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BENCHMARK TESTING OF ²³⁵U EVALUATIONS

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ABSTRACT

In this paper we investigate the adequacy of available ^{235}U cross-section data (ENDF/B-VI and JENDL-3) for calculation of critical experiments. An ad hoc revised ^{235}U evaluation is also tested and appears to give results which are improved relative to those obtained with either ENDF/B-VI or JENDL-3 cross sections. Calculations of k_{eff} were performed for ten fast benchmarks and six thermal benchmarks using the three cross-section sets. Central reaction-rate-ratio calculations were also performed.

AD HOC REVISED ^{235}U EVALUATION

A comparison of fast cross sections in the ENDF/B-VI and JENDL-3 evaluations indicates that the inelastic, fission, and capture cross sections in the JENDL-3 evaluation are higher than the corresponding ENDF/B-VI values. Based on a consideration of the cross-section data as well as benchmark data testing for fast and thermal benchmarks, we decided that an improved ^{235}U evaluation was possible based on a minor change to the JENDL-3 evaluation. A uniform reduction of 2.0% in the fission cross section between 0.1 and 3.6 MeV was made. The elastic cross section was increased in the revised evaluation to offset the reduction in the fission cross section so that the total cross section is unchanged. It is essential that the revised fission cross section be in good agreement with measured data. This has been demonstrated by showing that the evaluated $^{235}\text{U}/^{235}\text{U}$ fission ratio is in good agreement with measured values.¹ The evaluated and measured $^{235}\text{U}/^{235}\text{U}$ fission ratios are compared in Fig. 1.

The JENDL-3 and the ad hoc revised ^{235}U fission cross sections are compared in Fig. 2. The ENDF/B-VI and the ad hoc revised ^{235}U fission cross sections are compared in Fig. 3. The ad hoc revised fission cross section is lower than ENDF/B-VI between 0.1 and 0.8 MeV and is in fairly good agreement with ENDF/B-VI between 0.8 and 6 MeV. The ENDF/B-VI and JENDL-3 inelastic cross sections are compared in Fig. 4. The JENDL-3 inelastic is higher by as

much as 50% between 0.4 and 7 MeV. The JENDL-3 inelastic is unchanged in the ad hoc revised evaluation. The higher inelastic cross section and revised fission cross section have a significant impact, relative to ENDF/B-VI, on the fast benchmark calculations discussed in the next section.

DATA TESTING OF FAST AND THERMAL BENCHMARKS

With the exception of ^{235}U , data from the VITAMIN-B6 199-group cross-section library² were used in the benchmark calculations. The NJOY system³ was used to process the evaluations and generate cross-section files in NJOY format. The SMILER program was used to convert from NJOY to the AMPX master interface format. The benchmark calculations were performed using the XSDRNPM module from the SCALE-4 system.⁴ The calculated k_{eff} values using the three different ^{235}U evaluations are compared in Table 1. Specifications for the benchmarks in Table 1 are given in Refs. 5-7. U233-MET-FAST-001 (JEZEBEL-23) is a bare ^{235}U sphere; the other fast benchmarks are ^{235}U spheres with various reflectors. The Oak Ridge National Laboratory (ORNL) spheres are unreflected spheres of ^{235}U nitrate solutions and have thermal spectra. The calculated k_{eff} values for the thermal benchmarks using the ad hoc revised ^{235}U evaluation are almost unchanged from the JENDL-3 results. The calculated k_{eff} values for the fast benchmarks are greatly improved relative to both the ENDF/B-VI and JENDL-3 values. The calculated k_{eff} for the JEZEBEL-23 benchmark is 1.0007 compared to 0.9929 with ENDF/B-VI and 1.0125 with JENDL-3. Two benchmarks (U233-MET-FAST-004a and -b) have calculated k_{eff} values which are significantly higher than the other fast benchmarks. These two benchmarks have tungsten reflectors, and it appears that the higher calculated k_{eff} values are due to problems with the tungsten cross sections. Using the revised ^{235}U evaluation, the average k_{eff} for all 16 benchmarks (fast and thermal) is 0.9999. This is a substantial improvement relative to both ENDF/B-VI and JENDL-3.

CENTRAL REACTION-RATE-RATIO CALCULATIONS

In addition to the 16 k_{eff} benchmark calculations in Table 1, ^{233}U fission/ ^{235}U fission central-reaction-rate ratios for four additional fast benchmarks which do not contain ^{233}U have been calculated. Table 2 illustrates the comparisons of the experimental central reaction-rate ratios measured in JEZEBEL, GODIVA, FLATTOP-25, and BIG TEN with calculations using the ENDF/B-VI, JENDL-3, and AD HOC JENDL-REV evaluations, respectively. The result displayed in column 2 is the experimental ratio,⁶ whereas columns 3-5 show the calculated-to-experimental ratio (C/E) for the ENDF/B-VI, JENDL-3, and AD HOC JENDL-REV evaluations, respectively. The ENDF/B-VI calculated $^{233}\text{U}/^{235}\text{U}$ fission-rate ratios appear to be in better agreement with the measured values than the JENDL-3 results. The AD HOC JENDL-REV values are also in generally good agreement with the measured values, with the exception of BIG TEN, which is slightly low. With the exception of BIG TEN, the (C/E) values in Table 2 support the 2% reduction in the ^{233}U fission cross section for the AD HOC JENDL-REV evaluation, relative to the original JENDL-3 evaluation. Since the spectrum for the BIG TEN benchmark is softer than the other three benchmarks, Table 2 may give an indication that the ^{233}U fission cross section in the AD HOC JENDL-REV evaluation should be slightly higher for energies below 1 MeV. Such a change would be permissible based on the measured $^{233}\text{U}/^{235}\text{U}$ fission ratio (see Fig. 1). However, any additional change in the ^{233}U fission cross section would have to be evaluated to ensure that the excellent values obtained for the benchmark k_{eff} values in Table 1 are not adversely impacted.

Calculated (C/E) values of the $^{238}\text{U}/^{235}\text{U}$ and $^{237}\text{Np}/^{235}\text{U}$ fission ratios using the ENDF/B-VI, JENDL-3, and AD HOC JENDL-REV evaluations for the JEZEBEL-23 and FLATTOP-23 benchmarks are compared in Table 3. These benchmarks contain ^{233}U and were also included in Table 1. JEZEBEL-23 is actually the same as U233-MET-FAST-001 as noted previously in this paper. The calculated values for the $^{237}\text{Np}/^{235}\text{U}$ fission ratio using all three evaluations are in good agreement and are also in agreement with measured values. The calculated values for the $^{238}\text{U}/^{235}\text{U}$ fission ratio using the AD HOC JENDL-REV cross sections are lower than the corresponding ENDF/B-VI calculated values and are also low relative to the measured values. One important factor which influences the calculated $^{238}\text{U}/^{235}\text{U}$ fission ratio is the ^{233}U inelastic scattering cross section. The higher ^{233}U inelastic cross section in the JENDL-3 and AD HOC JENDL-REV evaluations, relative to the ENDF/B-VI evaluation, appears to be the principal reason for the lower

values of the calculated $^{238}\text{U}/^{235}\text{U}$ fission ratio using these evaluations, relative to the corresponding values using ENDF/B-VI.

CONCLUSIONS

Benchmark calculations for ten fast benchmarks and six thermal benchmarks were performed using three different ^{233}U evaluations. Using the revised JENDL-3 evaluation, excellent results for the calculated k_{eff} values are obtained for both the thermal and fast benchmarks considered in this study. Results obtained with the new evaluation represent a big improvement relative to either the ENDF/B-VI or JENDL-3 evaluations. The revised ^{233}U fission cross section is in agreement with the measured cross section, based on a comparison of the evaluated and measured $^{233}\text{U}/^{235}\text{U}$ fission ratio. Additional information concerning this study is given in Ref. 8.

Results from central reaction-rate-ratio calculations are shown in Tables 2 and 3. Results using the AD HOC REV-JENDL evaluation are generally in good agreement with measured values. Results using the revised evaluation are not quite as good as those obtained with ENDF/B-VI.

The lack of critical benchmark experiments with spectra peaking in the intermediate energy range is a serious limitation which prevents testing of the ^{233}U cross sections in this energy range. At the present time, measurements of ^{233}U cross sections from thermal to 600 eV are planned at ORELA (the Oak Ridge Electron Linear Accelerator). In addition, Los Alamos is planning to perform integral measurements on ^{233}U . These measurements will lead to more accurate ^{233}U data for use in applications which have spectra in the intermediate energy range.

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Table 1. Benchmark calculations for ^{235}U benchmarks 199-group cross sections

Benchmark	ENDF/B-VI	JENDL-3	AD HOC JENDL-REV
U233-MET-FAST-001	0.9929	1.0125	1.0007
U233-MET-FAST-002a	0.9952	1.0093	0.9989
U233-MET-FAST-002b	0.9975	1.0088	0.9995
U233-MET-FAST-003a	0.9958	1.0100	0.9988
U233-MET-FAST-003b	0.9971	1.0085	0.9976
U233-MET-FAST-004a	1.0027	1.0172	1.0068
U233-MET-FAST-004b	1.0061	1.0181	1.0057
U233-MET-FAST-005a	0.9949	1.0094	0.9980
U233-MET-FAST-005b	0.9974	1.0097	0.9988
FLATTOP-23	1.0004	1.0088	0.9985
AVERAGE	0.9980	1.0112	1.0003
Thermal Benchmarks:			
ORNL-5	0.9968	0.9997	0.9995
ORNL-6	0.9972	1.0002	1.0000
ORNL-7	0.9970	0.9999	0.9997
ORNL-8	0.9969	0.9999	0.9997
ORNL-9	0.9963	0.9993	0.9990
ORNL-11	0.9954	0.9980	0.9980
AVERAGE	0.9966	0.9995	0.9993

Table 2. Comparisons of $^{235}\text{U}/^{235}\text{U}$ Fission Central-Reaction-Rate Ratios

Benchmark	Experiment	ENDF/B-VI (C/E)	JENDL-3 (C/E)	AD HOC-REV (C/E)
JEZEBEL	$1.578 \pm 1.7\%$	1.000	1.016	0.998
GODIVA	$1.590 \pm 1.9\%$	1.001	1.012	0.994
FLATTOP-25	$1.595 \pm 1.9\%$	0.990	1.007	0.989
BIG TEN	$1.580 \pm 1.9\%$	0.996	0.992	0.976

Table 3. Comparisons of $^{238}\text{U}/^{235}\text{U}$ and $^{237}\text{Np}/^{235}\text{U}$ Fission Central-Reaction Rate Ratios

Benchmark	Experiment	ENDF/B-VI (C/E)	JENDL-3 (C/E)	AD HOC-REV (C/E)
$^{238}\text{U}/^{235}\text{U}$				
JEZEBEL-23	$0.213 \pm 1.1\%$	1.012	0.985	0.983
FLATTOP-23	$0.191 \pm 1.0\%$	0.998	0.981	0.977
$^{237}\text{Np}/^{235}\text{U}$				
JEZEBEL-23	$0.977 \pm 1.6\%$	1.010	1.008	1.007
FLATTOP-23	$0.892 \pm 1.6\%$	1.013	1.014	1.012

U-233/U-235 Fission-ratio Kanda ratio data (1985)

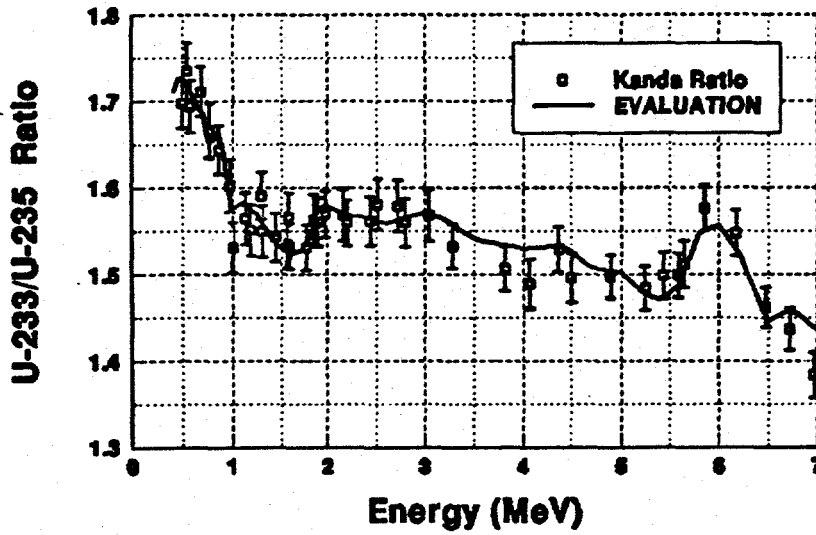


Figure 1. Comparisons of evaluated and measured $^{233}\text{U}/^{235}\text{U}$ fission ratios

U-233 Fission Cross Section JENDL-3 vs. AD HOC-REV

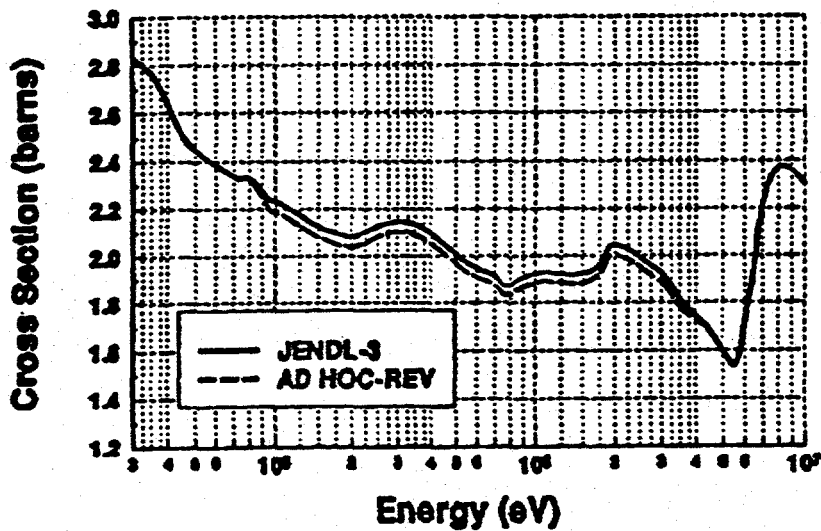


Figure 2. Comparison of fission cross section for JENDL-3 and ad hoc REV

U-233 Fission Cross Section ENDF/B-VI vs. AD HOC-REV

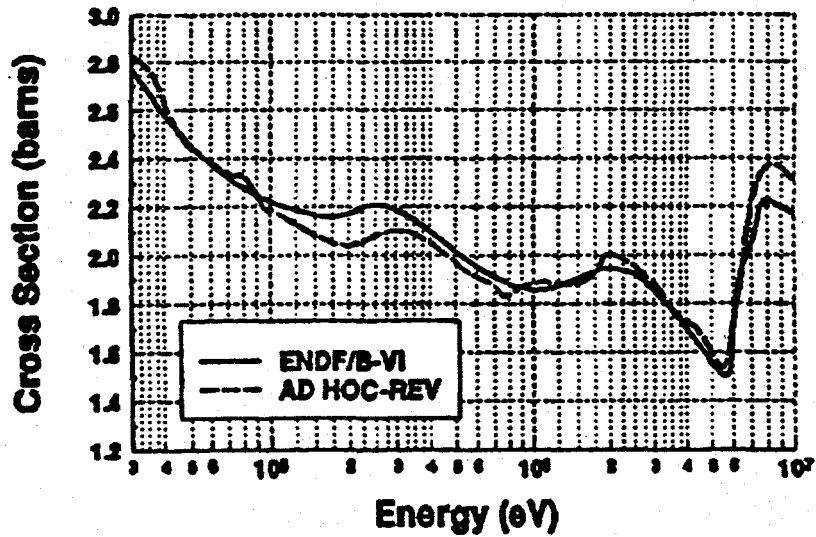


Figure 3. Comparison of fission cross section for ENDF/B-VI and ad hoc REV

U-233 Inelastic Cross Section ENDF/B-VI vs. JENDL-3

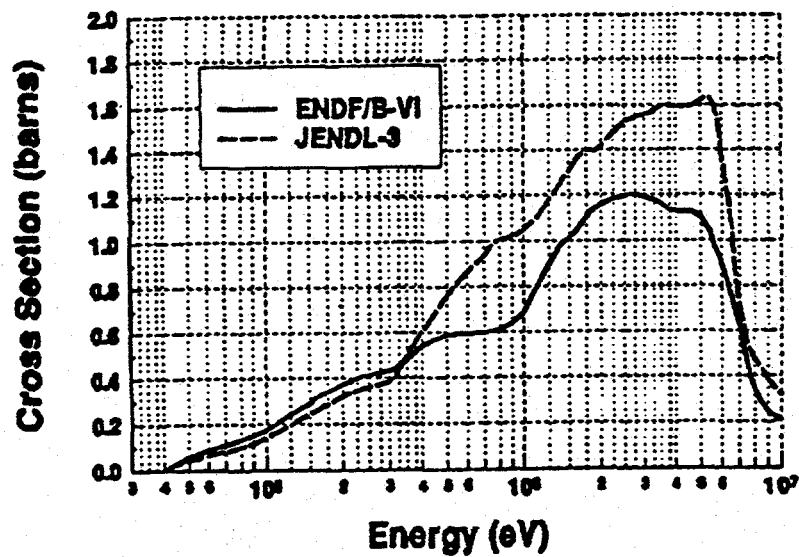


Figure 4. Comparison of the ENDF/B-VI and JENDL-3 inelastic cross sections