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Generation of a Cycle Dependant Core Model for a Domestic PWR Simulator

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1. Introduction

It is requested that the core model of the domestic pressurized water reactor (PWR) simulators be changed to a real reactor core reload one. However a change of the core model is very difficult, since the core model of the domestic simulators has been imported from foreign vendors. The difficulties originate from the simplified methodology of the core calculation model for the fast response, so a huge amount of adjustment factors are required for a simulation to obtain similar results to the real reactor response. As a result, the domestic PWR simulators have cycle difference problems because the cycle dependent core data to change the core models are not provided properly.

In order to solve the problems, R-MASTER [1] was developed by applying a real time core analysis methodology. Also, ARCADIS and DHCGEN [2] were developed for the automatic generation of a cycle dependent core model for the real time core analysis.

And thus the cycle dependent core data to change the core model can be standardized, which makes it possible to generate a cycle dependent core model automatically. It also can minimize the usage of adjustment factors in the core model.

2. Methods and Results

2.1 Procedure for Core Model Generation

The Procedure to generate the cycle dependent core model for the simulator is composed of R-MASTER, ARCADIS and DHCGEN as shown in Figure 1.

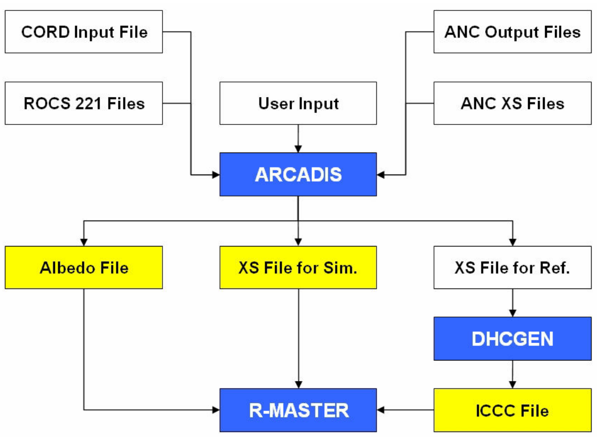

Figure 1. The procedure to generate the simulator core model

For a 4-cycle real time core analysis, ICCC (Interface Coupling Coefficient Correction) methodology [3] was developed. It solves a 2-group 3-dimensional space-time dependent neutron diffusion equation, by using the coarse mesh finite difference method with a tabulated interface coupling coefficient correction instead of performing a higher order nodal calculation. Developing R-MASTER based on this methodology, for an easy preparation of the cycle dependent core data is possible mainly due to the geometrical consistency of the core design as well as an improvement of the accuracy.

The core design and analysis for two types of PWRs which are operated in Korea is performed by the DIT/ ROCS (CE) and PHOENIX/ANC (WEC) nuclear design systems. In order to generate the cross sections for a real time core analysis, ARCADIS (ANC and ROCS Cross-section And Discontinuity factor Interface System) performs the automatic generation of the functionalized node-wise cross sections from the two nuclear design systems. DHCGEN carries out a 3-dimensional higher order nodal calculation with the reference node-wise cross sections produced by ARCADIS and it generates the interface coupling coefficients.

2.2 Cross Section Functionalization

The node-wise cross sections used in the core analysis are usually determined by the core parameters such as the burnup, soluble boron concentration, fuel temperature, and the moderator density. Considering the movement of the control rods and the change of xenon, the node-wise cross sections for the PWR simulator are functionalized by the following formula.

$$
\begin{aligned}
\Sigma = {} & \hat{\Sigma}(B_0,T_{f0},D_{m0}) + \frac{\partial\hat{\Sigma}}{\partial B}\Delta B + \frac{\partial\hat{\Sigma}}{\partial\sqrt{T_f}}\Delta\sqrt{T_f} + \frac{\partial\hat{\Sigma}}{\partial D_m}\Delta D_m \\
& + \Delta\Sigma_{CR}(B_0,T_{f0},D_{m0}) + \frac{\partial\Delta\Sigma_{CR}}{\partial B}\Delta B + \frac{\partial\Delta\Sigma_{CR}}{\partial\sqrt{T_f}}\Delta\sqrt{T_f} + \frac{\partial\Delta\Sigma_{CR}}{\partial D_m}\Delta D_m \\
& + N_B\left[\sigma_B(B_0,T_{f0},D_{m0}) + \frac{\partial\sigma_B}{\partial B}\Delta B + \frac{\partial\sigma_B}{\partial\sqrt{T_f}}\Delta\sqrt{T_f} + \frac{\partial\sigma_B}{\partial D_m}\Delta D_m\right] \\
& + N_{Xe}\left[\sigma_{Xe}(B_0,T_{f0},D_{m0}) + \frac{\partial\sigma_{Xe}}{\partial B}\Delta B + \frac{\partial\sigma_{Xe}}{\partial\sqrt{T_f}}\Delta\sqrt{T_f} + \frac{\partial\sigma_{Xe}}{\partial D_m}\Delta D_m\right]
\end{aligned}
$$

$$\hat{\Sigma} = \Sigma - N_B\sigma_B - N_{Xe}\sigma_{Xe}$$

$$\Delta\Sigma_{CR} = \Sigma(rodded) - \Sigma(unrodded)$$

where B, T_f, and D_m mean the soluble boron concentration, fuel temperature and moderator density, and the subscripts B and Xe denote B-10 in a soluble boron and xenon in each node, respectively.

In order to analyze the change of the cross section applied to real core design, the mask points according to the changes of the boron concentration, the core power, and the moderator temperature were selected as shown in Table 1.

Table 1. The mask points used in ROCS and ANC

Mask Point	Core Condition		Calculation Condition
1	Base	ARO	Xe and T_f Ref.
2		ARI	
3	Ref.	ARO	Boron and D_m Ref.
4		ARI	
5	High ppm	ARO	Boron Variation 1
6		ARI	
7	Low ppm	ARO	Boron Variation 2
8		ARI	
9	High Power	ARO	T_f Variation 1
10		ARI	
11	Low Power	ARO	T_f Variation 2
12		ARI	
13	D_m 1	ARO	D_m Variation 1
14		ARI	
..	….	….	….
N+12	D_m N	ARO	D_m Variation N
N+13		ARI	

N : Number of D_m Variation

2.3 Calculational Results

Using the ARCADIS and DHCGEN, we generated the core models for five domestic PWR simulators. R-MASTER calculations were performed with the core models. The R-MASTER calculational results such as the core reactivity, radial and axial power distribution and the control bank worth are compared with those of the ROCS or ANC as shown in Table 2.

Table 2. Summary of the maximum differences

NPP & Cycle	Condition	Core Reactivity (pcm)	Radial Power* (%)	Control Bank Worth (%)
Y3C09[1)]	Mask Point	102.4	0.29	1.40
	Feedback	17.3	0.72	-
U3C07[2)]	Mask Point	88.9	0.59	1.30
	Feedback	20.5	0.67	-
Y1C16[3)]	Mask Point	93.2	0.11	4.96
	Feedback	29.0	0.56	-
U1C14[4)]	Mask Point	88.4	0.16	5.57
	Feedback	44.0	0.69	-
K2C20[5)]	Mask Point	63.9	0.08	3.91
	Feedback	54.0	0.62	-

* P>1.0

The maximum differences for the core reactivity of 102.4 pcm, the radial power distribution of 0.72 % and the individual bank worth of 5.57 % were estimated. These results satisfy the functional requirements of a simulator core model of which the criteria are a core reactivity of 500 pcm, a radial power distribution of 5 % and a control bank worth of 10 %. As shown in Figure 2, the axial power distributions of R-MASTER are very consistent with those of ROCS or ANC.

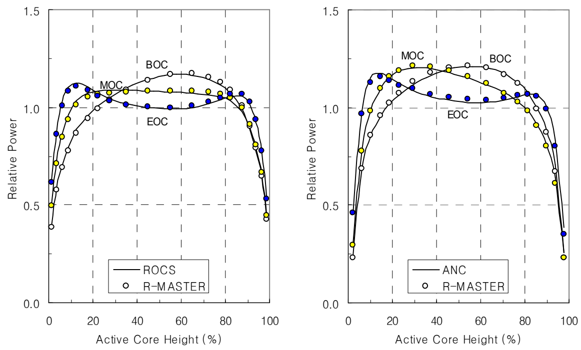

Figure 2. Comparison of axial power distribution of Ulchin unit 3 cycle 7 and Younggwang unit 1 cycle 16 (HFP, ARO)

The above results show that the procedure by ARCADIS, DHCGEN and R-MASTER is working appropriately and the latest cycle core models for all the domestic PWR simulators are available.

3. Conclusion

In order to solve the cycle difference problems of a domestic PWR simulator, we developed a methodology and software to perform a 4-cycle real time core calculation. And we developed a procedure to generate the cycle dependent core model and we then generated the core models for five domestic PWR simulators. The results show that the latest cycle core models for all the domestic PWR simulators are available.

REFERENCES

[1] J. S. Song, "Improvement of Cycle Dependent Core Model for NPP Simulator," KAERI/RR-2638/2005, KAERI, 2006.
[2] B. S. Koo *et al.*, "Development of Nuclear Data Transmittal System for Real Time Core Analysis of PWR Simulator," Proc. of KNS Spring Meeting, Gyeongju, Korea, 2004.
[3] H. Y. Kim *et al.*, "Coarse Mesh Finite Difference Method with Interface Coupling Coefficient Correction for Real Time Analysis of Space-Time Dependent Neutron Diffusion Equation," Proc. of KNS Autumn Meeting, Yongpyong, Korea, 2003.

1) Younggwang unit 3 cycle 9 (CE)
2) Ulchin unit 3 cycle 7 (CE)
3) Younggwang unit 1 cycle 16 (WEC)
4) Ulchin unit 1 cycle 14 (WEC)
5) Kori unit 2 cycle 20 (WEC)