. Figure 1 shows main flow chart of the LR analysis including code coupling scheme for pin-by-pin level power behavior transient.

For the pin-by-pin power behavior (step 1), CHASER controls the results of core analysis code using message passing interface (MPI). ASTRA (3D core neutron kinetics code) calculates nuclear power and FROST (fuel performance analysis) calculates fuel temperature and

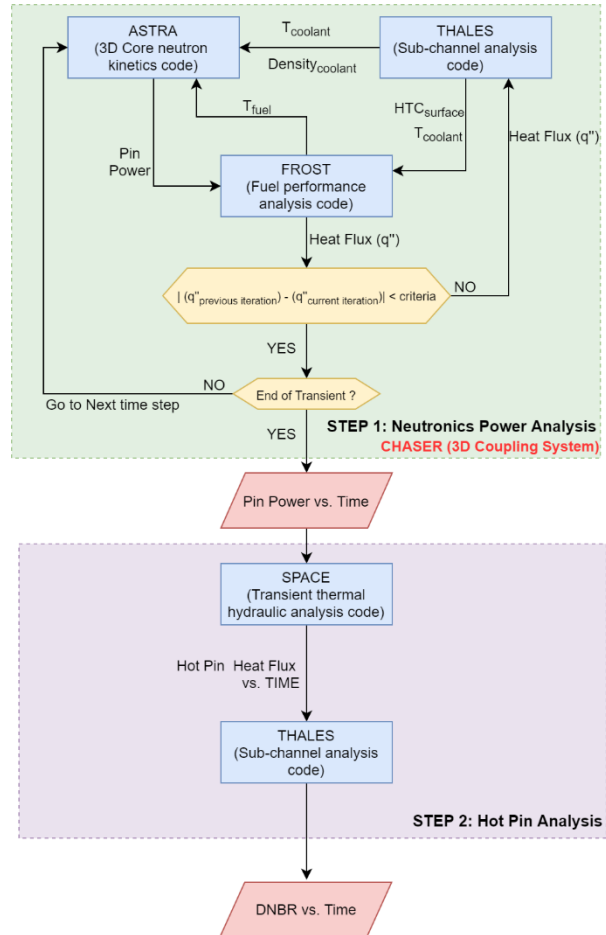


Figure 1. Main flow chart of the LR analysis

THALES (subchannel analysis code) calculates coolant temperature/density. 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 the FROST which calculates heat flux at the fuel outside surface. It is transferred to the THALES which calculates coolant temperature, density and heat transfer coefficient. They are transferred to the ASTRA and the FROST. ASTRA/FROST/THALES 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. When heat flux difference between previous iteration and current iteration is smaller than the criteria, the next time step calculation is conducted. Otherwise the additional iterated calculation is performed.

The hot pin behavior (step 2) is conducted after the end of step 1. The hot pin power behavior with time is

transferred from CHASER to SPACE code and it calculates fuel surface heat flux during the transient. The modified NFI model with high fuel burnup for fuel thermal conductivity and minimum value for fuel-clad gap conductance are assumed to delay the dropping the heat flux after scram. THALES calculates DNBR using KCE-1 CHF correlation with the transferred heat flux. This calculation logic and assumptions from hot pin power to DNBR are same with the current methodology using RETRAN or SPACE code.

### 2.2 Axial Power Distribution Grouping

The current method (point kinetics) cannot consider APD (axial power distribution) changes during the core power transient. Therefore, 3D kinetics model is introduced to calculate power distribution change by thermal hydraulic condition changes and CEA movements. Sensitivity studies for APDs are conducted in order to evaluate the DNBR result variations by changing of initial APD assumptions. Figure 2 shows the extremely various APDs for 0.1, 0.2, 0.3 ASI (axial shape index)<sup>1</sup> within a band ( $\pm 0.03$ ) which are generated by xenon oscillation. Since most APDs are similar to others, the shape classification model [4] is used to reduce the number of analysis cases. Figure 3 shows the representative APDs.

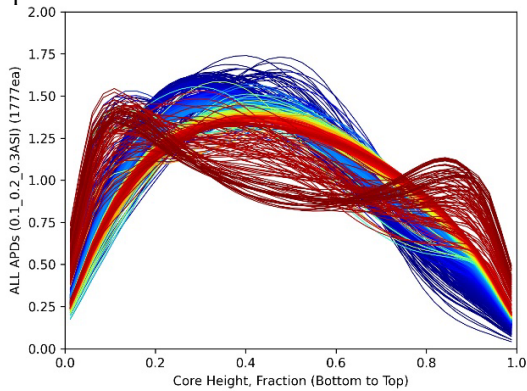


Figure 2. APDs for 0.1, 0.2, 0.3 ASI

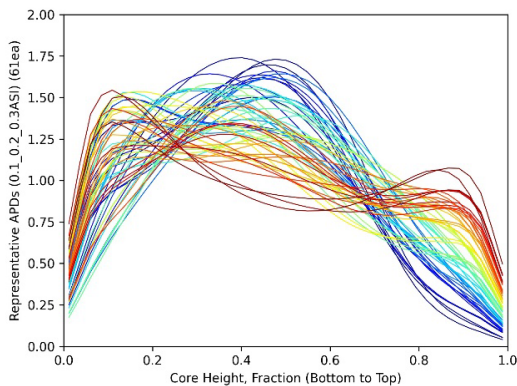


Figure 3. Representative APDs

<sup>1</sup> ASI = ((lower power) – (upper power)) / ((lower power) + (upper power))

### 2.3 Analysis Results

Table 1 and Figure 4 shows minimum DNBR results between the 3D kinetics (CHASER, 3D) and the point kinetics (SPACE, 0D) methodology. Initial conditions and analysis assumptions between 3D and 0D are the same except analysis model.

DNBR results are significantly improved by using CHASER(3D). This trend is caused by faster core power reduction and power distribution change due to the 3D effect.

Figure 5 shows core average power behaviors for CHASER (3D) and SPACE(0D) assuming the same ASI (0.1 ASI). The faster core power reduction is due to the explicit modeling of neutron absorption by CEA insertion in CHASER(3D). SPACE(0D) for core power calculation assumes the same negative reactivity insertion data after reactor trip for all APD cases. The negative reactivity data with CEA insertion length is calculated using ASTRA. It is calculated with bottom skewed APD (0.3ASI) to delay the core power reduction and cover all APD cases.

Figure 6 and 7 show the radial and axial core power distribution changes by CHASER(3D) due to core flow reduction and CEA insertion. Core flow reduction results in the radial power peak decrease before CEA insertion. CEA insertion leads to APD movements to the bottom. However, SPACE(0D) cannot consider power distribution change during transient.

Figure 8 shows DNBR with time for the limiting case of 0.1 ASI. The faster core power reduction and power distribution change result in higher minimum DNBR and earlier DNBR time than the results of SPACE(0D).

Table 1. DNBR Results for CHASER(3D) and SPACE(0D)

	0.1ASI		0.2ASI		0.3ASI	
	C(3D)	S(0D)	C(3D)	S(0D)	C(3D)	S(0D)
AVG	1.318	1.069	1.382	1.155	1.404	1.277
S. Dev. <sup>2</sup>	0.022	0.078	0.026	0.107	0.006	0.087
MIN	1.281	0.958	1.344	1.006	1.392	1.133

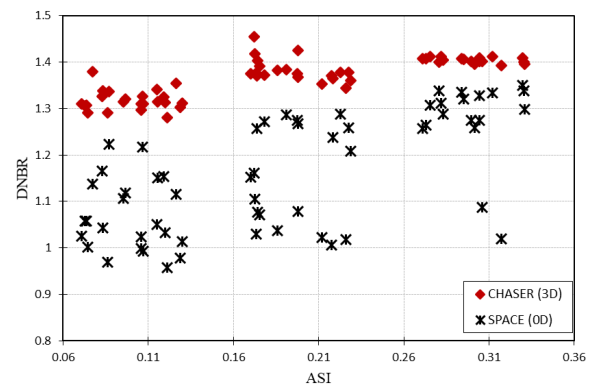


Figure 4. DNBR vs. ASI

<sup>2</sup> S. Dev.: Standard deviation

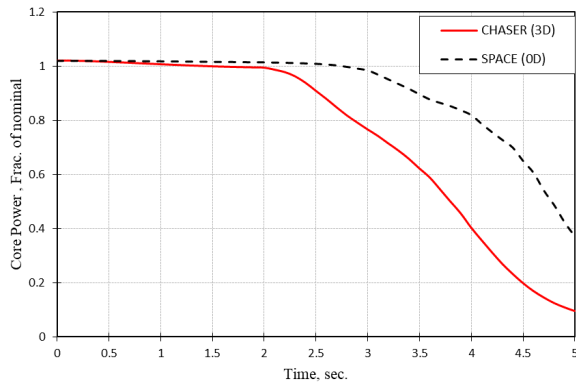


Figure 5. Core Power vs. Time

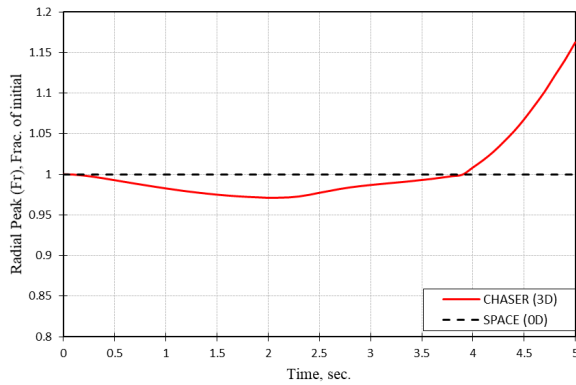


Figure 6. Radial Peak (FR) vs. Time

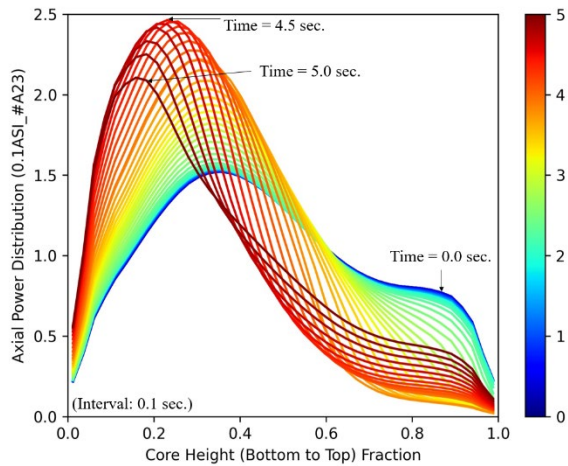


Figure 7. APD (CHASER 3D) vs. Time

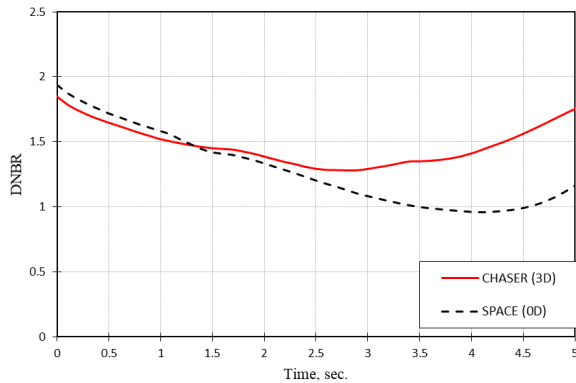


Figure 8. DNBR vs. Time

### 3. Conclusions

The LR analysis was conducted using the 3D neutron kinetics system (CHASER) for the pin-by-pin power behavior calculation and the transient thermal hydraulic analysis code (SPACE) for the hot pin behavior calculation. CHASER calculates faster core power reduction and power distribution changes due to the explicit modeling of neutron absorption by CEA insertion and thermal hydraulic condition changes. In conclusion, this 3D kinetics model results in more safety margin for DNBR than the current point kinetics model.

### REFERENCES

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