THE USE OF WIMS-ANL LUMPED FISSION PRODUCT CROSS SECTIONS FOR BURNED CORE ANALYSIS WITH THE MCNP MONTE CARLO CODE*

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ABSTRACT

Most Monte Carlo neutronics analyses are performed for fresh cores. To model snapshots of the cores at different stages during burnup using MCNP[1], a method is presented that uses lumped fission product (LFP) cross sections generated by the WIMS-ANL[2] code and processed for use in MCNP. Results of analyses for four very different reactor cores using MTR-type and Russian-designed fuel assemblies, with LEU and HEU fuels, are provided to demonstrate the use of this method.

INTRODUCTION

To model reactor cores at different levels of burnup using Monte Carlo (MC) methods, the models must include a representation of the fission products. Inclusion of all the fission products in the models would be ideal. However, the diffusion theory codes used to perform reactor burnup calculations with multi-group cross sections represent only some of the fission products explicitly and lump the others into one or two so-called LFP. In order to use the compositions from the burnup analyses, a method needs to be developed to use the same lumped fission product(s) in the Monte Carlo code as those used in the diffusion theory burnup codes.

The RERTR program at Argonne National Laboratory (ANL) has for many years successfully used the WIMS code to generate burnup dependent cross sections (including LFP) and the REBUS[3] code for reactor burnup analyses. Also, in the last five years, the MCNP Monte Carlo code with a continuous energy cross section library has been used extensively. MCNP can be run using a mixture of continuous energy and discrete energy cross sections.

In this paper, a method using the WIMS-ANL code to generate multi-group LFP cross sections (discrete cross sections in MCNP nomenclature) for use in MCNP is discussed. Results of the use of this method for four research reactors are provided.

LFP CROSS SECTIONS GENERATION IN WIMS-ANL

The cross section libraries (ENDF-B/V and ENDF-B/VI) for the WIMS-ANL code contain explicit data for 35 fission products and data for a lumped fission product that simulates all of the remaining fission products. This representation of the fission products is the same as for the WIMS-D4[4] code; other cross section codes use similar representations.

The WIMS-ANL code is capable of generating lumped fission product cross sections for all of the fission products or with selected isotopes excluded. These cell or region averaged data can be extracted at the broad group level (up to 20 energy groups) as microscopic cross sections in the ISOTXS format. These cross sections are used in the REBUS burnup code. Internally, the WIMS code also generates region-averaged cross sections in an intermediate group structure that can utilize the maximum number of fine groups in the library. Presently, fine-group libraries with 69 and 172 groups are used in the ANL RERTR Program.

A code was written to extract region-averaged capture and scattering cross sections for the lumped fission product(s) from WIMS-ANL in 69 or 172 groups in a format accepted by MCNP. The number of energy groups in this discrete cross section library is limited only by the data available in the WIMS fine group library.

Figures 1 and 2 show the burnup-dependent, 69-group capture cross sections for two of the reactors used in this paper. These figures show that the LFP cross sections are very dependent upon the fuel burnup in the thermal range; they also vary from reactor to reactor because of differences in neutron spectra. This strong burnup dependence requires the generation of these LFP at many stages in the burnup in order to match the different burnup levels in all the regions/zones in the burned core.

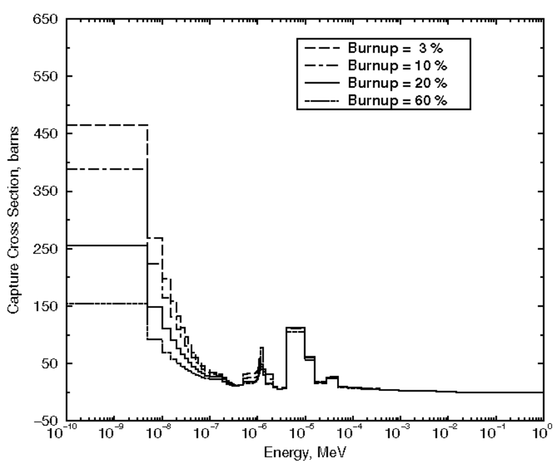

Figure 1. MARIA: Burnup Dependent Lumped Fission Product Cross Section

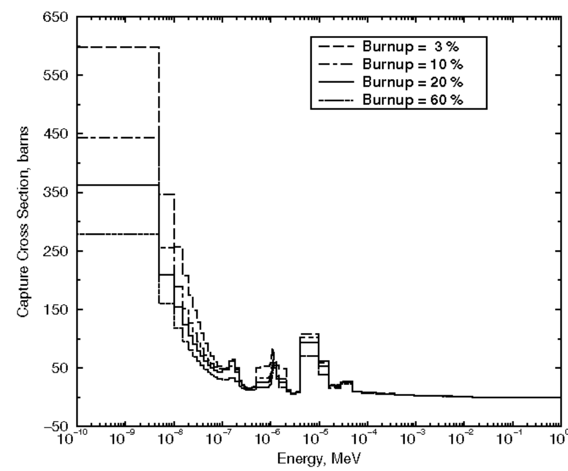

Figure 2. HFBR: Burnup Dependent Lumped Fission Product Cross Section

RESULTS

Four reactors with very different designs (two using MTR-type fuel and two using Russian-designed fuel assemblies) and several different enrichments where used to compare the results of REBUS calculations with MCNP calculations using 69-group LFP cross-sections generated by WIMS-ANL. To maximize the importance of the LFP, the analyses presented in this paper uses only Xe, I, Sm, and Pm as explicit fission products.

The MARIA Reactor

The MARIA Reactor[5], is a multipurpose, high-flux research reactor located in Swierk, Poland. Standard U-Al alloy HEU (80 wt % ^{235}U) fuel assemblies consist of six circular concentric fuel tubes each with a wall thickness (clad plus fuel meat) of 2.0 mm, water channels of thickness 2.5 mm between the fuel tubes, and a fuel height of 100 cm. Fuel assemblies are surrounded by beryllium and are located on a square grid with a 13 cm pitch on the core midplane. The reactor power depends on the core configuration, but is typically of the order of 20 MW. The reactor core has a graphite reflector.

In the analysis for the MARIA reactor presented in this paper, the equilibrium cycle of a core containing 16 fuel assemblies and a power level of 17 MW was used. The cycle length was seven days and one fuel assembly was replaced at the end of each cycle.

A comparison of the REBUS results with the MCNP4B results using the LFP generated with the WIMS-ANL code are provided in Table 1. These analyses were performed for the core with fresh fuel, and at the beginning and at the end of the equilibrium cycle. The results in Table 1 show that the reactivity worth of the LFP, and of all fission products is nearly the same for both methods, validating the use of the LFP cross-sections in MCNP. Table 1 shows that the reactivity worth of the LFP is 1.24% and 1.51% in the diffusion theory analysis at the BOEC and EOEC, respectively. The equivalent worths in the MC analysis are 1.33% ± 0.08% and 1.54 % ± 0.08. Table 1 also shows, in the last column, that the reactivity bias between the two codes is nearly constant through the cycle.

Table 1: Comparison of Fission Product Reactivity Worths for the MARIA Reactor

Case	REBUS/DIF3D	MCNP	(%Δρ)
Fresh Core, k-eff	1.21496	1.19144 (± 0.00090)	1.63 (± 0.06)
Beginning Of Equilibrium Cycle			
k-eff with All Fission Products	1.08008	1.06178 (± 0.00065)	1.60 (± 0.06)
k-eff without LFP	1.09480	1.07704 (± 0.00066)	1.51 (±0.06)
k-eff without Any Fission Products	1.13988	1.12048 (± 0.00081)	1.52 (± 0.06)
Worth of LFP (% Δρ)	-1.24	-1.33 (±0.08)	
Worth of All FP (% Δρ)	-4.86	-4.93 (± 0.09)	
End Of Equilibrium Cycle			
k-eff with All Fission Products	1.05869	1.04001 (± 0.00069)	1.70 (± 0.06)
k-eff without LFP	1.07591	1.05698 (± 0.00052)	1.66 (± 0.06)
k-eff without Any Fission Products	1.12935	1.10924 (± 0.00040)	1.61 (± 0.03)
Worth of LFP (% Δρ)	-1.51	-1.54 (± 0.08)	
Worth of All FP (% Δρ)	-5.91	-6.00 (± 0.07)	

The BNL High Flux Beam Reactor (HFBR)

The HFBR[6] is a heavy-water-moderated and cooled high-flux beam-tube reactor located at the Brookhaven National Laboratory. The core consists of 28 closely packed, MTR-type fuel assemblies. Each fuel assembly contains 351 g of ^{235}U using 93% enriched uranium. At a power of 40 MW, the reactor is designed to operate on a 22-day equilibrium fuel cycle in which 7 spent fuel assemblies are discharged, fuel is shuffled, and 7 fresh fuel assemblies are inserted. The equilibrium fuel cycle is used in this paper.

A comparison of the REBUS results with the MCNP4B results using LFP cross sections generated with the WIMS-ANL code are provided in Table 2. These analyses were performed for the core with fresh fuel, and at the beginning of the equilibrium cycle (BOEC) and at the end of the equilibrium cycle (EOEC). The results in Table 2 show that the reactivity worth for all fission products is nearly the same for both methods (6.40% vs. 6.44% ± 0.07% at BOEC, and 9.53% vs. 9.65% ± 0.08% at EOEC). The reactivity worth of the Lumped Fission Product is also basically the same at BOEC (2.73% in REBUS and 2.81% ± 0.06% in MCNP). However, at EOEC some difference does exist in the reactivity worth of the LFP (about 0.33% ± 0.08%). The reason for this small difference has not yet been determined, but it is probably due to differences in flux spectra. It is important to note that the most important result is the worth of all fission products because that really defines the state of the reactor at that instant in time.

Table 2: Comparison of Fission Product Reactivity Worths for the HFBR

Case	REBUS/DIF3D	MCNP	(%Δρ)
Fresh Core, k-eff	1.23996	1.24003 (± 0.00062)	0.005 (± 0.04)
Beginning Of Equilibrium Cycle			
k-eff with All Fission Products	1.11956	1.12296 (+/0. 00056)	0.27 (± 0.04)
k-eff without LFP	1.15486	1.15955 (+/0. 00058)	0.36 (± 0.04)
k-eff without Any Fission Products	1.20597	1.21053 (± 0.00072)	0.31 (± 0.05)
Worth of LFP (% Δρ)	-2.73	-2.81 (± 0.06)	
Worth of All FP (% Δρ)	-6.40	-6.44 (± 0.07)	
End Of Equilibrium Cycle			
k-eff with All Fission Products	1.06066	1.06463 (± 0.00064)	0.35 (± 0.06)
k-eff without LFP	1.11888	1.12754 (± 0.00068)	0.69 (± 0.05)
k-eff without Any Fission Products	1.17993	1.18655 (± 0.00084)	0.47 (± 0.06)
Worth of LFP (% Δρ)	-4.91	-5.24 (± 0.08)	
Worth of All FP (% Δρ)	-9.53	-9.65 (± 0.08)	

The Brookhaven Medical Research Reactor (BMRR)

The BMRR[7] is a 3 MW research reactor that is cooled and moderated with light water and reflected with graphite. It is used for medical research purposes. The present BMRR core uses 28 HEU (93% enriched) MTR-type fuel assemblies. However, in this analysis, a potential alternative core[7] containing 17 MTR-type fuel assemblies with LEU (19.75% enrichment) is used. This core is similar to the first HEU core of the BMRR.

In this paper, a non-equilibrium fuel cycle with the equivalent of fifteen full-power days (basically one full year of operation) is used. The results of the REBUS and MCNP analyses are presented in Table 3. These results show that the reactivity worth of the LFP (0.21% in REBUS and 0.20% ± 0.05% in MCNP), and of all the fission products (3.67% in REBUS and 3.67% ± 0.05% in MCNP) are the same in both REBUS and MCNP.

Table 3: Comparison of Fission Product Reactivity Worths for a Potential LEU Core in the BMRR

Case	REBUS/DIF3D	MCNP	(%Δρ)
Fresh Core, k-eff	1.05795	1.06684 (± 0.00018)	0.79 (± 0.02)
End of Cycle			
k-eff with All Fission Products	1.01288	1.02177 (± 0.00044)	0.86 (± 0.04)
k-eff without LFP	1.01508	1.02385 (± 0.00030)	0.84 (± 0.04)
k-eff without Any Fission Products	1.05195	1.06155 (± 0.00029)	0.86 (± 0.03)
Worth of LFP (% Δρ)	-0.21	-0.20 (± 0.05)	
Worth of All FP (% Δρ)	-3.67	-3.67 (± 0.05)	

A Reactor Using VVR-M2 Fuel Assemblies

Reference 8 describes several critical experiments using Russian-designed VVR-M2 fuel assemblies. Based on this information, a model was created for a reactor that contains 127 fuel assemblies and is light-water cooled and reflector. The VVR-M2 fuel assemblies selected use HEU fuel with 36% enrichment and consist of three fuel elements: two inner concentric elements and an outer hexagonal element. A power level of 5 MW, and a reactivity rundown equivalent to 27 full-power days was used.

The results of the analyses for this reactor are shown in Table 4. The reactivity worth of the LFP (0.95% in REBUS and 0.90% ± 0.05% in MCNP), and of all fission products (4.96% in REBUS and 5.07% ± 0.05% in MCNP) are essentially the same in both analyses.

Table 4: Comparison of Fission Product Reactivity Worths for a Reactor With VVR-M2 Fuel

Case	REBUS/DIF3D	MCNP	(%Δρ)
Fresh Core, k-eff	1.08870	1.06930 (± 0.00038)	1.67(± 0.03)
End of Cycle			
k-eff with All Fission Products	1.01601	0.99777 (± 0. 00036)	1.80 (± 0.04)
k-eff without LFP	1.02591	1.00680 (± 0. 00034)	1.85 (± 0.03)
k-eff without Any Fission Products	1.06995	1.05093 (± 0.00042)	1.69 (± 0.04)
Worth of LFP (% Δρ)	-0.95	-0.90 (± 0.05)	
Worth of All FP (% Δρ)	-4.96	-5.07 (± 0.05)	

CONCLUSIONS

Most Monte Carlo neutronics analyses are performed for fresh cores. To adequately model snapshots of reactor cores at different stages of burnup with Monte Carlo codes, a method was developed that uses lumped fission product cross sections generated by the WIMS-ANL code and processed for use in MCNP.

Four very different reactors were used in this paper to demonstrate that the developed method can adequately represent the reactors at different burnup conditions. The results presented here clearly show that the use of the WIMS-ANL cross sections for the LFP with the MCNP code provides a good method for Monte Carlo analysis of burned cores.

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