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Monte Carlo Few Group Constants Generation for CANDU Reactor Core Analysis

Seung Yeol Yoo[a*], Hyung Jin Shim[a]
[a]*Seoul National University, 559 Gwanakro, Gwanak-gu, Seoul, 151-744*
[*]*Corresponding author: ryu72@snu.ac.kr*

1. Introduction

In the two-step CANDU core analysis, the lattice physics code WIMS-IST is used for generation of the few-group diffusion theory constants (hereafter, few-group constants), and the neutronics design parameters such as the effective multiplication factor (k_{eff}), the power distribution, reactivity coefficients, etc. of the reactor core are calculated by the diffusion theory code RFSP-IST. In addition, three dimensional (3-D) supercell calculations are conducted to take into account the effect of the reactivity devices perpendicular to the horizontal fuel channels by DRAGON-IST.

Recently, the Monte Carlo (MC) few-group constant generation method [1] has been successfully applied for the two-step reactor core analysis. In this paper, the CANDU reactor core analysis is performed with the two-group constants generated by the Seoul National University MC code, McCARD [2].

2. Methodology

In the McCARD few-group constant generation method, the fine group cross-sections are estimated in the MC simulations by their definitions:

$$\Sigma_{\alpha g} = \frac{\int \int_{\Delta E_g} \int_{4\pi} \Sigma_\alpha(\mathbf{r},E)\phi(\mathbf{r},E,\mathbf{\Omega})d\mathbf{\Omega}dEd\mathbf{r}}{\int \int_{\Delta E_g} \int_{4\pi} \phi(\mathbf{r},E,\mathbf{\Omega})d\mathbf{\Omega}dEd\mathbf{r}}, \quad (1)$$

$$\Sigma_{gg'} = \frac{\int_V \int_{\Delta E_g} \int_{\Delta E_g'} \Sigma_s(\mathbf{r},E'\to E)\phi(\mathbf{r},E')dE'dEd\mathbf{r}}{\int_V \int_{\Delta E_g} \phi(\mathbf{r},E)dEd\mathbf{r}}. \quad (2)$$

$\Sigma_{\alpha g}$ denotes the macroscopic cross section of reaction type α for energy group g. $\Sigma_{gg'}$ is the differential scattering cross-section from energy group g' to g.

In the McCARD method, the critical spectrum is determined by the B_1 equations from the estimated fine-group cross-section. Then the few-group constants including the diffusion constants can be calculated by

$$\Sigma_{\alpha G} = \frac{\sum_{g\in G} \Sigma_{\alpha g}\phi_g^B}{\sum_{g\in G}\phi_g^B}, \quad (3)$$

where ϕ_g^B denotes the critical spectrum.

3. Numerical Results

Two-group constants of a CANDU lattice problem were generated with the infinite medium spectrum by McCARD. Table 1 shows the comparison of the two-group constants generated by McCARD and WIMS-IST. From the table, it is observed that the maximum relative difference is 2.12% for Σ_{a2}. In the table, k_{inf} (Trans.) and k_{inf} (2Gr.) indicate k_{inf}'s calculated by the transport and from the two-group constants, respectively.

Table 1: Two-group constants by the infinite system spectrum

Two Group[1)] Constants	McCARD	WIMS-IST	Rel. Diff.[3)] (%)
Σ_{a1}	1.65×10^{-3}	1.66×10^{-3}	0.61
Σ_{a2}	3.49×10^{-3}	3.56×10^{-3}	2.12
$\nu\Sigma_{f1}$	8.78×10^{-4}	8.95×10^{-4}	1.95
$\nu\Sigma_{f2}$	4.30×10^{-3}	4.38×10^{-3}	1.80
Σ_{s12}	8.80×10^{-3}	8.88×10^{-3}	0.92
k_{inf} (Trans.)	1.12184 ± 0.00012	1.11996	-0.17
k_{inf} (2Gr.)[2)]	1.12178	1.11996	-0.16

1) Group 1 ($<1.0\times10^{30}$ MeV), Group 2 ($<0.625\times10^{-06}$ MeV)

2) $k_{inf}(2\text{Gr.}) = (\nu\Sigma_{f1}\Sigma_{r2} + \nu\Sigma_{f2}\Sigma_{12})/(\Sigma_{r1}\Sigma_{r2} - \Sigma_{21}\Sigma_{12})$
$\Sigma_{rg} = \Sigma_{tg} - \Sigma_{sgg} - 2\cdot\Sigma_{2n,g} - 3\cdot\Sigma_{3n,g}$

3) Rel. Diff : Relative difference between McCARD and WIMS

To examine the effectiveness of the generated few-group constants, the full core analyses were performed by the diffusion theory code RFSP-IST and SCAN [3] with the fine mesh model (42x34x20). As for the core condition, every fuel loaded in the core is a fresh fuel and all reactivity devices are not modeled. The reference solutions were obtained by the McCARD full core calculations with the continuous energy cross section libraries.

Table 2 shows the comparisons of k_{eff}'s calculated by McCARD/RFSP and McCARD/SCAN with reference. From the table, it is observed that the differences from the reference are 677 pcm in McCARD/RFSP and 675 pcm in McCARD/SCAN. Figure 1 shows the comparison of the channel power distributions. For the power distribution, it can be noted that the root mean square (RMS) errors are 1.86% in McCARD/RFSP and 1.92% in McCARD/SCAN, while the maximum errors -5.47% in RFSP-IST and -5.83% in SCAN.

Table 2: k_{eff} for the CANDU core

Case	k_{eff}	Difference(pcm)
McCARD(Ref.)	1.08809 ± 0.00014	-
McCARD/RFSP	1.09486	677
McCARD/SCAN	1.09484	675

1.675 0.88 3.75 3.91	1.663 0.88 2.72 2.87	1.638 0.88 0.81 0.95	1.560 0.88 0.46 0.59	1.459 0.88 -0.10 0.02	1.316 0.88 0.84 0.92	1.149 0.88 2.42 2.47	1.002 0.88 1.01 1.00	0.818 0.88 2.12 2.04	0.657 0.88 -0.89 -1.09	0.488 0.88 -3.35 -3.77
1.657 0.90 3.02 3.31	1.643 0.90 2.12 2.40	1.607 0.90 0.88 1.15	1.540 0.90 -0.15 0.11	1.427 0.90 0.17 0.41	1.289 0.90 0.82 1.06	1.155 0.90 -0.38 -0.17	0.984 0.90 0.38 0.54	0.814 0.90 -0.18 -0.07	0.647 0.90 -2.64 -2.63	0.468 0.90 -3.38 -3.62
1.606 0.93 2.86 2.80	1.596 0.93 1.75 1.68	1.569 0.93 -0.12 -0.20	1.505 0.93 -1.31 -1.41	1.398 0.93 -1.35 -1.48	1.247 0.93 0.32 0.16	1.098 0.93 0.58 0.35	0.948 0.93 -0.32 -0.63	0.790 0.93 -2.35 -2.77	0.604 0.93 -1.75 -2.31	0.442 0.93 -4.10 -4.62
1.555 0.82 0.85 0.98	1.543 0.82 -0.14 -0.02	1.497 0.82 -0.77 -0.65	1.429 0.82 -1.63 -1.52	1.322 0.82 -1.50 -1.42	1.182 0.82 -0.42 -0.37	1.029 0.82 0.50 0.51	0.872 0.82 0.75 0.69	0.716 0.82 -0.74 -0.91	0.567 0.82 -3.78 -4.13	
1.477 0.88 -1.17 -1.05	1.440 0.88 -0.49 -0.38	1.392 0.88 -0.85 -0.74	1.318 0.88 -1.21 -1.12	1.236 0.88 -2.76 -2.69	1.097 0.88 -1.38 -1.34	0.948 0.88 -0.44 -0.44	0.777 0.88 2.11 2.01	0.631 0.88 0.32 0.08	0.503 0.88 -4.40 -5.05	
1.344 0.82 -1.24 -1.05	1.324 0.82 -1.67 -1.48	1.262 0.82 -0.84 -0.65	1.215 0.82 -3.10 -2.93	1.097 0.82 -1.42 -1.26	0.966 0.82 -0.06 0.08	0.818 0.82 1.98 2.06	0.691 0.82 0.05 0.04	0.558 0.82 -2.18 -2.37		
1.190 0.92 -0.95 -1.05	1.157 0.92 -0.20 -0.29	1.133 0.92 -2.30 -2.40	1.065 0.92 -2.70 -2.83	0.969 0.92 -2.46 -2.62	0.822 0.92 1.72 1.49	0.695 0.92 2.37 2.07	0.568 0.92 1.49 1.15	0.460 0.92 -3.66 -3.80		
1.011 0.90 0.25 0.28	1.003 0.90 -1.17 -1.14	0.957 0.90 -1.14 -1.12	0.901 0.90 -2.34 -2.34	0.809 0.90 -1.84 -1.87	0.690 0.90 0.21 0.12	0.572 0.90 0.87 0.70	0.455 0.90 1.63 1.29			
0.821 0.94 2.03 2.00	0.819 0.94 -0.37 -0.41	0.788 0.94 -1.73 -1.78	0.733 0.94 -2.75 -2.82	0.658 0.94 -3.72 -3.83	0.557 0.94 -3.01 -3.17	0.457 0.94 -2.43 -2.71				
0.650 0.99 0.62 0.51	0.646 0.99 -1.72 -1.83	0.618 0.99 -3.27 -3.42	0.574 0.99 -4.56 -4.73	0.493 0.99 -3.76 -4.00	0.419 0.99 -5.47 -5.83					
0.472 0.98 1.44 1.15	0.473 0.98 -2.74 -3.01	0.448 0.98 -2.45 -2.78								McCARD Rel. Err. % Diff. (1) % Diff. (2) %

Diff. (1) : (**McCARD/RFSP** - McCARD)/McCARD

Diff. (2) : (**McCARD/SCAN** - McCARD)/ McCARD

Rel. Err. % : Relative Error of Channel Power

Figure 1: Normalized channel power distribution

For the comparison, the RFSP-IST calculations were conducted by using the two-group constants generated by WIMS-IST. Table 3 and figure 2 compare k_{eff} and the channel power distribution, respectively, calculated by McCARD/RFSP and WIMS/RFSP. The maximum and RMS error in the power distribution estimated by WIMS/RFSP are -4.76% and 1.77%, respectively.

Table 3: k_{eff} for the full core calculation

Case	k_{eff}	Difference(pcm)
McCARD(Ref.)	1.08809 ± 0.00014	-
McCARD/RFSP	1.09486	677
WIMS/RFSP	1.09330	521

1.675 0.88 3.47 3.75	1.663 0.88 2.44 2.72	1.638 0.88 0.56 0.81	1.560 0.88 0.23 0.46	1.459 0.88 -0.29 -0.10	1.316 0.88 0.68 0.84	1.149 0.88 2.34 2.42	1.002 0.88 1.01 1.01	0.818 0.88 2.26 2.12	0.657 0.88 -0.58 -0.89	0.488 0.88 -2.75 -3.35
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Diff. (2) : (**McCARD/RFSP** - McCARD)/McCARD

Rel. Err. % : Relative Error of Channel Power

Figure 2: Normalized channel power distribution

4. Conclusions

The McCARD few-group constant generation system is qualified through the CANDU core analyses. As a result, the power distribution of the CANDU reactor core calculated by diffusion codes with the two-group constants generated by McCARD shows a good agreement with the MC full core calculation despite the 677 pcm difference of the k_{eff}. From the comparison of k_{eff} and the power distribution calculated by McCARD/RFSP and SCAN/RFSP, it is found that the results reveal well consistent with each other. However these results are limited to the fresh core without any reactivity devices. For further works, the CANDU reactor core analyses with considering reactivity device effects will be conducted.

REFERENCES

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