KARMA 1.1 Benchmark Calculations for the B&W Critical Experiments with ENDF/B-VI R8 and ENDF/B-VII R0

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1. Introduction

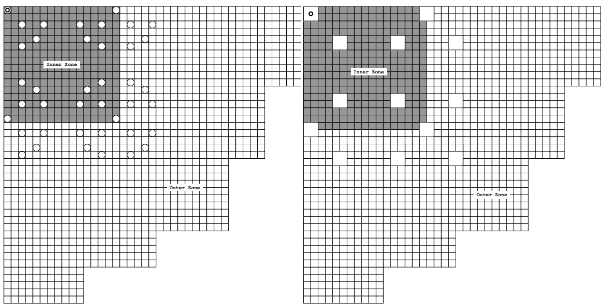
The transport lattice code KARMA 1.1 [1] has been developed at KAERI for the reactor physics analysis of the pressurized water reactor. This program includes the 47-group and 190-group libraries which are provided by the KAERI library processing system [2]. These multi-group libraries have been processed from ENDF/B-VI R8 (E6R8) and ENDF/B-VII R0 (E7R0), respectively.

As a part of code verification and validation for KARMA, benchmark calculations have been performed for the various critical experiments, which provide a more direct method for code evaluation. These critical experiments represent realistic reactor configurations with the typical PWR fuels.

In this study KARMA has been benchmarked against the B&W 1810 series [3] which consisted of a total of 23 different critical core configurations. The 1810 series is one of the most widely used to verify the modeling accuracy of gadolinia fuel. All core configurations have been analyzed, with the exception of Core 11, which was designed to measure resonance parameters. The multiplication factors have been calculated by using both the E6R8 and E7R0 based 47-group libraries, and the calculated fission rate distributions in the central pseudo-assembly for 6 cores have been compared to the measured one. Characteristics of the E6R8 and E7R0 libraries have been identified by comparing to the measured data for the B&W critical experiments.

2. Methods and Results

2.1 B&W Criticals (1810 Series)



(a) Core 1~17 (b) Core 18~20

Fig. 1. Core configurations for the B&W critical experiments.

Fig. 1(a) shows the geometry of Cores 1 through 17 which is representative of Bobcock & Wilcox (B&W), or Westinghouse type of reactor design. These cores consisted of a 5×5 array of pseudo-assemblies, each containing a 15×15 pin array. Cores 1 through 10 consisted of a uniform fuel enrichment distribution. Cores 12 through 17 consisted of a high enrichment central area surrounded by a low enriched zone. From one experiment to the next, the central pseudo-assembly was modified with gadolinia fuel rods, Ag-In-Cd (AIC) or B_4C control rods or hollow rods, which is listed in Table I.

Fig. 1(b) shows the geometry of Cores 18 through 20 which is representative of Combustion Engineering type of reactor design. These cores consisted of a 5×5 array of pseudo-assemblies, each containing a 16×16 pin array. All of these cores contained a high enrichment central area surrounded by a low enriched zone. These cores differed only in the number of gadolinia fuel rods, which is listed in Table I.

The UO_2 fuel was enriched to 2.46 and 4.02 wt% ^{235}U, and the gadolinia fuel was enriched to 1.94 wt% ^{235}U with a gadolinia loading of 4.0 wt%. Criticality was achieved by varying the boron concentration, which is listed in Table I. The geometrical axial buckling was measured for the 2-D analysis. The fission rate distributions were measured for the base configuration (Cores 1, 12, and 18) and also measured for variation (Cores 5, 14, and 20) of basic core.

2.2 Axial Leakage Consideration

Axial leakages (D_gB^2) were considered by using the measured geometrical buckling (B^2) of 0.00037 cm^{-2} [4] and the diffusion coefficients (D_g). The axial leakages were considered homogeneous for the whole critical cores. Diffusion coefficients were obtained from the KARMA B1 criticality spectrum calculations, which enabled to calculate the axial leakage D_gB^2. However, the axial leakage D_gB^2 might be far from the actual axial leakages.

2.3 Benchmark Calculation

Benchmark calculations were performed for 22 core configurations. The core was modeled as octant core symmetry with reflective boundary conditions on the two fuel sides and a vacuum boundary on the reflector sides. The KARMA model used a single ring in every cylinder region and moderator region of each pin cell. Flat source regions in water reflector used the same model. The KARMA calculations were run with the ray tracking option of 3 polar angles for 90°, 8 azimuthal angles for 90°, and a ray-spacing of 0.03 cm.

Table I: Comparison of KARMA Results

Core No.	No. of Gd Pins	No. of B_4C Pins	No. of AIC Pins	No. of Void Pins	CBC (ppm)	Multiplication Factor		Fission Rate RMS (%)	
						E6R8 Library	E7R0 Library	E6R8 Library	E7R0 Library
1	0	0	0	0	1337.9	1.00294	1.00858	0.580	0.596
2	0	0	16	0	1250.0	1.00184	1.00741		
3	20	0	0	0	1239.3	1.00198	1.00748		
4	20	0	16	0	1171.7	1.00208	1.00758		
5	28	0	0	0	1208.0	1.00135	1.00684	0.676	0.683
5A	32	0	0	0	1191.3	1.00119	1.00665		
5B	28	0	0	0	1207.1	1.00147	1.00695		
6	28	0	16	0	1155.8	1.00122	1.00671		
6A	32	0	16	0	1135.6	1.00100	1.00647		
7	28[1)]	0	0	0	1208.8	1.00145	1.00695		
8	36	0	0	0	1170.7	1.00124	1.00671		
9	36	0	16	0	1130.5	1.00079	1.00627		
10	36	0	0	16	1177.1	1.00107	1.00652		
12	0	0	0	0	1899.3	1.00339	1.00897	0.734	0.711
13	0	16	0	0	1635.4	1.00194	1.00741		
14	28	0	0	0	1653.8	1.00256	1.00795	0.820	0.817
15	28	16	0	0	1479.7	1.00180	1.00718		
16	36	0	0	0	1579.4	1.00255	1.00788		
17	36	16	0	0	1432.1	1.00139	1.00673		
Average (Cores 1~17)						1.00175	1.00722		
Std. Dev. (Cores 1~17)						0.00070	0.00073		
18	0	0	0	0	1776.8	1.00507	1.01087	0.952	0.955
19	16	0	0	0	1628.3	1.00444	1.01011		
20	32	0	0	0	1499.0	1.00409	1.00965	1.099	1.117
Average (Cores 18~20)						1.00454	1.01021		
Std. Dev. (Cores 18~20)						0.00050	0.00061		
Average (All Cores)						1.00213	1.00763		
Std. Dev. (All Cores)						0.00118	0.00126		

1) Annular

2.4 Results

Table I provides a comparison of the multiplication factors and the fission rate RMS errors between the calculated and measured for the B&W critical cores. Although approximate diffusion coefficients have been used in the KARMA calculations, the multiplication factors calculated by using the E6R8 library are very close to the criticality within the errors of 70~510 pcm. The average is 1.00213 with a standard deviation of 0.00118 for all cores. However, the E7R0 library overestimates the multiplication factors within the errors of 620~1020 pcm. The average is 1.00763 with a standard deviation of 0.00126 for all cores. There is a significant difference between the E6R8 and the E7R0 libraries for the multiplication factors with an average of 550 pcm. Fission rate distributions are not sensitive to the axial leakage. These benchmark calculations could be very helpful in estimating the prediction capability of KARMA for the fission rate distributions. Since the measured fission rate distributions were obtained by the summation for the symmetric fission rates, the measured uncertainty is included in the measured fission rate distribution. The calculated fission rates are very consistent with the measured values, where the maximum RMS error is about 1.1 %. There is no difference between the E6R8 and E7R0 libraries for the fission rates.

3. Conclusions

KARMA 1.1 benchmark calculations were performed for the B&W critical experiments by using both the E6R8 and the E7R0 libraries. The benchmark results show that the multiplication factors for the E7R0 library are greater than those for the E6R8 library. It can be concluded that newly developed KARMA 1.1 and the E6R8 based library are working reasonably.

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