Generation of Transport Lattice code KARMA Library with Doppler-Broadening Rejection Correction Method

Ho Jin Park [a*], Ser Gi Hong[b], Kang-Seog Kim[c], Jin Young Cho[a], Sang Yoon Park [a]
[a]*Korea Atomic Energy Research Institute, 989-111 Daedeok-Daero, Yuseong-gu, Daejeon, Korea*
[b]*Kyung Hee University, 1732 Deokyoungdaero, Yongin-si, Gyeonggi-do, 446-701, Korea*
[c]*Oak Ridge National Laboratory, Oak Ridg TN, United States*
[*]*Corresponding author: parkhj@kaeri.re.kr*

1. Introduction

In order to solve the exact neutron transport equations, the temperature-dependent neutron cross sections including scattering kernel are needed. However, the current cross section generation systems such as NJOY do not generate the temperature-dependent scatting kernels. In Monte Carlo (MC) code, the sampling of velocity of target nucleus method is used to determine the energy and direction of outgoing neutron by the approximated constant cross section model. Recently, the Doppler-broadening rejection correction (DBRC)[1] and weight correction method [2] are proposed for the exact sampling.

In this study, the KARMA(Kernel Analyzer by Ray-tracing Method for fuel Assembly)[3] library system incorporating McCARD[4] calculations with the DBRC method are established and the effect of improved Doppler treatment will be examined.

2. Methods and Results

2.1 Doppler Feedback Model for MC method

Though all the neutron cross sections for MC calculations should be Doppler-broadened by the cell temperatures, the scattering kernel taken from NJOY are independent of temperature. In order to correct this problem, on-the-fly Doppler broadening is implemented by sampling the target nucleus's velocity vector and using the relative neutron energy in the MC simulation of the collision kernel. Eq. (1) shows the exact target probability density function [5].

$$P^T(V,\mu_t) = \frac{\sigma_s(v_r)v_r\, p(\beta,V)}{2\sigma_s^{eff}(v_n)v_n} \qquad (1)$$

where V and μ_t is target velocity and the cosine of angle between neutron and target, $\sigma_s^{eff}(v_n)$ is the Doppler-broadened scattering cross section, and $p(\beta,V)$ is the pdf for the target velocities. The v_n and v_r is the neutron velocity and relative to target. $\sigma_s(v_r)$ is the function for zero-Kelvin scattering cross sections. In the constant cross section model it is assumed that the variation of $\sigma_s(v_r)$ with target velocity can be ignored. In the DBRC model, the rejection probability $\sigma_s(v_r)$ to the sampling procedure of the constant cross section model are added in order to sample the exact target velocity.

2.2 KAERI Library Processing System

Figure 1 shows the flow chart of KAERI library processing system[6] to generate the KARMA library. The procedure of effective cross section generation by MC calculations is added to the existing system in order to adopt the DBRC method. An absorption cross section (σ_a) and ν*fission cross section ($\nu\sigma_f$) are generated by the McCARD calculations with constant cross section model or DBRC model. Using the generated effective cross section, the resonance integral (RI) tables are replaced. The other procedures are used without any modification.

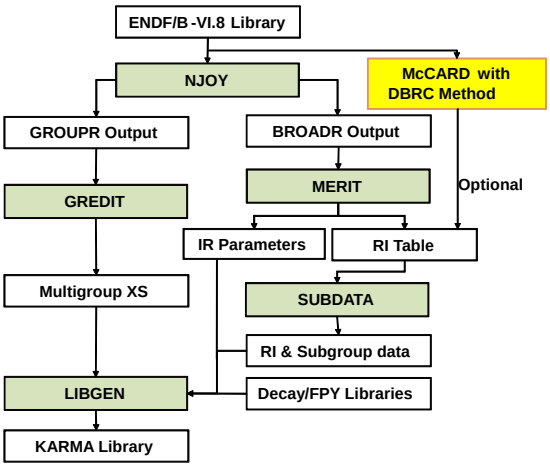

Fig. 1. Flowchart for the KAERI library processing system

2.3 Numerical Results

In order to examine the effect of the DBRC model, the KARMA 47-group library based on ENDF/B-VI.8 is generated with the new KAERI library processing system. The microscopic cross section of ^{238}U for the resonance energy groups (1.85-9118 eV) are adjusted by McCARD calculations while the microscopic cross sections for other nuclides such as ^{1}H, ^{16}O, ^{235}U are used from the existing KARMA library. The McCARD calculations are performed using 10,000 neutron histories per a cycle with 1,000 active cycles. For

benchmark, 3 w/o UO_2 pin and assembly calculations are performed. The detailed geometry and composition data of the pin are shown in Table 1.

Table I: Geometry and Composition for 3 w/o UO_2 pin

Region	*Material*	*Temp. (K)*	*Radius (cm)*	*Density (g/cm^3)*
Fuel	UO_2	700	0.4025	10.4
Clad	^{90}Y	600	0.4759	2.7
Moderator	H_2O	600	1.2633	0.66

Table II provides the computational results of 3 w/o UO^2 pin problem for the continuous McCARD, the 47-group KARMA for each model. The reference cases are taken from the direct McCARD calculations using 100,000 neutron histories per a cycle with 1,000 active cycles. The difference of k-effective between KARMA and reference for the constant cross section model is 20 pcm while the difference with DBRC model is 23 pcm. Table III shows the k-effective of fuel assembly problem. The difference of k-effective between KARMA and reference with the constant cross section model is 95 pcm while the difference with DBRC model is 106 pcm.

Table II: k-effective for 3 w/o UO_2 pin (700K)

Case	*k-effective*	*Diff. (pcm)*
Reference (Contant Model)	1.31224 ± 0.00007	
KARMA (Contant Model)	1.31244	20
Reference (DBRC Model)	1.31101 ± 0.00007	
KARMA (DBRC Model)	1.31084	17

Table III: k-effective for UO_2 fuel assembly (700K)

Case	*k-effective*	*Diff. (pcm)*
Reference (Contant Model)	1.33604 ± 0.00007	
KARMA (Contant Model)	1.33509	95
Reference (DBRC Model)	1.33465 ± 0.00007	
KARMA (DBRC Model)	1.33359	106

Table IV and V compare the fuel temperature coefficients (FTC) for each model. It can be observed from these results that the DBRC model makes FTC more negative by 13-14%.

Table IV: FTCs for a 3/wo UO_2 pin

Temp (Kelvin)	KARMA *(Constant XS Model)*		KARMA *(DBRC Model)*	
	k_{eff}	FTC (pcm/K)	k_{eff}	FTC (pcm/K)
700	1.31244	-3.13	1.31084	-3.56
1100	1.29990		1.29660	
2000	1.27651	-2.60	1.26922	-2.96

Table V: FTCs for UO_2 fuel Assembly

Temp (Kelvin)	*Constant XS Model*		*DBRC Model*	
	k_{eff}	FTC (pcm/K)	k_{eff}	FTC (pcm/K)
700	1.33509	-2.90	1.33359	-3.29
1100	1.32349		1.32044	
2000	1.30165	-2.43	1.29560	-2.76

3. Conclusions

From the various study, it was known that the constant cross section model lead to under predictions of FTCs for PWR system.[2,7] In order to solve this problem, we have generated new KARMA 47-group library with the aid of McCARD with the DBRC model for the exact sampling. From the results for the pin and assembly problem, it is observed that the FTC of the DBRC model is more negative by 13-14% than that of the constant cross section model.

Acknowledgements

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REFERENCES

[1] B. Becker, "On the influence of the Resonances Scattering Treatment in Monte Carlo Codes on High Temperature Reactor Characteristics," Ph.D. Thesis, University Stuttgart, Jun. 2010 (2010)
[2] D. J. Lee, K. Smith, J. Rhodes, "The impact of ^{238}U Resonance Elastic Scattering Approximations on Thermal Reactor Doppler Reactivity," Annals of Nuclear Energy **36**, p274-280. (2009)
[3] K. S. Kim, S. G. Hong, J. Y. Cho, and J. S. Song, "Transport Lattice Code KARMA 1.1," Transactions of the Korean Nuclear Society Autumn Meeting, Gyeongju, Korea, October 29-30 (2009)
[4] H. J. Shim, B. S. Han, J. S. Jung, H. J. Park, and C. H. Kim, "McCARD: Monte Carlo Code for Advanced Reactor Design and Analysis," Nuclear Engineering and Technology **44**, p161, (2012)
[5] H. J. Shim and C. H. Kim,"McCARD Methodology v1.0," SNUMCL/TR001/2010(01)
[6] K. S. Kim and S. G. Hong, "A New Procedure to Generate Resonance Integral Tables with an Explicit Resonance Interference for Transport Lattice Codes," Annals of Nuclear Energy **38**, p118-127 (2011)
[7] C. H. Lim, J. Y. Sang, H. G. Joo, "Incorporation of Resonance Upscattering and Intra-Pellet Power Profile in Direct Whole Core Calculation," Transactions of the Korean Nuclear Society Spring Meeting, Jeju, Korea, May 17-18 (2012)