Transactions of the Korean Nuclear Society Autumn Meeting
Jeju, Korea, May 12-13, 2016

3-D rod ejection analysis using a conservative methodology

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1. Introduction

The point kinetics model which simplifies the core phenomena and physical specifications is used for the conventional rod ejection accident analysis. The point kinetics model is convenient to assume conservative core parameters but this simplification loses large amount of safety margin. More realistic and detailed 3-D rod ejection analysis methodology using the CHASER system can gain safety margin.

The CHASER coupling system has been set up using the message passing interface (MPI) method. The CHASER system couples the three-dimensional core neutron kinetics code ASTRA, the sub-channel analysis code THALES and the fuel performance analysis code FROST. The validation study for the CHASER system is addressed using the NEACRP three-dimensional PWR core transient benchmark problem [1].

A series of conservative rod ejection analyses for the APR1400 type plant is performed for both hot full power (HFP) and hot zero power (HZP) conditions to determine the most limiting cases. The conservative rod ejection analysis methodology is designed to properly consider important phenomena and physical parameters.

2. Methods and Results

2.1. KNF 3-D rod ejection analysis methodology

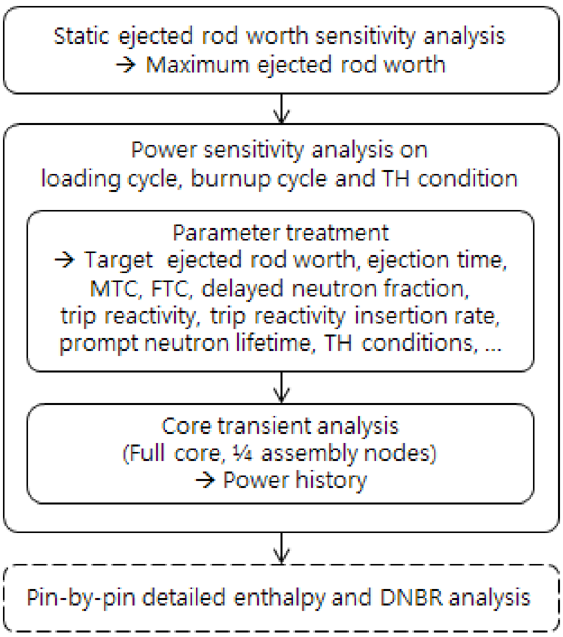

Fig. 1. KNF 3-D rod ejection analysis methodology

It is well known that the most important parameter to the power increase in the rod ejection transient analysis is ejected control rod worth. Maximum ejected rod worth and the core conditions are derived from the static ejected rod worth sensitivity analysis. Other core parameters are conservatively treated to meet the target values. Limiting cases for the HFP and HZP conditions are derived from the peak power sensitivity study on core loading cycle and burnup cycle. The overall process is schematized in Fig. 1.

2.2. Static ejected rod worth sensitivity analysis

Static ejected rod worth sensitivity analysis for various conditions is performed. The sensitivity parameters include operating power, core loading cycle, rod inserted depletion model, burnup cycle, ejected control rod, and part strength control rod insertion.

The original position of ejected control rod before ejection is assumed to be power dependent insertion limit (PDIL), the possible maximum insertion during plant operation. Axial xenon distribution corresponding to the most top skewed power shape which leads the maximum rod worth is assumed [2].

Final ejected rod worth values are multiplied for conservatism considering 10% of azimuthal tile allowance and 30% of code uncertainty. Also the control rod inserted depletion assumption combined with top skewed power shape derives highly conservative result on ejected rod worth.

The limiting control rod worth values for HFP and HZP derived from the sensitivity analysis are presented in Fig. 2.

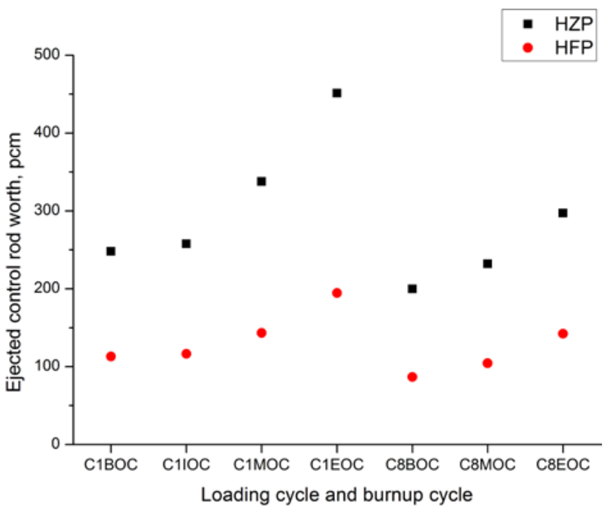

Fig. 2. Maximum rod worth by core cycle

2.3. The method to treat important core parameters

US NRC presents important parameters for plant transient analysis of rod ejection accident [3]. These parameters are ejected control rod worth, rate of reactivity insertion, moderator feedback, fuel temperature feedback, delayed neutron fraction, reactor trip reactivity, fuel cycle design, cladding to coolant heat transfer coefficient, fuel heat capacity, pellet energy deposition, pellet radial power distribution and pin peaking factors.

For the 3-D rod ejection analysis, KNF conservatively treats ejected rod worth, rod ejection time, MTC, FTC, delayed neutron fraction, reactor trip reactivity and trip reactivity insertion rate. Cross section modification is used to adjust ejected rod worth, MTC, FTC and scram worth.

Uncertainty related to the fuel cycle design is considered by the loading cycle and burnup cycle sensitivity analysis. Other heat transfer related parameters are realistically modeled in 3-D CHASER coupling system.

2.4. Sensitivity analysis for HFP condition

Power sensitivity study on fuel loading cycle and burnup cycle is performed to derive the limiting condition.

As in Fig. 3, the average core power results from the best estimate calculations without core parameter treatment shows that the power behavior of loading cycle 1 bounds loading cycle 8.

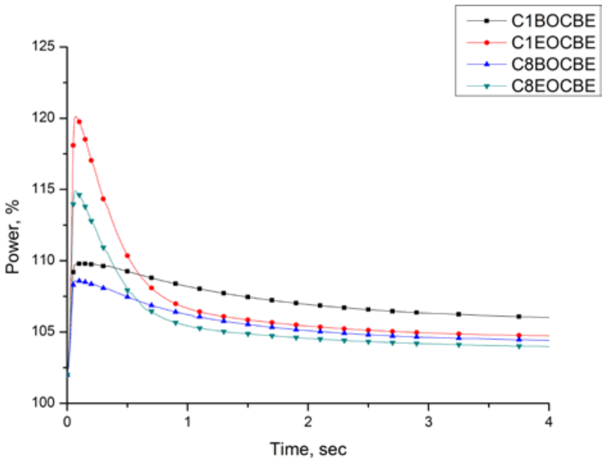

Fig. 3. Power transient of BE cases, C1/C8 and BOC/EOC

The conservative directions of kinetic parameters and reactivity coefficients are examined by adding parameter treatment for EOC case of loading cycle 1. Average core power results are presented in Fig. 4.

EOC case has a large ejected rod worth and the most negative MTC, and BOC case has a smaller ejected rod worth and the least negative MTC. This leads to a higher peak power of EOC case and more cumulative energy generation of BOC case. Therefore both BOC and EOC cases are checked by detailed pin-by-pin enthalpy and DNBR calculation. The average core power results of limiting BOC and EOC cases are presented in Fig. 5.

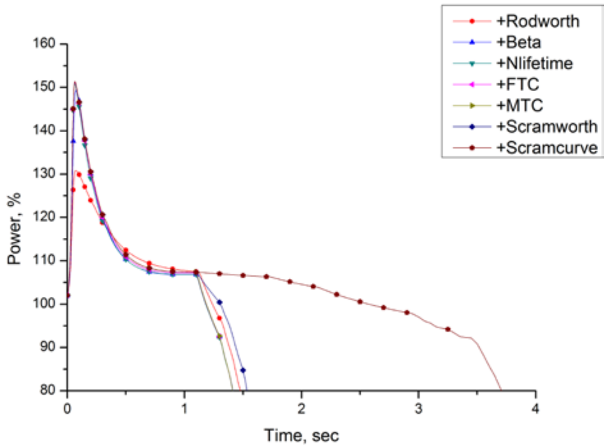

Fig. 4. Power transient by adding parameter treatment, HFP

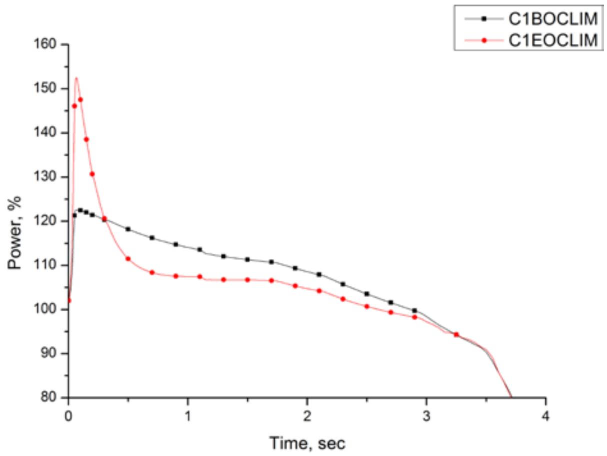

Fig. 5. Power transient of limiting cases, HFP

2.5. Sensitivity analysis for HZP condition

The bounding EOC case of loading cycle 1 is shown to be limiting because only this case showed ejected control rod worth larger than 1$. Other cases did not show meaningful power increase as in Fig. 6.

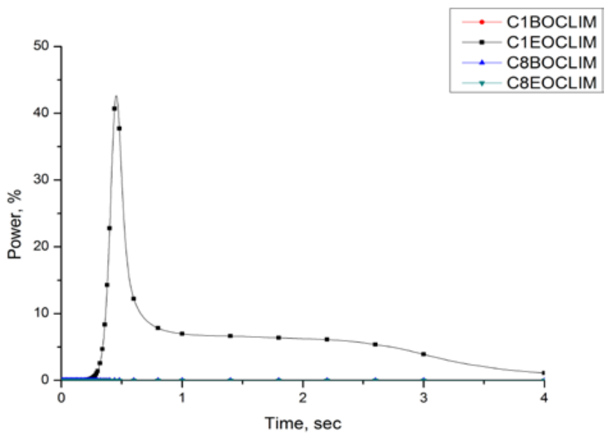

Fig. 6. Power transient by adding parameter treatment, HZP

The average core power results of EOC cases of loading cycle 1 by adding kinetic parameters and reactivity coefficients treatments are presented in Fig. 7.

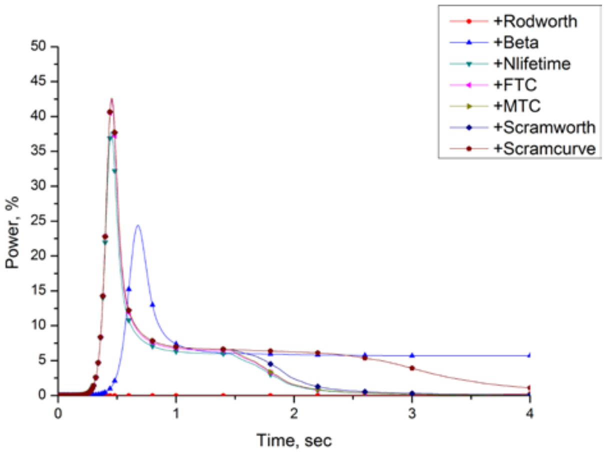

Fig. 7. Power transient by adding parameter treatment, HZP

EOC case of loading cycle 8 having 1.3$ of virtual ejected rod worth is additionally analyzed to evaluate pellet to cladding mechanical interaction (PCMI) of high burnup fuel. Also a larger ejected rod worth of 1.3$ is assumed for EOC case of loading cycle 1 to evaluate DNBR and enthalpy for a more severe condition. The average core power results are presented in Fig. 8.

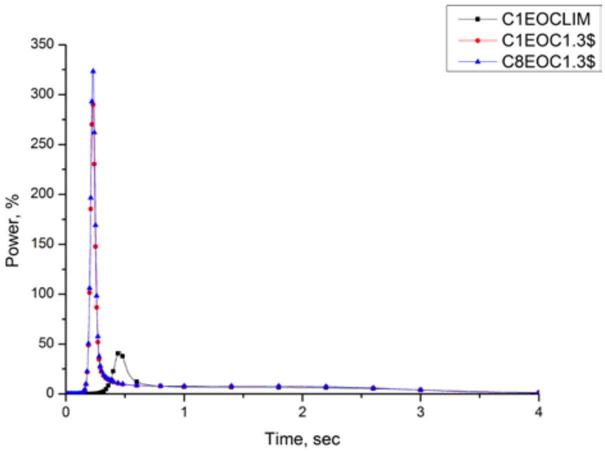

Fig. 8. Power transient of 1.3$ cases, HZP

3. Conclusions

The rod ejection accident of the APR1400 type plant is analyzed by deriving conservative bounding cases with respect to the power increase for HFP and HZP conditions using the 3-D CHASER system.

The most limiting HFP cases are derived as BOC and EOC conditions of loading cycle 1. The transient pin power history generated from these cases will be linked to the detailed pin-by-pin DNBR and enthalpy calculation to evaluate fuel integrity.

The most limiting HZP case is derived as EOC condition of loading cycle 1 which has the maximum ejected control rod worth. More severe conditions having 1.3$ of ejected rod worth for EOC cases of loading cycle 1 and 8 are calculated to evaluate detailed pin DNBR, enthalpy and PCMI.

3-D rod ejection analysis is performed by determining limiting rod ejection cases of an APR1400 type plant using the CHASER system in a conservative bounding analysis approach. Still assuring the conservatism, the safety margin will be obtained when the 3-D rod ejection analysis methodology is used for the reactor design.

REFERENCES

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