BENCHMARK CALCULATIONS OF DENT-2D CODE FOR PWR FUEL ASSEMBLIES

Kang-Seog Kim, Ha Yong Kim and Sung Quun Zee
Korea Atomic Energy Research Institute
P.O. Box 105, Yuseong, Daejeon, 305-333 Korea
kimks@kaeri.re.kr ; kim@kaeri.re.kr ; zee@kaeri.re.kr

ABSTRACT

We developed a new transport lattice code called DENT-2D (Deterministic Neutral Particle Transport Code in 2-Dimensional Space). This code is designed to generate few-group constants for the reactor physics analysis diffusion code such as KAERI reactor analysis nodal code, MASTER, and to perform a whole-core transport calculation. CASMO-3 and HELIOS have been used in generating the few-group constants for MASTER. DENT-2D adopts characteristics method for the spatial discretization, CMFD (Coarse Mesh Finite Difference) for the speedup of eigenvalue calculation, subgroup method for the resonance treatment, B1 approximation for the criticality spectrum, and exponential matrix method for the depletion calculation.

We performed benchmark calculations for the fuel assemblies of pressurized water reactor and compared results with those of the conventional reference codes such as CASMO-3, HELIOS and MCNP4C. The results show that the multiplication factors of DENT-2D are consistent with HELIOS within 100 pcm for the single pins and within 200 pcm for the assembly. The reactivity changes from the changes of fuel and moderator temperatures are also very consistent with each other. Pin power distributions predicted by DENT-2D are very close to those of HELIOS code. The multiplication factors as a function of burnup are also consistent with those of HELIOS and CASMO-3.

1. INTRODUCTION

KAERI (Korea Atomic Energy Research Institute) developed MASTER[1] (Multi-purpose Analyzer for Static and Transient Effects of Reactor) for reactor physics analysis based on the few-group diffusion theory. MASTER is capable of calculating the steady-state and transient pressurized or boiling water reactor cores in a 3-dimensional Cartesian or hexagonal geometry. The few-group constants for MASTER have been provided through CASMO-3[2] or HELIOS[3] lattice calculations. Since these transport lattice codes including their libraries are prepared for the specified type of reactors, it is not easy to modify and update those codes for the other purposes. And it is a world-wide trend that the whole-core transport calculation is performed to analyze the reactor physics with the development of the increasing computational power of digital computers. The technology of transport lattice code is indispensable for the world-wide whole core transport calculation. Therefore, we developed a transport lattice code called DENT-2D[4]. This new

transport lattice code will be used to provide the few-group constants for MASTER and to be a basis for the development of the multi-dimensional whole-core transport code. For these purposes, DENT-2D adopts characteristics method[5 ,6, 7] for the spatial discretization and exponential matrix method[8] for depletion, which enable easy extension to large size problem and to a lot of nuclides. Currently DENT-2D includes only neutron particle transport calculation in Cartesian geometry.

The main features of DENT-2D are introduced in this paper and we performed benchmark calculations for PWR fuel pins and assemblies. The multiplication factors and pin powers were calculated for various fuel types with various moderator and fuel temperatures. The depletion calculations were performed to obtain the isotopic concentrations as a function of burnup. These results of the benchmark calculations are compared with those of other reference calculations such as CASMO-3, HELIOS and MCNP-4C[9].

2. METHODOLOGIES

The characteristics method[5, 6, 7] is adopted for the spatial discretization which includes merits of the integral transport method and S_N method. The former is advantageous for the complicated geometrical structure and the latter for the highly anisotropic scattering and large problems. Since the characteristics method does not solve the huge matrix, this can be easily extended to the whole-core transport calculations. Coarse mesh finite difference (CMFD) methodhas been used to obtain the transport solution quickly.[10] CMFD is very effective to reduce the computing time by the order of 10~50 for eigenvalue problems.

The subgroup method[11, 12] has been implemented to treat the resonance, where the resonance integrals are approximated by quadratures. To obtain the equivalence cross sections, the fixed source transport calculation using the characteristics method is performed at the resonance energy ranges.

While the reactor is operated at the critical reactivity condition (keff=1.0), the reactivity of assembly-level transport lattice calculation is far from the criticality. There will be some difference in neutron spectra between reactor core and assembly calculations. The criticality spectrum can be obtained by B_1 approximation[3] to consider the neutron leakage effect in the core with the buckling adjustment. This criticality spectrum is used to obtain the one-group cross sections and spectra for the depletion calculation.

The exponential matrix method[8] is implemented to perform the depletion calculation for the change of the compositions. This method can be easily extended and include lots of nuclides. Since the number of nuclides used in depletion calculation are much more than those in transport calculation, nuclide lumping procedure is required for the consistency.

For the time being, HELIOS library is used in transport calculation which includes fission-spectrum data, neutron cross section data and subgroup resonance data. ORIGEN-2[8] libraries are used for the depletion calculation which include 1-group cross section data, fission yield fraction data and decay constants.

Figure 1 shows the flow chart of DENT-2D calculation. DENT-2D is divided into sub-modules including input/output, geometry construction and ray tracing, particle number density and macroscopic cross section, resonance treatment, criticality spectrum, and depletion modules. DENT-2D is written in FORTRAN-90 and programmed so simple in the user input to reduce user's errors in preparing input files.

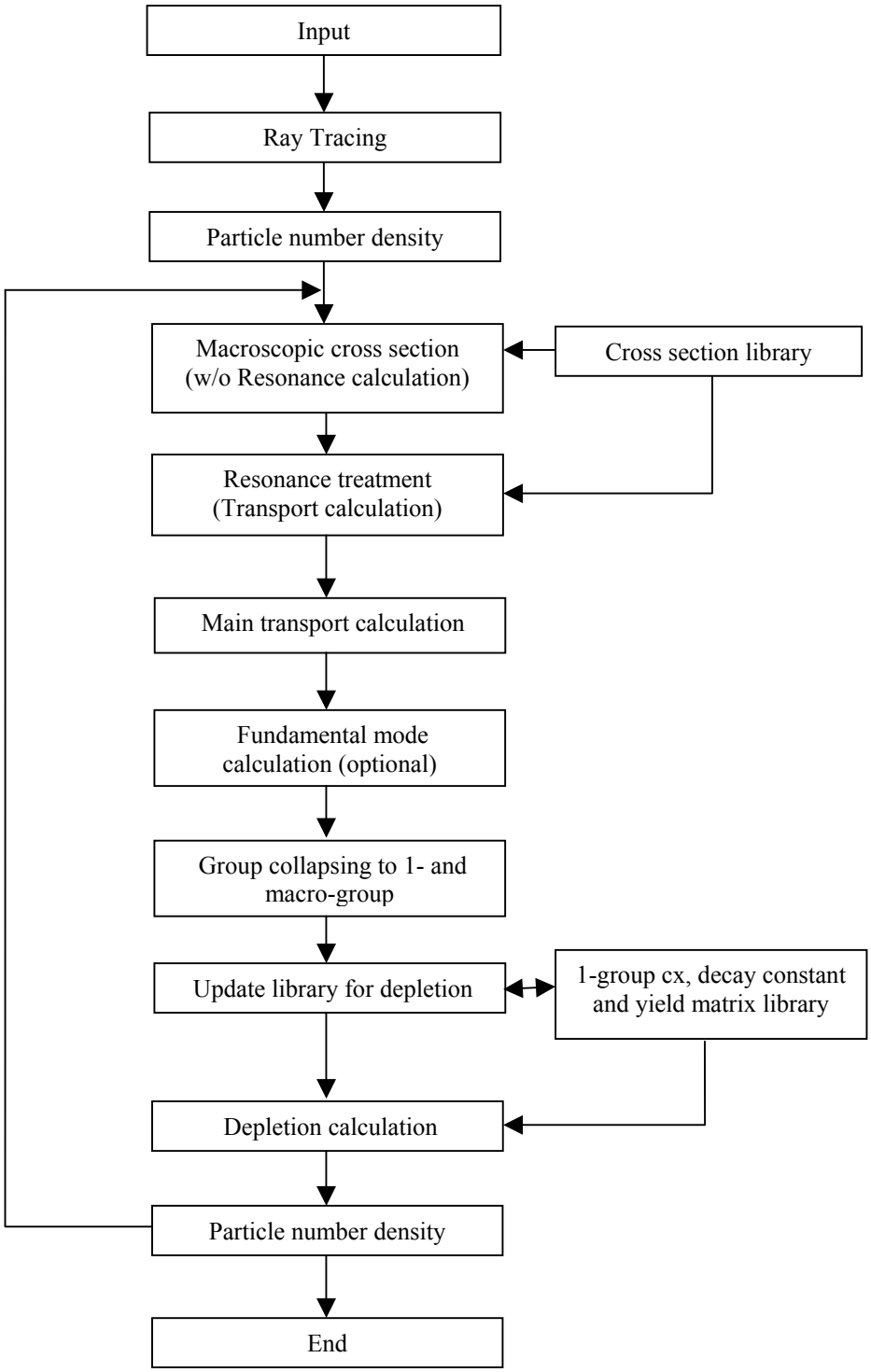

Figure 1. Flow chart for DENT-2D calculation

3. BENCHMARK CALCULATIONS

We performed benchmark calculations for the typical PWR fuel pins and assemblies and compared the results with those of the various lattice codes and Monte-Carlo code[9]. Table 1 shows the infinite multiplication factors for the variously enriched UO_2 and UO_2+Gd_2O_3 (8w/o) fuel pins with various moderator and fuel temperatures. The results of DENT-2D are consistent with those of HELIOS within maximum difference of 100 pcm. The temperature coefficients are also well consistent with those of HELIOS calculations.

We performed benchmark calculations for 16x16 PWR fuel assemblies bearing various burnable poisons by changing the moderator and fuel temperatures. Table 2 shows the multiplication factors and the pin powers compared to other reference calculations. The multiplication factors of DENT-2D are consistent with the results of HELIOS and CASMO-3 calculations. The maximum reactivity differences between DENT-2D and HELIOS are about 200 pcm. As the moderator and fuel temperature changes, the corresponding changes of multiplication factors are very consistent with those of HELIOS and CASMO-3 calculations. The pin power distributions of DENT-2D are very close to the results of HELIOS calculation with the maximum difference of 2.5%. The overall pin power distributions for 17x17 fuel assemblies shown in Figures 2 and 3 are consistent with those of HELIOS and CASMO-3 calculation.

We performed depletion calculation for the typical PWR pin cell using DENT-2D and compared the multiplication factors with those of other reference codes. Figure 4 shows the multiplication factors as a function of burnup. The multiplication factor of DENT-2D are well consistent with those of CASMO-3 and HELIOS.

Table 1. Comparison of the multiplication factors for the single pin calculations

U^{235} w/o	T_m (^oK)	T_f (^oK)	UO_2 Fuel			UO_2+Gd_2O_3 Fuel rod		
			MCNP	HELIOS	DENT-2D	MCNP	HELIOS	DENT-2D
3.0	300.0	300.0	1.39035 ±0.00073	1.39295	1.39307	0.21970 ±0.00023	0.21609	0.21619
	310.0	310.0	-	1.39220	1.39228	-	0.21674	0.21663
	300.0	600.0	1.37759 ±0.00086	1.38053	1.38061	0.21812 ±0.00030	0.21524	0.21503
5.0	300.0	300.0	1.49351 ±0.00083	1.49282	1.49386	0.30384 ±0.00034	0.30094	0.30109
	310.0	310.0	-	1.49199	1.49291	-	0.30154	0.30168
	300.0	600.0	1.47818 ±0.00096	1.47980	1.48068	0.30233 ±0.00035	0.29959	0.29954

Table 2. Comparison of the fuel assembly calculations

Case	T_m (^oK)	T_f (^oK)	Multiplication factor			*Pin power (max. % error)		
			HELIOS	CASMO-3	DENT-2D	HELIOS[a]	CASMO-3[b]	DENT-2D[b]
No-BP	300.0	300.0	1.50110	1.49775	1.50178	-	2.09	1.36
	310.0	310.0	1.50030	1.49701	1.50187	-	2.09	1.45
	300.0	600.0	1.48840	1.48788	1.49013	-	2.09	1.36
Gadolinia	300.0	300.0	1.45120	1.44930	1.45151	-	4.61	2.45
	310.0	310.0	1.45020	1.44830	1.45045	-	4.08	2.45
	300.0	600.0	1.43870	1.43970	1.43915	-	3.97	2.45
Pyrex	300.0	300.0	1.37690	1.38039	1.37492	-	3.14	1.44
	310.0	310.0	1.37570	1.37911	1.37360	-	2.81	1.45
	300.0	600.0	1.36540	1.37141	1.36350	-	2.92	1.54

*) |(b-a)/a|*100.0

0.000 0.000 0.000								
1.055 1.057 1.063	1.019 1.009 1.012							
1.056 1.058 1.064	1.019 1.008 1.012	1.020 1.008 1.013						
0.000 0.000 0.000	1.057 1.064 1.064	1.059 1.067 1.067	0.000 0.000 0.000					
1.054 1.057 1.063	1.018 1.008 1.012	1.022 1.010 1.016	1.072 1.079 1.080	1.068 1.051 1.058				
1.051 1.055 1.060	1.015 1.005 1.009	1.019 1.008 1.014	1.072 1.081 1.081	1.100 1.104 1.100	0.000 0.000 0.000			
0.000 0.000 0.000	1.043 1.053 1.051	1.047 1.057 1.054	0.000 0.000 0.000	1.077 1.083 1.078	1.038 1.050 1.046	0.970 0.967 0.967		
1.019 1.026 1.026	0.985 0.979 0.980	0.986 0.979 0.981	1.023 1.035 1.028	0.982 0.976 0.977	0.943 0.944 0.945	0.920 0.923 0.920	0.903 0.908 0.903	
0.939 0.940 0.941	0.937 0.937 0.936	0.937 0.937 0.936	0.938 0.939 0.940	0.929 0.930 0.929	0.915 0.918 0.916	0.904 0.908 0.904	0.896 0.901 0.895	0.892 0.898 0.891

HELIOS	1.50545
CASMO-3	1.50216
DENT-2D	1.50606

Figure 2. Comparison of pin power distributions (No burnable poison)

0.000 0.000 0.000								
1.130 1.134 1.139	1.086 1.077 1.079							
1.115 1.120 1.126	1.069 1.058 1.062	1.045 1.028 1.033						
0.000 0.000 0.000	1.067 1.075 1.078	1.016 0.996 1.017	0.000 0.000 0.000					
1.087 1.086 1.088	0.991 0.954 0.974	0.166 0.164 0.162	1.031 1.010 1.031	1.094 1.071 1.076				
1.101 1.106 1.109	1.035 1.027 1.030	1.001 0.964 0.985	1.092 1.101 1.102	1.147 1.151 1.143	0.000 0.000 0.000			
0.000 0.000 0.000	1.115 1.128 1.121	1.114 1.125 1.115	0.000 0.000 0.000	1.136 1.142 1.132	1.029 1.014 1.027	0.166 0.164 0.162		
1.111 1.122 1.115	1.074 1.070 1.064	1.073 1.068 1.062	1.108 1.124 1.110	1.050 1.046 1.043	0.969 0.972 0.973	0.905 0.884 0.896	0.923 0.933 0.927	
1.033 1.036 1.031	1.030 1.033 1.024	1.028 1.030 1.022	1.024 1.028 1.023	1.004 1.009 1.003	0.976 0.982 0.975	0.956 0.961 0.951	0.952 0.961 0.952	0.955 0.967 0.958

HELIOS	1.37026
CASMO-3	1.37081
DENT-2D	1.36817

Figure 3. Comparison of pin power distributions (Gadolinia Rods)

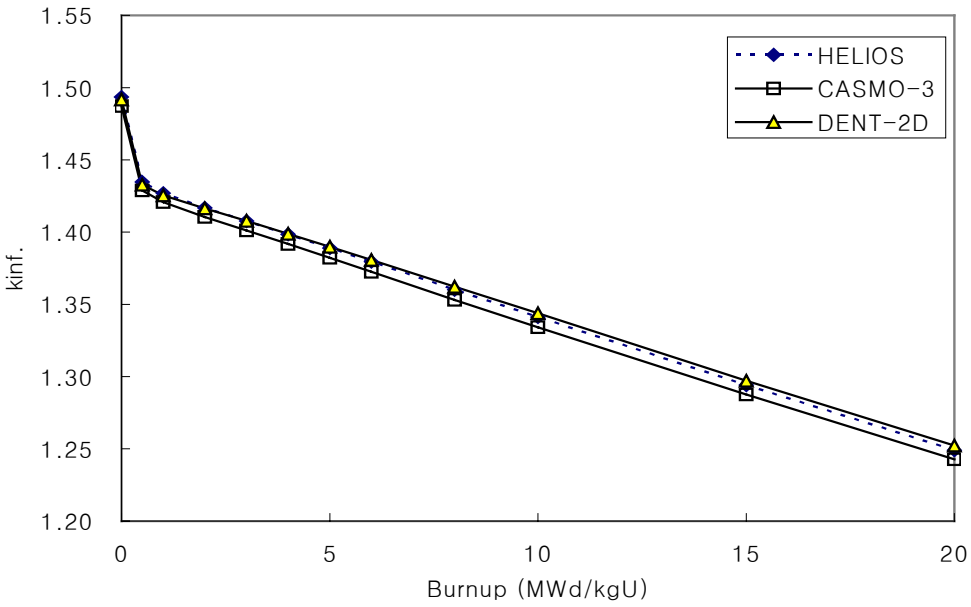

Figure 4. Comparison of infinite multiplication factors as a function of burnup

4. CONCLUSIONS

We described the features of newly developed lattice code DENT-2D and the results of benchmark calculations. The results of benchmark calculations for PWR fuel pins and assemblies show that the multiplication factors and pin powers of DENT-2D are consistent with those of other reference calculations. The multiplication factors as a function of burnup by DENT-2D are also well consistent with those of the reference codes. Therefore, DENT-2D can be used as a lattice code to generate few group constants for the subsequent diffusion nodal code such as MASTER, for the reactor physics analysis.

DENT-2D will be refined to have all the miscellaneous functions to be a complete lattice code and coupled with MASTER code. The coupled DENT-2D/MASTER package will be used to analyze the reactor physics for the operating PWR's.

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