Verification and Validation of Fast Systems with ENDF/B Data

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An extensive and systematic verification, validation and data testing effort using diverse Monte Carlo and deterministic methods with ENDF/B data (Versions V.2 and VI.5) is in progress. Methods verification is obtained by comparing independent methods, including continuous-energy Monte Carlo methods using the VIM[1] and MCNP[2] codes and 1D and 2D transport calculations using multigroup cross section sets generated with the ETOE-II/MC^2-2 system[3] combined with the TWODANT[4] code. Each of these code systems relies on independently processed data libraries. Inter-comparison of these results is used for verification. Further verification is achieved by comparing and plotting the point-wise cross section libraries of VIM and MCNP. Where possible, benchmark models are taken from both the ICSBEP Handbook[5] and the CSEWG Benchmark Specifications.[6] Inter-comparison of these results quantifies the generally small differences between these references. Calculations are repeated with both ENDF/B-V.2 and ENDF/B-VI.5 data. Inter-comparison of these results quantifies their data dependence. Analyses of criticality and reaction rate ratios are used for the validation and data testing. Calculated neutron balances and neutron energy spectra are also obtained and analyzed to explain the observed differences.

To date, selected fast critical assemblies, including nine of the standard LANL fast critical assemblies (GODIVA, JEZEBEL, FLATTOP-25, FLATTOP-PU, BIGTEN, FLATTOP-23, JEZEBEL-PU240 JEZEBEL-U233, JEZEBEL-TH232) and three of the ANL ZPR fast critical assemblies (ZPR-3 Assembly 48, ZPR-6 Assemblies 6A and 7), have been analyzed with VIM and MCNP as well as with multigroup cross section sets generated with the ETOE-II/MC^2-2 system.

Illustrative results for GODIVA and JEZEBEL are presented in Tables 1 (eigenvalues) and 2 (reaction rate ratios). Results shown in Table 1 indicate the improved treatment of the unresolved energy range in MCNP-4C (versus MCNP-4B) has no observable effect on k_{eff} for these very hard spectra. Note also the expected excellent agreement between VIM and MCNP. Agreement of the multigroup methods (P_3S_{16}) with the rigorous Monte Carlo methods is generally acceptable (within ~0.25%) for these simple systems. Furthermore, the results are virtually unchanged in switching between ENDF/B Versions V.2 and VI.5 for these two assemblies. The differences between the ICSBEP and CSEWG benchmark descriptions for these two assemblies are extremely minor – which is reflected in consistency of the calculated values.

Comparison of measured and calculated reaction rate ratios in these two assemblies are given in Table 2. Agreement between the deterministic and continuous energy Monte Carlo methods is again very good. The agreement with measured values is generally good with both Version V.2 and VI.5 data, except for the threshold reaction rate ratios. Note the consistency of the calculated-to-experimental (C/E) values on reaction rate ratios is much improved for both assemblies using the Version VI.5 data. For GODIVA the range of C/E values for these reaction rate ratios is reduced from 8.3% to 2.1% with ENDF/B-VI.5 and for JEZEBEL the range of C/E values is reduced from 4.0% to 2.0% with ENDF/B-VI.5.

Although the entire range of results for the nine LANL and three ZPR critical assemblies is somewhat larger than the limited results shown for GODIVA and JEZEBEL, the generally good agreement between these independent methods has been demonstrated for this range of fast critical assemblies. The verification and validation effort described herein – even though for a limited range of critical assemblies – has already identified small errors. Although not presented in the current paper, this effort will be extended to more varied and complicated systems. Repetition of V&V exercises such as these are requisite for quality assurance of production methods and libraries.

References

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Table 1.a. Results of keff for the GODIVA Benchmark using ENDF/B-V.2 and -VI.5 data.

	MC^2-2 (36 grp)	MC^2-2 (230 grp)	VIM	MCNP-4C	MCNP-4B
GODIVA	ENDF/B-V.2				
HEU-MET-FAST-001	0.99822	0.99824	0.9980 ± 0.0002	---	0.9975 ± 0.0003
ENDF-202	----	0.99837	---	---	---
GODIVA	ENDF/B-VI.5				
HEU-MET-FAST-001	0.99747	0.99714	0.9974 ± 0.0002	0.9969 ± 0.0005	0.9966 ± 0.0003
ENDF-202	---	0.99728	---	---	---

Table 1.b. Results of k_{eff} for the JEZEBEL Benchmark using ENDF/B-V.2 and -VI.5 data.

	MC^2-2 (36 grp)	MC^2-2 (230 grp)	VIM	MCNP-4C	MCNP-4B
JEZEBEL	ENDF/B-V.2				
PU -MET-FAST-001	0.99954	0.99922	0.9974 ± 0.0002	---	0.9970 ± 0.0003
ENDF-202	----	0.99970	---	---	---
JEZEBEL	ENDF/B-VI.5				
PU -MET-FAST-001	1.00017	1.00022	0.9978 ± 0.0002	0.9979 ± 0.0003	0.9978 ± 0.0003
ENDF-202	---	0.99728	---	---	---

Table 2.a Reaction Rate Ratios in GODIVA Calculated with ENDF/B-V.2 and -VI.5 Data.

	Experiment	VIM		MC^2-2	
		Calculation	C/E	Calculation	C/E
GODIVA		ENDF/B-V.2			
$\sigma_f(^{238}U)/ \sigma_f(^{235}U)$	0.1647 ± 0.0018	0.1719 ± 0.0003	1.0431 ± 0.0115	0.1716	1.0419 ± 0.0105
$\sigma_f(^{233}U)/ \sigma_f(^{235}U)$	1.59 ± 0.03	1.5679 ± 0.0002	0.9855 ± 0.0186	1.5690	0.9868 ± 0.0186
$\sigma_f(^{237}Np)/ \sigma_f(^{235}U)$	0.837 ± 0.013	0.8957 ± 0.0008	1.0688 ± 0.0166	0.8956	1.0700 ± 0.0154
$\sigma_f(^{239}Pu)/ \sigma_f(^{235}U)$	1.402 ± 0.025	1.3962 ± 0.0003	0.9957 ± 0.0178	1.3973	0.9966 ± 0.0172
GODIVA		ENDF/B-VI.5			
$\sigma_f(^{238}U)/ \sigma_f(^{235}U)$	0.1647 ± 0.0018	0.1614 ± 0.0005	0.9799 ± 0.0109	0.1604	0.9739 ± 0.0106
$\sigma_f(^{233}U)/ \sigma_f(^{235}U)$	1.59 ± 0.03	1.5920 ± 0.0003	1.0013 ± 0.0189	1.5916	1.0010 ± 0.0189
$\sigma_f(^{237}Np)/ \sigma_f(^{235}U)$	0.837 ± 0.013	0.8247± 0.0010	0.9842 ± 0.0153	0.8241	0.9846 ± 0.0153
$\sigma_f(^{239}Pu)/ \sigma_f(^{235}U)$	1.402 ± 0.025	1.3858± 0.0005	0.9884 ± 0.0176	1.3849	0.9878 ± 0.0174

Table 2.b. Reaction Rate Ratios in JEZEBEL Calculated with ENDF/B-V.2 and -VI.5 Data.

	Experiment	VIM		MC^2-2	
		Calculation	C/E	Calculation	C/E
JEZEBEL		ENDF/B-V.2			
$\sigma_f(^{238}U)/ \sigma_f(^{235}U)$	0.21371 ± 0.0023	0.2066 ± 0.0003	0.9666 ± 0.0105	0.2033	0.9512 ± 0.0102
$\sigma_f(^{233}U)/ \sigma_f(^{235}U)$	1.578 ± 0.027	1.5542 ± 0.0002	0.9849 ± 0.0169	1.5558	0.9859 ± 0.0166
$\sigma_f(^{237}Np)/ \sigma_f(^{235}U)$	0.962 ± 0.016	0.9679 ± 0.0007	1.0061 ± 0.0167	0.9646	1.0027 ± 0.0167
$\sigma_f(^{239}Pu)/ \sigma_f(^{235}U)$	1.448 ± 0.029	1.4124 ± 0.0003	0.9754 ± 0.0195	1.4120	0.9751 ± 0.0195
JEZEBEL		ENDF/B-VI.5			
$\sigma_f(^{238}U)/ \sigma_f(^{235}U)$	0.21371 ± 0.0023	0.2094 ± 0.0003	0.9799 ± 0.0106	0.2059	0.9634 ± 0.0104
$\sigma_f(^{233}U)/ \sigma_f(^{235}U)$	1.578 ± 0.027	1.5775 ± 0.0002	0.9998 ± 0.0171	1.5785	1.0003 ± 0.0171
$\sigma_f(^{237}Np)/ \sigma_f(^{235}U)$	0.962 ± 0.016	0.9594 ± 0.0008	0.9973± 0.0166	0.9585	0.9904 ± 0.0165
$\sigma_f(^{239}Pu)/ \sigma_f(^{235}U)$	1.448 ± 0.029	1.4262 ± 0.0004	0.9850 ± 0.0197	1.4247	0.9839 ± 0.0197