FAST AND THERMAL DATA TESTING OF LEU, IEU, AND HEU CRITICAL ASSEMBLIES[1]

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Abstract

The purpose of this paper is to report on data testing of the ENDF/B-VI, release 5, evaluation for LEU, IEU, and HEU benchmarks. In terms of the energy spectrum, there are 10 fast, 3 intermediate, and 21 thermal cases. The characteristics of each benchmark are discussed briefly. The SCALE system (either XSDRN or KENOV.a) with the VITAMIN-B6 (199-group) cross section library were utilized. Hydrogen and U235 from the ENDF/B-VI, release 5, were used in the calculations.

Introduction

The ENDF/B-VI evaluation of U235 uses the multilevel Reich-Moore formalism up to 2250 eV; the first release of the ENDF/B-VI evaluation [1] was in 1990. The ENDF/B-VI U235 evaluation was modified in 1994, release 3, by C. R. Lubitz [2]. The latest evaluation, release 5 [3] is significantly improved relative to the earlier evaluations. The principal changes which have affected the calculated k-effs for the benchmarks considered in this paper are an increase of 0.12% in the U235 total nubar and a decrease of 0.18% in the hydrogen capture cross-section. Considerable testing of the release 3 and pre-release 5 evaluations has been reported previously. One of the most significant results reported thus far is for the improved prediction of the U236 buildup in irradiated fuel. Mounier [4] found that the ENDF/B-VI release 5 evaluation is significantly better compared to the JEF-2.2 evaluation for the prediction of U236 buildup.

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The purpose of this paper is to report on data testing of the final ENDF/B-VI release 5 for LEU, IEU, and HEU benchmarks. We have included 16 LEU, 5 IEU, and 13 HEU benchmarks; in terms of the energy spectrum, there are 10 fast, 3 intermediate, and 21 thermal cases. The characteristics of each benchmark are discussed briefly. The 34 benchmarks considered in this study are a subset of the 58 benchmarks included in our previous data testing [5] of ENDF/B-VI release 3. The SCALE system with the VITAMIN-B6 (199-gr) cross section library, including the ENDF/B-VI, release 5, H-1 and U-235 evaluations were used in these calculations.

Low Enrichment Uranium (LEU) Benchmarks

CSEWG has traditionally used the TRX-1, TRX-2, BAPL-1, BAPL-2, and BAPL-3 benchmarks [6]. The PCTR experiments (1.006 to 1.157 wt% U235) are also very useful LEU benchmarks [7]. The CENTRM module (pointwise discrete-ordinates resonance self-shielding calculation) was used for calculations of the LEU benchmarks. Calculated results using ENDF/B-VI, release 5, hydrogen and U235 are given in Table 1.

Intermediate Enrichment (IEU) Benchmarks

Intermediate enrichment benchmarks are given in Volume III of the International Handbook of Evaluation Criticality Safety Benchmark Experiments [8]. IEU-MET-FAST-001 is a bare cylindrical configuration of enriched and natural uranium. IEU-MET-FAST-003 through -006 are intermediate enrichment (36 wt%) Russian critical experiments. IEU-MET-FAST-003 is a bare spherical assembly of U235 (36 wt%); -004 through -006 are U235 (36 wt%) assemblies which are reflected by graphite, steel, and duralumin, respectively. Results for these benchmarks using ENDF/B-VI release 5, hydrogen and U235 cross sections are also shown in Table 2.

High Enrichment (HEU) Benchmarks

HEU Fast Benchmarks

The highly enriched (HEU) benchmarks considered in this work are GODIVA [4], HEU-MET-FAST-018, HEU-MET-FAST-004, HEU-MET-FAST-023 [6], and 2C8 (HEU 2x2x2, [9]). Calculated results using ENDF/B-VI release 5, hydrogen and U235 cross sections are shown in Table 3.

HEU Intermediate Energy Benchmarks

We have included only three HEU intermediate energy benchmarks. These benchmarks are HISS(HUG) [10], UH3-UR, and UH3-NI [11]. The HISS(HUG) central region experiment is modeled as an infinite homogeneous uranium-graphite-boron mixture. The UH3-UR and UH3-NI critical assemblies consist of a 93 weight percent U235-hydride powder and polyethylene mixture (sphere) with an eight inch reflector shell of natural uranium or nickel, respectively. Calculated results using ENDF/B-VI, release 5 hydrogen and U235 cross sections are shown in Table 3.

HEU Thermal Benchmarks

For many years CSEWG has used the U235 ORNL spheres [6] as part of the thermal data testing program. The ORNL spheres are highly enriched uranium-nitrate solution spheres with H/U235 in the range 971 to 1835. Calculated results for the U235 ORNL spheres using ENDF/B-VI release 5 cross sections are also given in Table 3.

Conclusions

The calculated k-eff for TRX-1 is slightly low; this may be due to an overprediction of the U238 epithermal capture rate. The C/E for IEU-MET-FAST-006 (36 wt% U235 reflected by aluminum) is low and this may indicate either a problem with the aluminum cross-sections in the MeV range or possibly with the benchmark specifications. Calculated results for the intermediate energy benchmarks, HISS(HUG), UH3-UR, and UH3-NI, are improved using the ENDF/B-VI release 5 cross-sections but are still high. This may be interpreted as a problem with the U235 cross-sections but additional confirmation would be highly desirable. Additional intermediate energy HEU benchmarks would help to answer this question. The ORNL spheres are slightly underpredicted using the ENDF/B-VI, release 5, cross-sections.

The principal changes which have affected the calculated k-effs for the benchmarks considered in this paper are an increase of 0.12% in the U-235 total nubar and a decrease of 0.18% in the hydrogen capture cross-section. These changes have lead to a significant improvement in the overall performance of the revised cross-sections relative to ENDF/B-VI release 3 cross-sections. The range in the calculated k-effs is from 0.9902 to 1.0146 with an average k-eff of 1.0003 for all 34 benchmarks.

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Table 1. Low enriched uranium (LEU) benchmarks

	BENCHMARK	ENDF/B-VI.5	C/E
TRX-1	1.0000	0.9933	0.9933
TRX-2	1.0000	0.9964	0.9964
BAPL-1	1.0000	0.9996	0.9996
BAPL-2	1.0000	0.9999	0.9999
BAPL-3	1.0000	1.0011	1.0011
PCTR-1	0.986 ± 0.005	0.9902	1.0043
PCTR-2	0.986 ± 0.007	0.9833	0.9973
PCTR-3	0.974 ± 0.005	0.9756	1.0016
PCTR-4	0.960 ± 0.005	0.9684	1.0088
PCTR-5	1.005 ± 0.006	1.0104	1.0054
PCTR-6	1.005 ± 0.006	1.0101	1.0051
PCTR-7	0.992 ± 0.007	0.9977	1.0057
PCTR-8	1.031 ± 0.006	1.0348	1.0037
PCTR-9	1.031 ± 0.005	1.0375	1.0063
PTCR-10	1.030 ± 0.007	1.0299	0.9999
PCTR-11	1.019 ± 0.005	1.0232	1.0041
AVERAGE			1.0020

Table 2. Intermediate enrichment uranium (IEU) benchmarks

	BENCHMARK	ENDF/B-VI.5	C/E
IEU-MET-FAST-001	0.9988 ± 0.0009	0.9957 ± 0.0007	0.9969

	BENCHMARK	ENDF/B-VI.5	C/E
IEU-MET-FAST-003	1.0000 ± 0.0017	0.9978 ± 0.0008	0.9978
IEU-MET-FAST-004	1.0000 ± 0.0030	1.0030 ± 0.0008	1.0030
IEU-MET-FAST-005	1.0000 ± 0.0021	0.9964 ± 0.0007	0.9964
IEU-MET-FAST-006	1.0000 ± 0.0023	0.9902 ± 0.0007	0.9902
AVERAGE			0.9969

Table 3. High enrichment uranium (HEU) benchmarks.

	BENCHMARK	ENDF/B-VI.5	C/E
GODIVA (sphere)	1.0000 ± 0.0010	0.9963	0.9963
HEU-MET-FAST-018	1.0000 ± 0.0016	0.9956 ± 0.0007	0.9956
HEU-MET-FAST-004	0.9988 ± NG	0.9958 ± 0.0012	0.9970
2C8 (HEU, 2×2×2)	1.0000 ± NG	0.9942 ± 0.0008	0.9942
HEU-MET-FAST-023 (CASE 16)	0.9973 ± 0.0052	0.9945 ± 0.0009	0.9972
HISS(HUG)	1.0000 ± 0.0040	1.0087	1.0087
UH3-UR	1.0000 ± NG	1.0073	1.0073
UH3-NI	1.0000 ± NG	1.0146	1.0146
ORNL-1	1.0012 ± 0.0026	0.9985	0.9973
ORNL-2	1.0007 ± 0.0036	0.9980	0.9973
ORNL-3	1.0009 ± 0.0036	0.9949	0.9940
ORNL-4	1.0003 ± 0.0036	0.9963	0.9960
ORNL-10	1.0000 ± NG	0.9993	0.9993
AVERAGE			0.9996

NG means uncertainty is not given for benchmark.