Verification of KARMA GEOM/TRPT Module with Given Multi-group Cross Sections

Bon-Seung Koo, Ser-Gi Hong, Jae-Seung Song
Korea Atomic Energy Research Institute, 1045, Daedeokdaero, Yuseong-gu,Daejon, 305-353, Korea

1. Introduction

KAERI has developed a two-dimensional multi-group transport theory code KARMA (Kernel Analyzer by Ray-tracing Method for Fuel Assembly). KARMA uses CMFD (Coarse Mesh Finite Difference) accelerated MOC (Method of Characteristics) method for burnup calculation on a single fuel pin, a fuel assembly and a core consisting of rectangular array of fuel pins [1].

KARMA code intends to be employed as a nuclear design tool for the Korean commercial pressurizer water reactor. Prior to the application to actual assembly designs, the code has to be approved by regularity agency. Therefore, it is essential that the reliability of KARMA code should be sufficiently evaluated against well-defined benchmark problems.

In this paper, verification of GEOM/TRPT modules of KARMA was performed to confirm a reliability of the KARMA transport solution via comparisons with Monte Carlo calculations [2] by using a consistent set of multi-group macroscopic cross-sections.

2. General Description

A set of comprehensive benchmark problems called as a benchmark matrix was defined and macroscopic cross sections were described for each problem [3]. Benchmark problems for verification consist of 4 different two-dimensional problems as follows:

1. single pin cell problem,
2. multi pin cell problem,
3. single assembly problem, and
4. colorset problem.

A unique type of pin cell geometry is used in this benchmark for simplicity. The side length of pin cell is 1.26 cm, and the inner and outer radii of the clad are 0.48 and 0.54 cm, respectively. The outer region of the clad is filled with water moderator. The gap region between pellet and clad is ignored for simplicity.

The configuration of 4-benchmark problems is illustrated in Fig. 1 to Fig. 2. Single pin cell problem is loaded with 3.3 wt% UO_2 fuel and 3×3 multi pin cell problem is consisted of 8 normal UO_2 fuel rods and a central gadolinia-bearing fuel rod which is loaded with 8.0 wt% Gd_2O_3 admixed in 1.8wt% UO_2 fuel. Single assembly problem is made up of a 17×17 array of 252 normal UO_2 fuel rods, 12 gadolinia-bearing UO_2 fuel rods and 25 guide tubes. All guide tubes are filled with water moderator. Colorset problem consists of a 2×2 periodic array of the 3.3 wt% UO_2 fuel assembly described in the single assembly problem and the 4.3 wt% UO_2 fuel assembly containing 24 control rods. 24 guide tubes are filled with Ag-In-Cd as a neutron absorber and a central guide tube is filled with water moderator. For all the benchmark problems, reflective boundary condition for the radial direction and infinite condition for the axial direction (i.e. zero axial buckling) are assumed.

In the KARMA calculation, adequate numbers of ray for polar, azimuthal angels and ray width may be different for problem by problem considering the calculation time and accuracy. Generally, default ray option is provided for typical fuel assembly calculations of pressurized water reactor. Thus, sensitivity test for ray option was studied for 4-benchmark problems and following ray option was selected in this calculation.

1. Single pin cell problem
- RAY 2 8 0.05 (N_{POL}, N_{AZI}, W_{IDTH})

2. Bigger problem than single pin cell
- Ray 2 4 0.05 (default value)

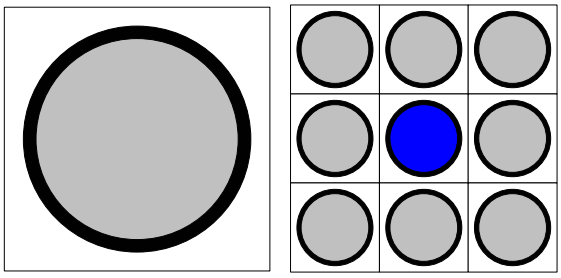

Fig. 1. Configuration of single and multi pin cell problems.

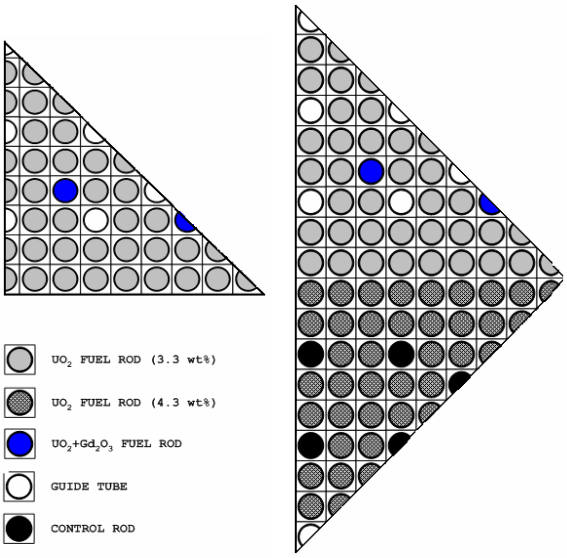

Fig. 2. Configuration of single assembly and colorset problems.

3. Calculational Results and Conclusion

The results obtained via a multi-group MCNP calculation utilizing with 50 million histories were used as a reference solution and eigenvalue and pin-by-pin fission rate distributions were compared. Table 1 shows eigenvalue differences between KARMA and MCNP calculations for each benchmark problem. It shows that results of two independent codes are good agreement within ~0.00010 delta-k for single pin cell problem and ~0.00120 delta-k for fuel assembly problems. The maximum difference of fission rate distribution is not greater than 0.5% for every benchmark problems. Fig. 3 to Fig. 5 show the pin-by-pin fission rate distributions for the benchmark problems.

These differences are within the acceptance criteria of 0.00150 for eigenvalue and 0.5% for fission rate distribution [4]. Thus, the calculational results with the given multi-group cross sections are satisfactory and demonstrated that the GEOM/TRPT module of KARMA works correctly within the acceptable criteria.

Table. 1. Eigenvalue difference between KARMA and MCNP.

No	Problem type	KARMA	MCNP	Delta_K
1	Single pin cell	1.17638	1.17649	0.00011
2	Multi pin cell	0.88535	0.88603	0.00068
3	Single FA	1.07268	1.07373	0.00105
4	Colorset FA	0.97364	0.97482	0.00118

1.101 1.102 0.07	1.062 1.062 0.00	1.101 1.102 0.10
1.063 1.062 -0.06	0.345 0.346 0.23	1.062 1.062 -0.04
1.101 1.102 0.05	1.063 1.062 -0.07	1.101 1.102 0.06

MCNP
KARMA
(K-M)/M•100

Fig. 3. Pin-by-pin fission rate distribution - multi pin cell.

								MCNP KARMA (K-M)/M•100
1.161 1.160 -0.11	1.121 1.119 -0.20							
1.150 1.146 -0.39	1.109 1.110 0.11	1.097 1.097 -0.03						
	1.122 1.121 -0.08	1.108 1.108 -0.04						
1.099 1.100 0.07	1.042 1.042 -0.03	0.998 1.000 0.23	1.075 1.074 -0.07	1.073 1.074 0.13				
1.073 1.070 -0.24	0.986 0.988 0.18	0.273 0.273 -0.13	1.028 1.032 0.35	1.091 1.090 -0.09				
	1.058 1.058 -0.04	1.015 1.016 0.10		1.077 1.074 -0.31	0.997 0.999 0.19	0.268 0.268 -0.03		
1.081 1.079 -0.17	1.045 1.043 -0.17	1.035 1.033 -0.15	1.066 1.067 0.13	1.024 1.025 0.05	0.971 0.970 -0.11	0.905 0.905 0.02	0.929 0.930 0.14	
1.034 1.035 0.12	1.028 1.028 0.03	1.023 1.022 -0.10	1.021 1.023 0.15	1.003 1.001 -0.15	0.977 0.979 0.22	0.952 0.952 -0.03	0.950 0.951 0.08	0.953 0.954 0.06

Fig. 4. Pin-by-pin fission rate distribution – single assembly.

								MCNP KARMA (K-M)/M•100
1.540 1.537 -0.17	1.415 1.415 -0.01							
1.465 1.464 -0.07	1.357 1.356 -0.04	1.304 1.303 -0.05						
	1.346 1.346 0.01	1.291 1.291 0.00						
1.351 1.350 -0.08	1.225 1.225 -0.01	1.142 1.144 0.17	1.204 1.201 -0.25	1.181 1.181 0.04				
1.289 1.286 -0.25	1.131 1.133 0.19	0.306 0.305 -0.29	1.123 1.126 0.29	1.178 1.176 -0.13				
	1.169 1.168 -0.10	1.088 1.090 0.16		1.137 1.134 -0.24	1.050 1.052 0.15	0.289 0.289 0.00		
1.166 1.165 -0.13	1.091 1.090 -0.06	1.064 1.061 -0.31	1.091 1.093 0.19	1.047 1.046 -0.13	0.993 0.991 -0.20	0.920 0.922 0.20	0.939 0.940 0.07	
1.000 1.001 0.06	0.986 0.987 0.05	0.978 0.978 -0.04	0.979 0.980 0.07	0.968 0.967 -0.13	0.956 0.955 -0.10	0.942 0.940 -0.19	0.943 0.941 -0.18	0.942 0.941 -0.08
1.061 1.059 -0.18	1.064 1.068 0.34	1.069 1.069 -0.02	1.072 1.069 -0.32	1.080 1.079 -0.07	1.089 1.089 -0.01	1.100 1.102 0.15	1.118 1.117 -0.05	1.135 1.135 -0.01
0.874 0.878 0.41	0.930 0.930 -0.04	0.941 0.940 -0.06	0.918 0.920 0.18	0.961 0.961 -0.03	1.001 0.999 -0.17	1.040 1.041 0.12	1.078 1.080 0.20	
	0.810 0.808 -0.26	0.819 0.820 0.10		0.828 0.829 0.10	0.881 0.880 -0.09	0.967 0.966 -0.15		
0.711 0.713 0.27	0.786 0.788 0.23	0.799 0.799 0.03	0.761 0.761 -0.06	0.763 0.765 0.30				
0.699 0.700 0.09	0.767 0.769 0.27	0.779 0.782 0.34	0.748 0.751 0.38	0.766 0.770 0.49				
	0.753 0.752 -0.18	0.752 0.753 0.17						
0.800 0.801 0.16	0.823 0.823 -0.02	0.798 0.800 0.27						
1.017 1.014 -0.26	0.917 0.919 0.22							

Fig. 5. Pin-by-pin fission rate distribution - colorset.

Acknowledgements

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