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CASMO-5 GAMMA LIBRARY

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ABSTRACT

A new ENDF/B-VII gamma library for 214 nuclides/materials in 18 gamma/70 neutron energy groups has been built for inclusion with the CASMO-5 lattice physics code. The methodology for developing this library uses NJOY-99.259 and other newly developed processing codes in contrast to the nuclear data and the methods of 1980's employed for the current CASMO-4 gamma library. Validation and verification of the new library is mainly done through CASMO-5 and MCNP-5 comparisons. Gamma energy depositions are also analyzed for various test problems and gamma TIP full core SIMULATE-3 predictions are compared for the new and the (old) production CASMO-4 gamma libraries.

1. INTRODUCTION

The current CASMO-4 production gamma library contains CLOSEUP data based on ENDF/B-IV files and processed with SCALE[1] in the mid 1980's. The development of the state-of-the-art CASMO-5[2] lattice physics code and the progress of nuclear data and processing codes demand a new gamma library and a new development methodology, based on the recent ENDF/B-VII R0 data files[3] (released December 15, 2006) and the latest NJOY-99.259 code[4] (from Los Alamos National Laboratory, released October 16, 2007). Here, we describe the CASMO-5 gamma library with data extended for 214 nuclides/materials in coupled 18 gamma /70 neutron energy groups compared to the only 19 nuclides/materials and 18 gamma /25 neutron groups of the old CASMO-4 gamma library[5]. A challenging task is the evaluation and verification of the library due to the absence in the literature of benchmarks for gamma lattice calculations. First we performed the testing through inter-code comparisons for ad hoc problems, and second, we analyzed the results of the same CASMO code run with two different gamma libraries, respectively with the well-tested production library and the newly developed library. The inter-code comparisons, CASMO versus MCNP, are critical for the testing of the new library. The second testing procedure is mostly intended for double-checking the implementation of the new methodology and data, because the two libraries are expected to deliver similar results. In this paper, we compare CASMO and MCNP gamma energy depositions for an 8x8 BWR fuel lattice at different state conditions. The same BWR fuel segment depleted up to 70 GWD/Mt and the APWR reactor model[6] have been also used to compare CASMO results of the old and the new gamma libraries. In addition, full core gamma TIP predictions from CASMO and SIMULATE-3 have been compared for the new and old gamma libraries. As other tests become available, we will continue the evaluation of the new library, since this is an ongoing process.

2. DEVELOPMENT AND DESCRIPTION

The library includes the following data: frequency functions for prompt and delayed gamma, gamma absorption, transport, P0-scattering and energy deposition cross sections. The prompt frequency function of isotope *m* is defined as the ratio of total gamma production cross section [barns] in gamma group *g* from neutrons in group *n* to the neutron absorption cross section [barns] of isotope *m* in group *n.* The gamma production cross section includes production from fission, capture, incoherent photon (Compton), coherent photon scattering (Rayleigh), and neutron inelastic scattering. The delayed frequency function in each gamma group *g* is calculated from prompt gamma fission data (MF=16, MT=18) by using a photon multiplicity that is determined as the ratio of a reduced delayed energy per fission to the prompt gamma energy per fission.

The gamma only data depend on the atomic number (Z), but are not isotope dependent, while the frequency functions vary with (n,γ) production matrices and neutronic cross sections that are different for each isotope. In the new calculational methodology, both the prompt and delayed frequency functions are simply derived from the (n,γ) production matrices[7], while in the old approach the delayed frequency functions used fits of delayed gamma sources along the cooling time axis with a linear combination of exponentials[3]. In the case of natural elements with no data in ENDF/B-VII (e.g., iron, tin, gadolinium), the frequency functions were derived by adding the frequency functions of the constituent nuclides according to their natural abundance[8]. For the fission products with missing ENDF/B-VII data, the (n,γ) production matrices were produced with the R-parameter method[8], which calculates gamma multiplicities from each continuum gamma reaction and from inelastic neutron scattering to discrete levels.

The energy group boundaries of the library are identical to the CASMO-4[5] standard 70/18 neutron and gamma group structures, and all the required data have been evaluated at a temperature of 296K because the gamma cross sections are temperature independent. The calculation of the specific parameters used in the CASMO gamma transport module was done by processing the GENDF files resulting from NJOY runs with the new auxiliary GAMPREP[7] code. The GAMPREP code reads different cross section types identified by the MF and MT ENDF parameters and calculates the cross section data of the CASMO-5 gamma library. To this end, the ASCII file produced by GAMPREP was processed with the CASLIB[9] code to obtain the library file in binary format.

3. VALIDATION TESTS

3.1 Prompt Gamma Calculations for a BWR 8x8 Fuel Segment

Gamma calculations for a BWR 8x8 fuel segment (3.4 % wt ^{235}U) with one large central water rod and 9 fuel types including natural Gd (4% wt) were performed for a range of cases including uncontrolled (un), B_4C controlled (cr), cold zero power (CZP), hot zero power (HZP), and 80% void. CASMO-5 was run with the production galb418 (G4) and the new E7 gamma library, and the e7r0.124.586.bin neutronic library. The MCNP-5 (version 1.40) calculations were run with 5 million histories, 10,000/500 active cycles, and ENDF/B-VII cross section data, for prompt gamma energy (F6 tally) and fission energy depositions (F7 tally). For theses runs, we also built the MCNP gamma cross sections with the ACER module of NJOY. The prompt CZP gamma depositions relative to the total fission energy deposition are shown in Tables 1-3 with FU and NF referring to Fueled and Non Fueled regions, respectively.

Table 1 BWR 8x8 (Cold Zero Power) Prompt Gamma Energy Depositions

Case	CAS5 (G4)	CAS5 (E7)	MCNP-5	1-sigma	ΔCAS5 (G4)	ΔCAS5 (E7)	(G4-E7) / G4%
FU-un	5.430	5.420	5.225	0.005	3.93%	3.74%	0.18%
NF-un	1.714	1.743	1.907	0.005	-10.14%	-8.57%	-1.69%
TOT-un	7.145	7.163	7.145	0.006	-0.01%	0.25%	-0.25%
FU-cr	5.680	5.623	5.549	0.004	2.35%	1.33%	1.00%
NF-cr	1.892	1.945	2.175	0.004	-13.00%	-10.56%	-2.80%
TOT-cr	7.573	7.569	7.724	0.006	-1.96%	-2.01%	0.05%

Table 2 BWR 8x8 (Hot Zero Power) Prompt Gamma Energy Depositions

Case	CAS5 (G4)	CAS5 (E7)	MCNP-5	1-sigma	ΔCAS5 (G4)	ΔCAS5 (E7)	(G4-E7) / G4%
FU-un	5.656	5.645	5.517	0.004	2.52%	2.32%	0.19%
NF-un	1.672	1.645	1.898	0.005	-11.89%	-13.31%	1.61%
TOT-un	7.145	7.290	7.331	0.006	-2.53%	-0.55%	-2.03%
FU-cr	6.175	5.909	5.918	0.003	4.33%	-0.16%	4.31%
NF-cr	1.958	1.882	2.112	0.004	-7.29%	-10.89%	3.88%
TOT-cr	8.133	7.791	8.030	0.005	1.28%	-2.98%	4.21%

These tables show the relative differences (Δ) between CASMO and MCNP as well as the differences between the results of the old and new CASMO gamma libraries. In both the controlled and uncontrolled cases, the CASMO errors relative to MCNP vary between [0.55%, 15.84%] for the old and [-0.16%, -11.49%] for the new gamma library. The errors are larger in controlled non-fuel regions that have smaller gamma energy depositions and are smaller in fuelled regions. Also, there is no specific bias for the relative errors in the fuelled controlled-uncontrolled regions. However, both libraries obtain very close results (less than 5.17%), as shown in the last column of Table 3.

Table 3 BWR8x8 (Cold V80) Prompt Gamma Energy Depositions

Case	CAS5 (G4)	CAS5 (E7)	MCNP-5	1-sigma	ΔCAS5 (G4)	ΔCAS5 (E7)	(G4-E7) / G4%
FU-un	6.275	6.323	6.346	0.004	-1.12%	-0.37%	-0.76%
NF-un	1.514	1.559	1.718	0.005	-11.90%	-9.28%	-2.97%
TOT-un	7.788	7.881	8.068	0.006	-3.47%	-2.31%	-1.19%
FU-cr	6.812	6.819	7.055	0.004	-3.45%	-3.35%	-0.10%
NF-cr	1.800	1.893	2.139	0.004	-15.84%	-11.49%	-5.17%
TOT-cr	8.612	8.711	9.194	0.005	-6.33%	-5.25%	-1.15%

3.2 Gamma Energy Deposition in APWR model

In this section, we present some gamma results for the CASMO APWR model (w/ baffle and water reflector, hot full power, zero exposure) shown in Figure 1. Comparisons of total (prompt + delayed) gamma energy depositions are given with the new and the old production gamma library and the e7r0.120.586.bin neutronic library.

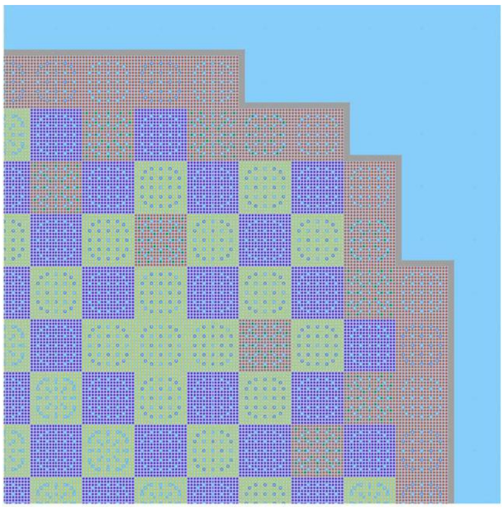

Fig. 1 CASMO MxN Model of APWR w/Baffle and Water Reflector

As seen in Table 4, the maximum relative differences between the old and new gamma energy results occur in NF regions that have lower gamma deposition (-3.24% in the 12th reflector segment and 2.44% in the NF region of the 34th fuel segment). However, the gamma depositions are very similar for the two gamma libraries with a difference of ~1.2% in the fuel segment. The prompt gamma fluxes in fuel segment 34 are also shown in Figure 2 for both gamma data.

Table 4 APWR Total Gamma Energy Deposition Comparison

Case	Gamma-ED (W)		(E7-G4)/ G4%
	G4	E7	
Ref12-NF	4.996E+02	4.834E+02	-3.24%
Seg34-NF	8.433E+02	8.639E+02	2.44%
Seg34-FU	3.582E+03	3.615E+03	0.92%
Seg34-Tot	4.425E+03	4.479E+03	1.21%

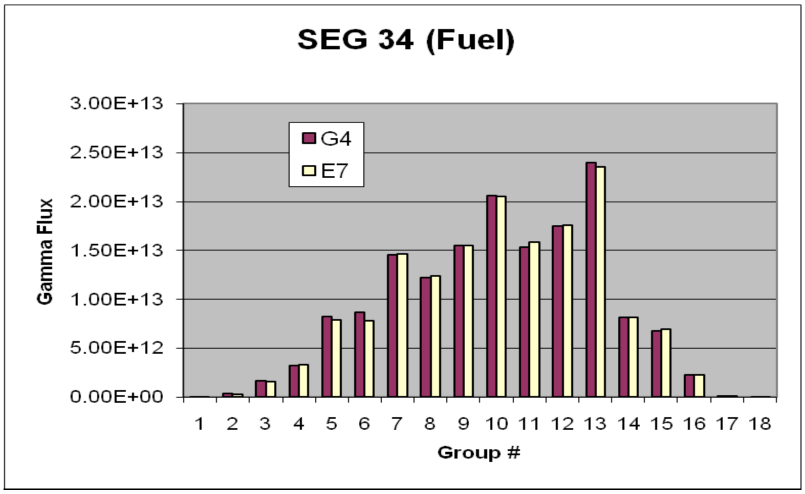

Fig. 2 Prompt Gamma Flux Comparison in 18 Groups

More significant differences between the old and new gamma fluxes occur in groups with low flux values, but the total gamma fluxes per segment (defined as the sum of all the group fluxes) are within 0.5%.

3.3 Comparisons of Gamma Energy Deposition versus Depletion

To assess gamma data and results for the large number of isotopes that appear during fuel depletion, we performed BWR 8x8 burnup calculations and evaluated the total gamma energy deposition up to 70 GWd/Mt. The CASMO results for the new and old gamma libraries are very similar, with the differences between the energy depositions of the two libraries varying within [-5.10%, 4.05%] for the entire range of exposures and fuel – non-fuel regions. The gamma energy deposition profiles in non-fuel and fuel region and the variation of the relative differences between the old and new results for each of the region and state (controlled and uncontrolled) are plotted in Figures 3 and 4.

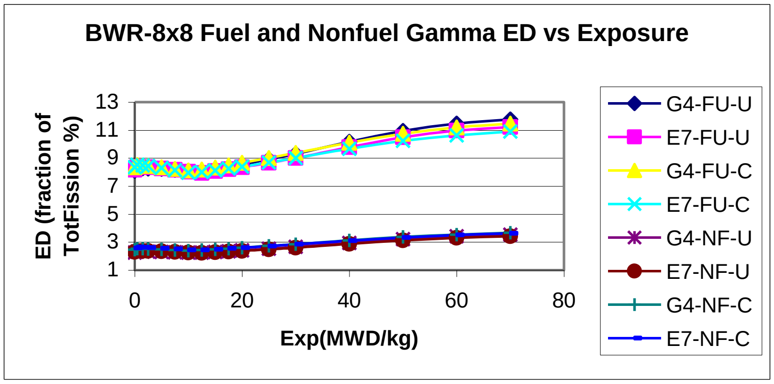

Fig.3 BWR-8x8 Gamma Energy Deposition versus Exposure

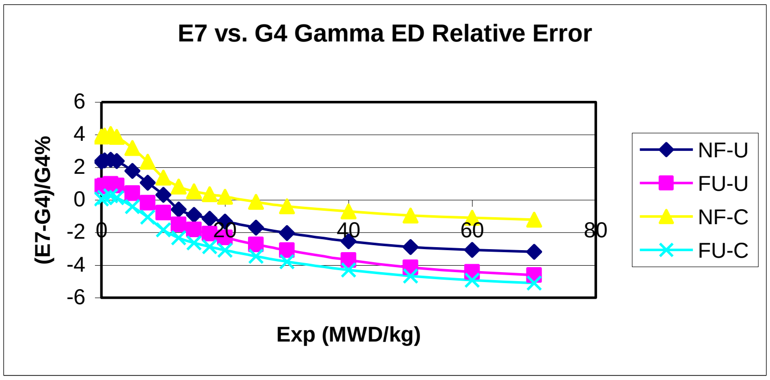

Fig.4 BWR-8x8 Gamma Energy Relative Error versus Exposure

3.4 Gamma Tip Detector Comparisons

Gamma tip measurements were compared to detector responses calculated with SIMULATE-3 via gamma detector factors obtained with CASMO-5. The prediction calculations were performed for 20 cycles of two different reactors and a total of 243 state points. The RMS differences of the calculated individual TIP results and the measured values are 5.14% (G4) and 5.01% (E7), respectively. So, both the old and new gamma libraries show comparable SIMULATE-3 gamma TIP predictions, with a slight improvement of the E7 over the G4 tip results.

4. CONCLUSIONS

A new CASMO-5 gamma library was developed with a methodology based on ENDF/B-VII cross section data and the latest NJOY-99.259 code package. Preliminary testing with CASMO and MCNP showed total gamma energy depositions (fuel + non-fuel regions) within about 2%. Also, CASMO calculations for the APWR model with the old and new gamma libraries have produced similar gamma results (within 3.24%). There are some larger differences for the group gamma fluxes of the APWR reflector, but this is expected, due to large uncertainties in the (n,γ) production data. The use of the new gamma library in global reactor calculations resulted in slightly TIP results.

5. REFERENCES

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