Implementation of the Gamma Transport Calculation Module in KARMA 1.2

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1. Introduction

Korea Atomic Energy Research Institute (KAERI) has developed the transport lattice code called KARMA[1] (Kernel Analyzer by Ray-tracing Method for fuel Assembly) to be used in the nuclear design for the operating domestic PWRs. This program adopts MOC (Method Of Characteristics) for the spatial discretization, a subgroup method and a direct resonance table method for the resonance treatment, B1 method for the criticality spectrum, and exponential matrix method with Krylov subspace method for the burnup calculation. Multigroup libraries are provided by the KAERI library processing system[2].

Recently the gamma transport calculation module has been implemented in KARMA 1.2. Gamma flux distributions are simulated by using this module from which local gamma energy depositions can be estimated. Previously gamma smeared pin power distributions were estimated by assuming the flat gamma flux distribution and thus flat fractional gamma pin powers. This capability enables to estimate the gamma smeared power distributions explicitly. Some gamma in-core detector material such as Vanadium produces electrical signal from the gamma reaction, which requires precise gamma reaction rates.

When using the HELIOS[3] neutron and gamma library converted into the KARMA format, the computational results of KARMA for the neutron and gamma transport calculations are very consistent with the HELIOS ones.

2. Methods and Results

2.1 Gamma transport equation

The typical gamma transport equation is as follows:

$$\hat{\Omega}_m \cdot \nabla \psi_{m,g} + \Sigma_{tr,g}\psi_{m,g} = \sum_{g' \to g} \Sigma_{s,g' \to g}\phi_{g'} + Q_g^n \ , \qquad (1)$$

where

$$\sigma_{a,g} = \sigma_{PE,g} - \sigma_{PP,g},$$

$$\sigma_{tr,g} = \sigma_{PE,g} + \sigma_{PP,g} + \sigma_{C,g},$$

$$\sigma_{s,g\to g'} = \sigma_{C,g\to g'} + 2\delta_{g_P g'}\sigma_{PP,g},$$

g is the gamma energy group, Q_g^n is the external gamma source, and subscripts PE, PP and C denote photoelectric effect, pair production and Compton scattering, respectively. The gamma transport calculation should be performed followed by the neutron transport calculation from which the external gamma source is estimated as follows:

$$Q_g^n = \sum_{g_n} \phi_{g_n} \sum_i N_i \sigma_{nr,g_n \to g}, \qquad (2)$$

where g_n is the neutron energy group, ϕ_{g_n} the neutron scalar flux, N_i the particle number density of nuclide i and $\sigma_{nr,g_n\to g}$ the gamma production cross section. The gamma production cross section is composed of prompt gammas which come from the (n,r) and (n,f) reactions, and delayed gammas which are from the radioactive decays of the fission product nuclides.

In KARMA eq. (1) is solved by MOC to obtain the gamma flux distribution as is to obtain the neutron flux distribution. The obtained gamma flux distribution can be used in obtaining the local deposited gamma energies. The gamma rays can be converted into the deposited energy through the gamma absorption and the gamma slowing down processes as shown in eq. (3).

$$E_{deposit} = \sum_i V_i \sum_g [\phi_{i,g}\Sigma_{i,a,g}E_g + \sum_{g'} \phi_{i,g'}\Sigma_{i,s,g'\to g}(E_{g'} - E_g)], \qquad (3)$$

where $\phi_{i,g}$ is gamma flux at region i, E_g the average group energy and V_i the volume of region i, and $\Sigma_{i,a,g}$ and $\Sigma_{i,s,g'g}$ are the macroscopic absorption and scattering matrix, respectively. When imposing reflecting boundary condition, the total gamma energy from the external gamma source in eq. (4) should be identical to the deposited gamma energy because there is no gamma ray loss from the system.

$$E_{incident} = \sum_i V_i \sum_g Q_{i,g}^n E_g \ . \qquad (4)$$

Since the incident gamma energy is identical to the deposited gamma one, eqs. (3) and (4) can be used in validating the gamma transport calculation module.

2.2 Computational results

The gamma transport calculations were performed to see if the KARMA gamma transport calculation module is working reasonably. In order to compare the KARMA computational results with the HELIOS ones, the HELIOS 47-group neutron and 18-group gamma library was converted into the KARMA library. By using the same neutron and gamma cross section library the neutron and gamma transport calculations were performed for the single pin and the single assembly.

Fig. 1 provides a comparison of the gamma spectrum for a single fuel pin in which the gamma fluxes from the KARMA calculation are very consistent with the HELIOS ones. Table 1 shows a comparison of the multiplication factors and the deposited gamma energies between HELIOS and KARMA. The multiplication factors are very consistent with an error of 15 pcm and there is only 0.05% difference in the deposited gamma energies. Slight differences might come from the difference in the resonance interference treatment which results in the different self-shielded absorption cross section and thus different neutron induced external gamma source.

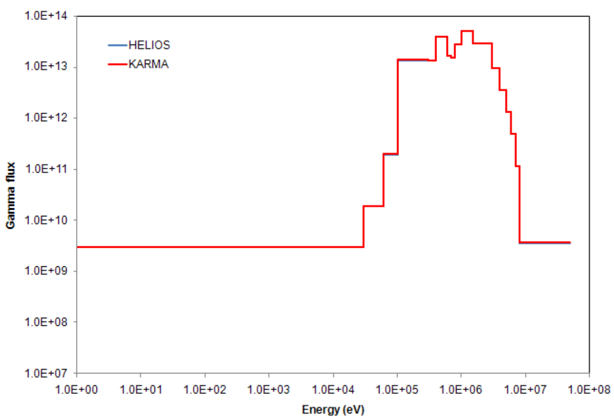

Fig. 1. A comparison of gamma flux

Table 1 A comparison of multiplication factors and gamma energy depositions

Temp.(K)	HELIOS	KARMA	Difference
$K_{eff.}$	1.30961	1.30987	15 pcm
Deposited energy (W/cm^2)	9.6313	9.6265	0.050 %

Fig. 2 shows a comparison of the gamma smeared pin power distributions which were obtained by the explicit neutron and gamma transport calculation and by the consideration of the constant gamma pin power fraction to be 0.085 without any gamma transport calculation. As shown in Figure there is almost no difference in the gamma smeared pin power distribution. This means that the gamma transport calculation is not indispensable in estimating the gamma smeared power distribution. However, since some the in-core detectors are utilizing gamma reactions producing electrical signals, the explicit gamma transport calculation is very important in estimating the in-core detector signals.

Explicit
Factor 0.085
Difference

0.000 0.000 0.000							
1.045 1.046 -0.001	1.014 1.015 -0.001						
0.998 0.998 0.000	0.998 0.998 0.000	1.013 1.013 0.000					
0.982 0.981 0.001	0.995 0.995 0.000	1.042 1.043 -0.001	0.000 0.000 0.000				
0.973 0.972 0.001	0.989 0.989 0.000	1.039 1.039 0.000	0.000 0.000 0.000	0.000 0.000 0.000			
0.966 0.966 0.000	0.978 0.977 0.001	1.004 1.004 0.000	1.041 1.042 -0.001	1.044 1.044 0.000	1.011 1.012 -0.001		
0.967 0.966 0.001	0.973 0.973 0.000	0.985 0.985 0.000	0.999 0.999 0.000	1.001 1.001 0.000	0.995 0.995 0.000	0.993 0.993 0.000	
0.980 0.980 0.000	0.984 0.983 0.001	0.991 0.991 0.000	0.998 0.998 0.000	1.001 1.001 0.000	1.001 1.001 0.000	1.005 1.005 0.000	1.020 1.020 0.000

Fig. 2. A comparison of the gamma smeared power distribution

3. Conclusion

The computation results show that the KARMA gamma transport calculation module has been successfully implemented into KARMA 1.2 and is working reasonably. It was also shown that gamma smeared power distribution can be predicted by adopting the constant adjustment factor and by performing the gamma transport calculation. However, since some in-core detector utilizing gamma reaction requires the explicit gamma transport calculations, this gamma transport module will play an important role in estimating gamma induced response.

REFERENCES

[1] Kang-Seog Kim, et al., “Transport Lattice Code KARMA 1.1,” Transactions of KNS Autumn Meeting, Gyeongju, Korea, Oct. 29-30, 2009.

[2] Kang-Seog Kim, et al., “Improvements on MERIT 1.1 and SUBDATA 1.1 and a New Procedure for Resonance Integral Adjustment,” Transactions of KNS Autumn Meeting, Gyeongju, Korea, Oct. 29-30, 2009.

[3] R.J.J. Stamm’ler, et al., “HELIOS Methods,” Studsvik Scandpower (2009)