Comparison of SMR Core Characteristic Parameters by DeCART and DeCART2D/MASTER

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1. Introduction

The SMR core nuclear design procedure at KAERI is based on the two-step procedure, in that it consists of group constants generation through fuel assembly calculation and three-dimensional core calculation using the generated group constants library. In KAERI SMR core design system, the group constants generation is performed by newly developed DeCART2D[1] and the three-dimensional (3D) core nodal calculation is performed by MASTER[2]. To verify this SMR core design system, the more rigorous code, namely DeCART[3] can be used. DeCART can perform high-fidelity 3D whole core transport calculation for rectangular and hexagonal cores. Effort to validate the solution capability of DeCART has been made by solving the VERA benchmark problem[4] which is a realistic core benchmark problem.

In this paper, an attempt is made to verify the DeCART2D/MASTER core design system with the DeCART code by comparing the calculation results of core characteristic parameters of a typical SMR core. Prior to the detailed verification tasks, reference calculations were made using McCARD[6], a Monte Carlo method code, to make sure the core modeling and calculation conditions of DeCART and DeCART2D/MASTER are well matched. After that, the multiplication factor, power distribution, control rod worth and MTC (Moderator Temperature Coefficient) were compared at BOC state. Finally depletion calculation was performed and core characteristics parameters such as critical boron concentration (CBC), peaking factors (F_q, F_r) and axial offset (AO) were compared.

2. Calculation Condition and Core Models

Three codes in total, i.e., MASTER, DeCART, and McCARD, were used to calculate the core characteristic parameters. Representative solution methodology of each code differs from each other. One is Monte Carlo (McCARD), another is MOC (DeCART), and the other is Nodal diffusion method (MASTER). Comparison calculation between three codes using a reference core state was performed to match the core model. In case of the McCARD code, the depletion and TH feedback calculation were somewhat difficult to adjust each model. Thus the DeCART and MASTER codes were used to verify the target core model.

2.1. Calculation Condition

For the comparison calculation, 3 codes had their respective calculation conditions. McCARD used full core model and continuous energy ENDF/B-VII.1 library. For a 3D calculation, 1,000,000 particles were simulated every each cycle. As the number of both inactive and active cycles, one hundred was set.

DeCART used octant core model and 47 group ENDF/B-VII.1 library. DeCART calculation is performed with ray option, ray spacing of 0.02cm and 8/2 azimuthal/polar angles in the octant of the solid angle sphere and P0 scattering MOC solver. Fuel temperature model was same as the MASTER code. For axial nodal, P3 LPEN method was used.

MASTER used full core model and 2 group library made by the DeCART2D code. The Source Expansion Nodal Method (SENM) was used to solve the target core problem.

2.2. The Core Model

The target core problem is a rectangular shaped one. It has two enrichment types of fuel assemblies. Low enriched fuels are at the core center positions while high enriched fuels are at the peripheral positions of the core. Both fuel assembly types have burnable absorbers (BAs) for reactivity balance and peaking control. For each fuel assembly, the fuel pins, BA pins and guide tubes were explicitly modeled. Figure 1 illustrates the schematic core geometry.

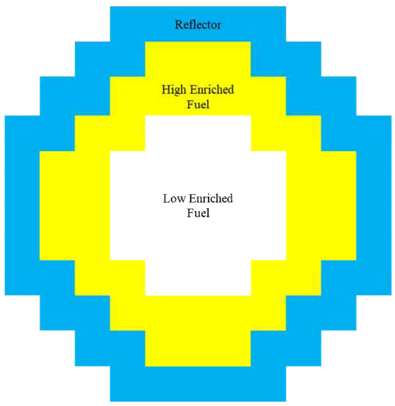

Fig. 1. Schematic core geometry.

3. Calculation Results and Assessments

To confirm that the calculation conditions and models of DeCART and MASTER match well, the results of DeCART and MASTER for the reference core state were compared with the counterparts of the McCARD code. After that, core characteristic parameters calculations were carried out at BOC condition using the DeCART and MASTER codes: compared core characteristic parameters at BOC condition including the multiplication factor (k_{eff}), radial and axial power distributions, control rod worths and the MTC. Additional parameters such as the peaking factors (F_q, F_r), CBC and the Axial Offsets (AOs) were compared as the core depletes.

3.1. Comparison Results with McCARD

The 3D steady state calculation was performed with fixed temperature condition (Fuel : 600°C, Cladding : 340°C, Moderator : 310°C), 500 ppm of boron concentration and no xenon condition. The following figures and tables show the comparison results of the k_{eff} and power distributions based on the McCARD results.

Table I: Comparison Results of k_{eff}

Code	Δk_{eff} (pcm)	ASM RMS Err	ASM Max Err
DeCART	64	0.70%	1.13%
MASTER	-94	1.01%	1.74%

1.13 1.74	0.67 1.19	0.73 0.63	0.32 -1.12	-1.09 -1.24
	0.82 1.08	0.03 -0.21	-0.15 -1.13	-1.07 0.41
		0.20 -0.46	-0.15 0.89	

x.xx x.xx	Err. DeCART (%) Err. MASTER (%)

Fig. 2. Comparison results of radial power distributions.

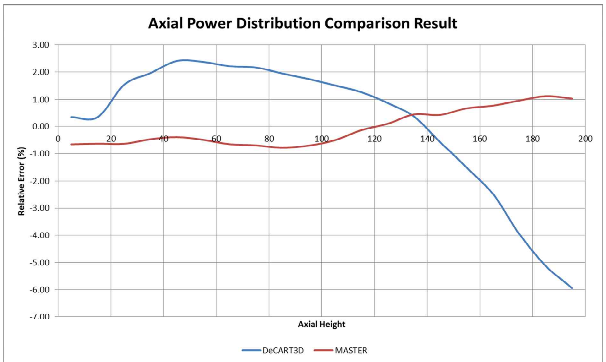

Fig. 3. Axial power distribution comparison result.

As shown in Figures 2 and 3, the relative errors in power distributions are small enough to verify that the core models and condition are well matched.

3.2. Core Characteristic Parameter Calculation at BOC Condition

At BOC condition, the k_{eff}, power distributions and control rod worths were calculated and compared. For all calculations, the TH feedback is included, and xenon effect is considered only for control rod worths calculation. Table II and Figure 4 show that the k_{eff} and radial power comparison result on the basis of the DeCART results.

Table II: Comparison Result of k_{eff} at BOC Condition

Code	Δk_{eff} (pcm)	ASM RMS Err	ASM Max Err
MASTER	-121	1.54%	2.77%

2.77	1.54	1.23	-1.55	-1.51
	2.63	0.76	-1.37	-0.30
		-0.59	-0.21	

x.xx	Err. MASTER (%)

Fig. 4. Radial power distributions comparison at BOC condition.

As shown in Table II and Figure 4, discrepancies between the DeCART and MASTER were small in both the k_{eff} and the power distributions. In Figure 4, the power distributions show tilted error between the two codes.

The control rod worths calculations were performed with equilibrium xenon condition. There are three types of control rod groups (S, R1, R2) and each group is fully inserted in the core sequentially. Table III shows the rod worths comparisons based on the results of DeCART. 'Grp.' and 'Acc.' denote group worth and accumulated worth, respectively.

Table III: Results of the Rod Worth Calculations

ID	Diff. Grp. (%)	Diff. Acc. (%)
R1	0.03	0.03
R2	-0.03	0.00
S	-0.11	-0.11

The reactivity difference attributed by full insertion of a control rod was assumed as the rod worth. The worth gained by all the inserted control rods was assumed as 'accumulated' worth and the reactivity difference between a certain state and the previous state was assumed as 'group' worth. Agreement between the DeCART and MASTER is good in all cases.

MTC calculation was done with four different conditions of xenon and power state, that include no xenon, equilibrium xenon, HZP (Hot Zero Power), CZP (Cold Zero Power). Table IV shows the MTC difference on the basis of the DeCART. Both codes show good agreement of less than about 2 pcm/°C diffenrece.

Table IV: Results of MTC Calculation

	Diff. (pcm/°C)
EqXe	2.1
NoXe	-0.5
HZP	-1.3
CZP	0.8

3.3. Core Depletion Calculation for Cycle 1

In order to obtain the critical boron concentration (CBC) curve and cycle length, a depletion calculation was performed with both codes. The core was depleted with HFP, xenon equilibrium condition. The final time step for depletion step was assumed as 870 effective full power days (EFPDs). Figure 5 illustrates the boron-letdown curve and CBC difference.

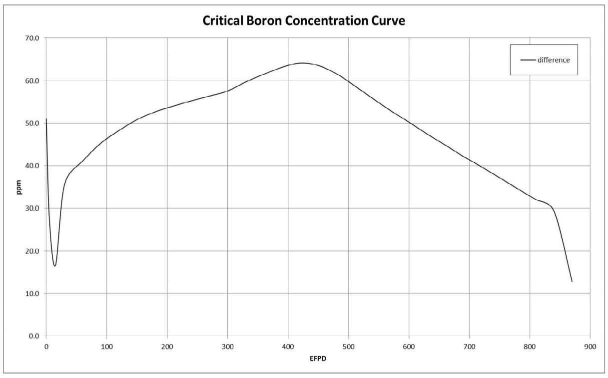

Fig. 5. Boron-letdown curve with CBC difference.

The CBC difference reaches maximum of 64 ppm at the BA burnout time near 400 EFPDs. Except BA burnout time, both codes shows good agreement of less than 45 ppm. The DeCART returns 6 days of shorter cycle length than the MASTER, since it can explicitly treat gadolinia burnable absorbers with rigorous isotopic chain. With this depletion results, power distributions, peaking factors (F_q, F_r) and AOs were obtained as well. Figures 6 and 7 show the power errors of MASTER compared with the result of DeCART for 5 EFPD and 300 EFPD.

3.62	3.21	1.07	-1.53	-1.39
	2.28	0.75	-1.33	-0.17
		-0.62	-0.15	
x.xx	Err. MASTER (%)			

Fig. 6. Comparison of radial power distributions at 5 EFPDs.

2.78	2.33	0.81	-1.49	-1.02
	1.78	0.59	-1.27	-0.15
		-0.71	-0.24	
x.xx	Err. MASTER (%)			

Fig. 7. Comparison of radial power distributions at 300 EFPDs.

Similarly to the result shown in Figure 4, same power tilting trend appears in the depleted core condition with maximum power error at the center assembly. The RMS error is 1.83% and 1.44% for 5 and 300 EFPDs, respectively.

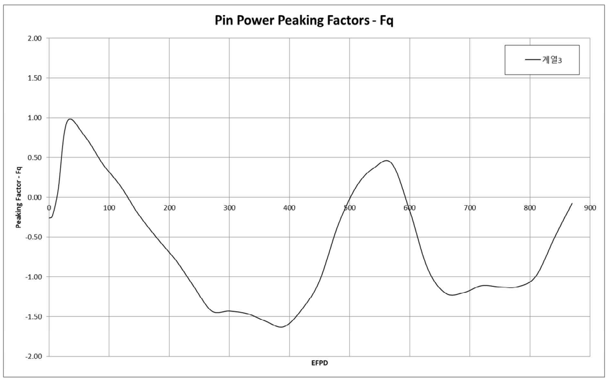

Fig. 8. Peaking factor comparison result - F_q.

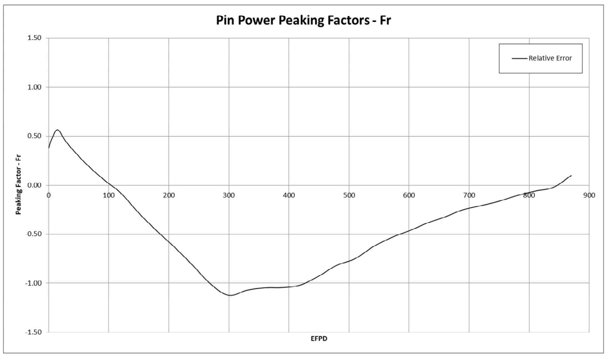

Fig. 9. Peaking factor comparison result - F_r.

Figures 8 and 9 show the peaking factors (Fq, Fr) comparison result. F_r and F_q have about 1.1% and 1.5% of maximum error, respectively, when BA effects exist. Both codes show a good agreement in the peaking factor estimation. In the overall behavior, MASTER overestimates the F_r and F_q except some initial time step.

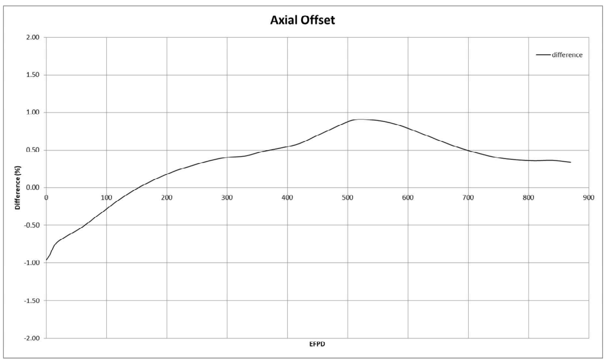

Fig. 10. Comparisons of axial offset.

Figure 10 illustrates the AO comparison result. MASTER estimates somewhat top shifted core power except at the initial time step. About the AO difference is negligible with maximum of 1% difference between the two codes.

4. Summary and Conclusions

Equivalent core models of the DeCART, McCARD and MASTER were established and the validity of the modeling was confirmed through a code to code comparison with the Monte-Carlo solutions by the McCARD code. Most of the core constituents including fuel rods, BA pins and guide tubes were explicitly modeled.

The comparisons confirm the overall validity of the SMR core design system. At BOC with fixed temperature condition, agreement between codes is good in the predictions of the k_{eff}, radial and axial power distributions, and control rod worths. The absolute errors in the radial assembly power distribution are within 1.2% and 1.8% respectively, and the core criticality difference is less than 100 pcm. Agreement is also satisfactory in the control rod worth predictions. In the depletion calculation, DeCART and MASTER show good enough agreement. In case of boron-letdown curve, the absolute difference is less than 64 ppm. Also in case of peaking factors, the absolute error is less than 1.1%. However, in the power distribution, comparison results show a power tilt between center positions and peripheral positions. Under- and over-estimation of the fission powers at the core center and periphery are also worthwhile to be noted.

Through this work, the capability of the KAERI SMR core design system based on the DeCART2D/MASTER was tested by the whole core transport code, DeCART. Further comparisons with the Monte Carlo code, McCARD, is planned to complete the verification process.

Acknowledgement

As a part of the KAERI SDCA licensing support study, we thank the KAERI SMART Core Design Team for their assistance.

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