The JEF-2.2 Nuclear Data Library
JEF 2-2

JANUARY 1996

ECN-I--96-002 DRAFT

The TRX-1 and TRX-2 benchmarks

Validation of the JEFF-3.0 evaluation for ^{235}U

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ECN project number 7.1111

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Abstract

The TRX-1 and TRX-2 benchmarks were modelled in MCNP4A. Calculations were performed with the Monte Carlo code MCNP4A, using cross-section data from the EJ2-MCNPlib library. The work was done in the framework of validation of this library (which is based upon the JEF-2.2 evaluation) for criticality applications. In a second set of calculations ^{235}U data from the JEFF-3.0 evaluation were used.

The values of k_{eff} and three spectral indices (ρ^{28}, δ^{25} and δ^{28}) were calculated.

Good agreement between measured and calculated values of k_{eff} and the spectral indices is obtained with JEF-2.2 and JEFF-3.0 data.

Keywords

Criticality calculations
Benchmark calculations
MCNP4A
EJ2-MCNPlib
JEF-2.2 cross-section data
JEFF-3.0 cross-section data

CONTENTS

1. INTRODUCTION

Core neutronics calculations require the benchmarking of nuclear data and neutron transport codes used in the analyses. Relevant benchmarks for cores in which metallic fuel is used, are the TRX benchmarks.

In this report the results are presented of the TRX-1 and TRX-2 benchmarks. Calculations were performed with the Monte Carlo neutron transport code MCNP4A, using ^{235}U data from the EJ2-MCNPlib library. The JEFF-3.0 evaluation for ^{235}U recently became available and was processed at ECN-Petten for use in MCNP4A. A comparison of results using ^{235}U data from the JEF-2.2 evaluation and from the JEFF-3.0 evaluation is given in this work.

A short description of the JEFF-3.0 evaluation for ^{235}U is given in chapter 2. In chapter 3 the TRX-benchmarks are described. The model which is used in the calculations is illustrated in chapter 4. The results of the calculations are given in chapter 5. Finally, in chapter 6 the conclusions from this work are drawn.

2. JEFF-3.0 DATA

Recently a preliminary JEFF-3.0 evaluation for ^{235}U became available [1]. In this evaluation the resolved resonance region was re-evaluated. The remainder of the evaluation was not changed. Differences between the JEF-2.2 and the JEFF-3.0 evaluation for ^{235}U mainly occur in the high-energy part of the resolved resonance region.

In fig 2.1 to 2.3 a comparison is made between the fission cross section (MT=18) on the two evaluations in the low-energy part of the resolved resonance region (200 eV $< E_n <$ 300 eV), in the middle part of the resolved resonance region (900 eV $< E_n <$ 1000 eV) and in the high-energy part of the resolved resonance region (1700 eV $< E_n <$ 1800 eV), respectively.

A good benchmark for testing ^{235}U data are the TRX-1 and TRX-2 benchmarks [2]. They present a simple geometry and composition. Moreover, the spectrum in the TRX-1 case is much harder than in the TRX-2 case, which makes it possible to probe the thermal and epithermal parts of the cross section.

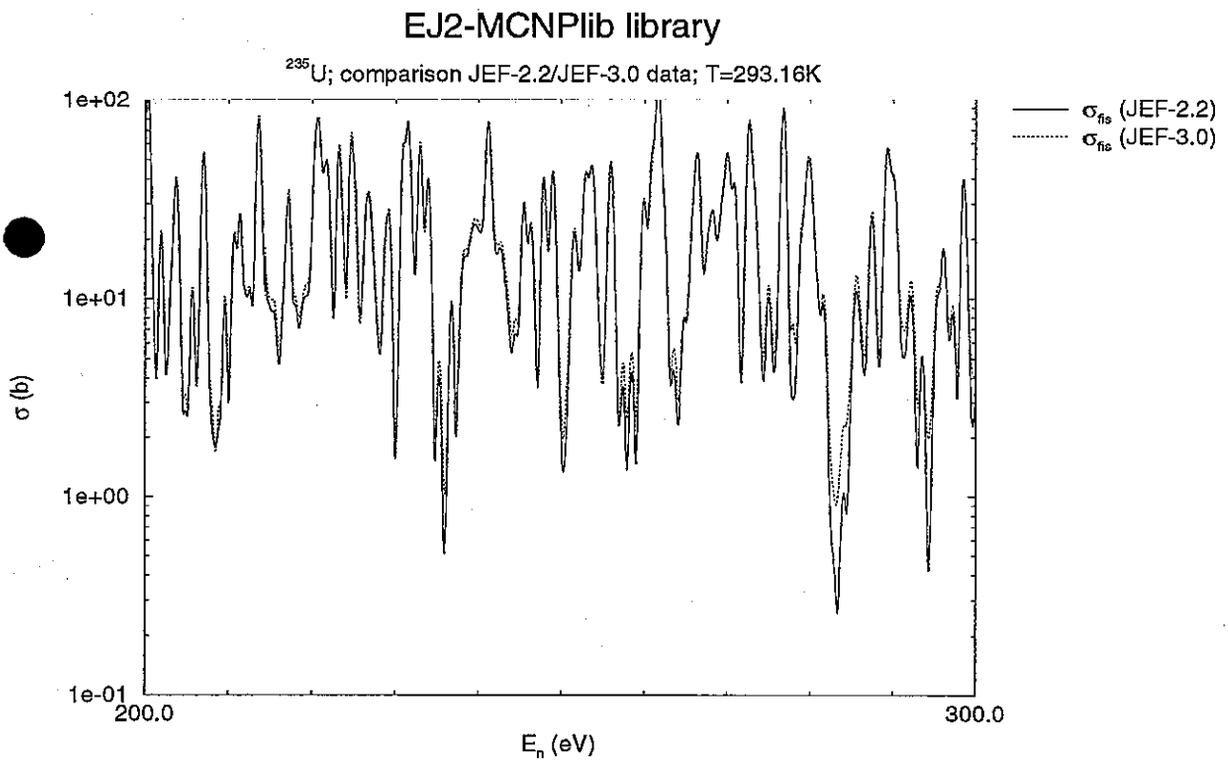

Figure 2.1 *Comparison of ^{235}U fission cross section data from the JEF-2.2 (full curve) and JEFF-3.0 evaluations (dashed curve) in the energy range* 200 eV $< E_n <$ 300 eV.

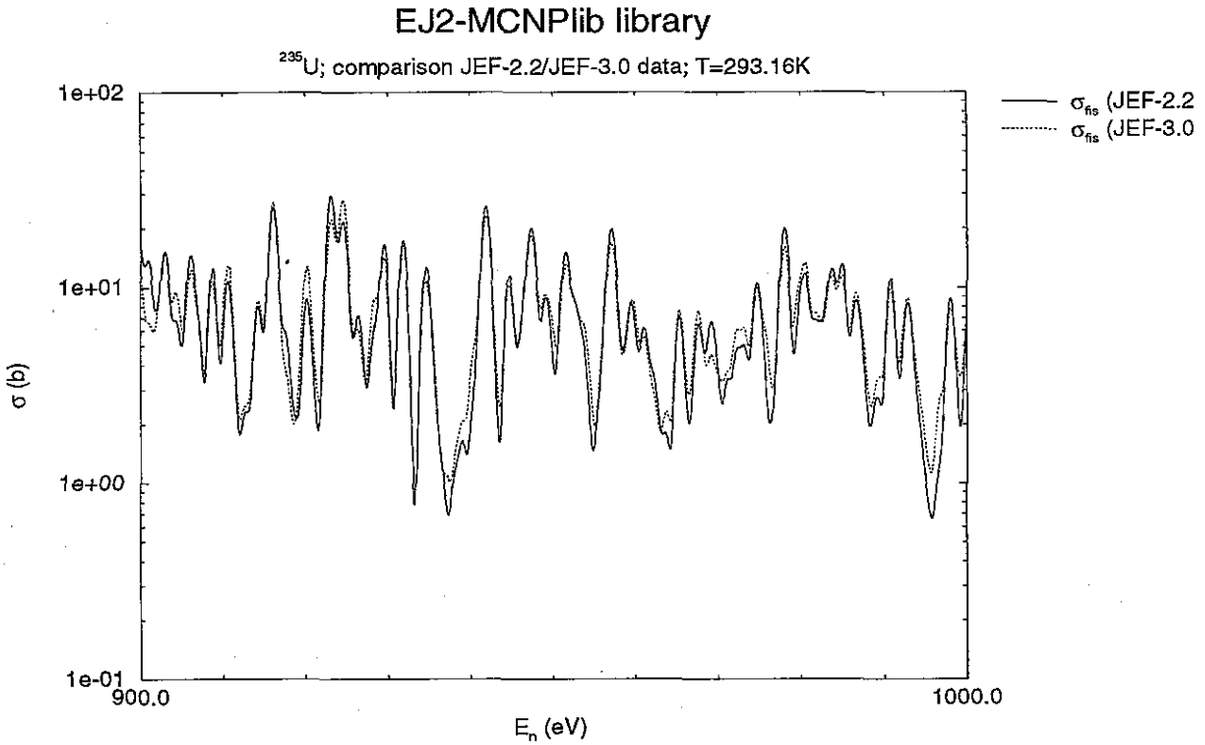

Figure 2.2 *Comparison of* ^{235}U *fission cross section data from the JEF-2.2 (full curve) and JEFF-3.0 evaluations (dashed curve) in the energy range* 900 eV $< E_n <$ 1000 eV.

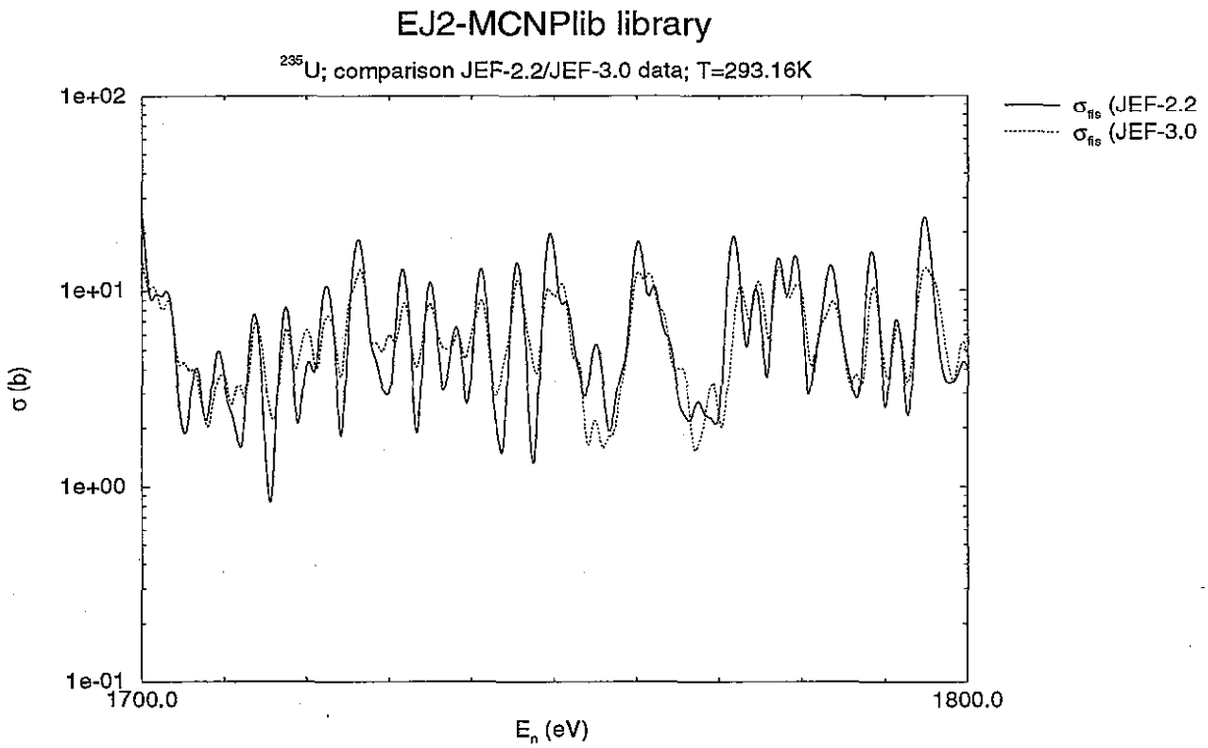

Figure 2.3 *Comparison of* ^{235}U *fission cross section data from the JEF-2.2 (full curve) and JEFF-3.0 evaluations (dashed curve) in the energy range* 1700 eV $< E_n <$ 1800 eV.

3. THE TRX BENCHMARKS

The TRX benchmarks [3] consist of light-water moderated metallic U (1.3% enriched) fuel pins with aluminium cladding in a hexagonal lattice. The benchmark experiment was performed at room temperature. Several spectral indices were measured in the centre of the lattice. The results from several lattices (with different pitch and hence different water/fuel volume ratio) are reported in [4].

In this report the TRX-1 and TRX-2 benchmarks were studied, with water/fuel volume ratios of 2.35 and 4.02, respectively. The composition of the materials used in the study is given in table 3.1.

Table 3.1 *Composition data for the materials used in the TRX-benchmarks.*

	Composition (atom/barn·cm)		
isotope	fuel	cladding	moderator
^{1}H			6.676E−2
^{16}O			3.383E−2
^{27}Al		6.025E−2	
^{235}U	6.253E−4		
^{238}U	4.7205E−2		

A complete 3-dimensional description of the benchmark geometry is lacking. However, using the leakage correction factors from [4] the systems can be modelled as a 2-dimensional infinite array. Due to the different pitch the spectrum in TRX-1 is harder than in TRX-2. This fact, combined with the simplicity of the system, makes the TRX-benchmarks a good tool to check ^{235}U data.

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4. CALCULATIONS

4.1 Geometrical model

A 2D geometrical model was constructed in MCNP4A for both the TRX-1 and the TRX-2 geometry. Outlines of the geometries are given in figs. 4.1 and 4.2. Data were taken from [4].

In order to compare spectral indices determined in a 2D calculation with actually measured values leakage correction factors should be used. For this work the factors as given in [4] were used. They are listed in table 4.1.

Table 4.1 *Leakage correction factors for spectral indices for the TRX-1 and TRX-2 geometry. Data taken from [4].*

	Correction factor	
parameter	TRX-1	TRX-2
k_{eff}	0.8479	0.8573
ρ^{28}	1.038	1.033
δ^{25}	1.030	1.027
δ^{28}	1.073	1.051

4.2 Spectral indices

The spectral indices are defined as follows:
ρ^{28} = ratio of epithermal-to-thermal ^{238}U captures
δ^{25} = ratio of epithermal-to-thermal ^{235}U fissions
δ^{28} = ratio of ^{238}U fissions to ^{235}U fissions

The breakpoint between the thermal- and the epi-thermal region lies at 0.625 eV.

4.3 Calculational procedure

Neutron transport calculations for this benchmark were performed using the Monte Carlo code MCNP4A [5]. Continuous-energy cross section data were used, which allow for a very detailed simulation of the neutron transport.

The calculation of k_{eff} and the reaction rates was divided into three subsequent steps:

1. As an initial source S_0 an isotropic point source in the centre of the fuel pin was taken. Using a batch size of 100 neutrons, in 100 cycles a geometrically converged source S_1 was produced, which was used in the second step of the calculation.
2. Starting with S_1 a second calculation was performed, using a batch size of 1000 neutrons. In 100 cycles the initial source S_2 for the final step was produced.
3. In the final run the batch size was extended from 1000 to 10000 neutrons. The values of k_{eff} and the reaction rates were calculated in 100 cycles.

4.4 Cross sections

JEF-2.2 based cross-section data for all isotopes were taken from the EJ2-MCNPlib library [6], processed at ECN Petten.

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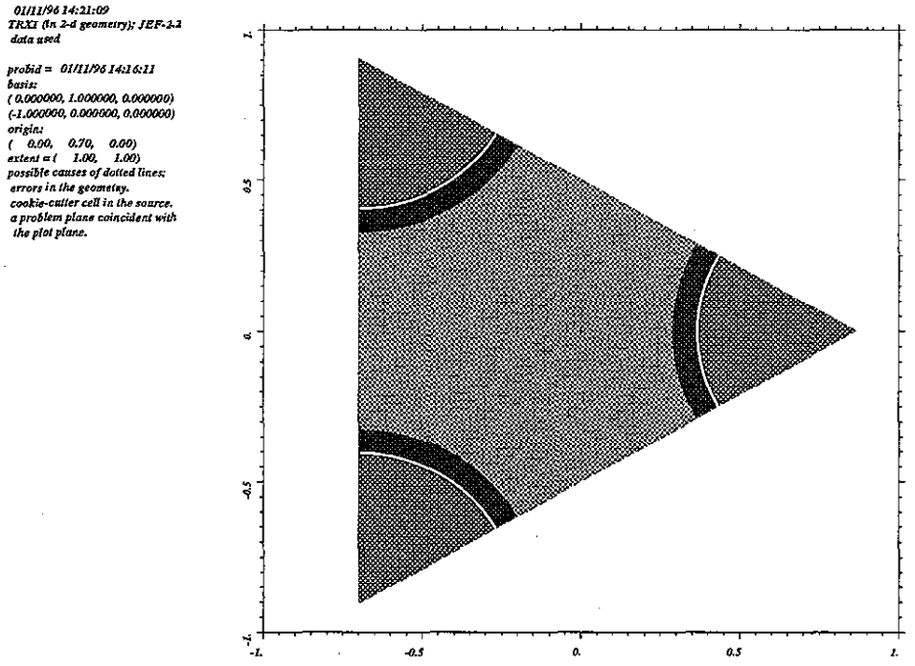

Figure 4.1 *Horizontal cross section through the MCNP4A model of the TRX-1 geometry. Fuel pins are located at the corners of the triangular geometry. The triangular boudaries are modelled as reflecting planes.*

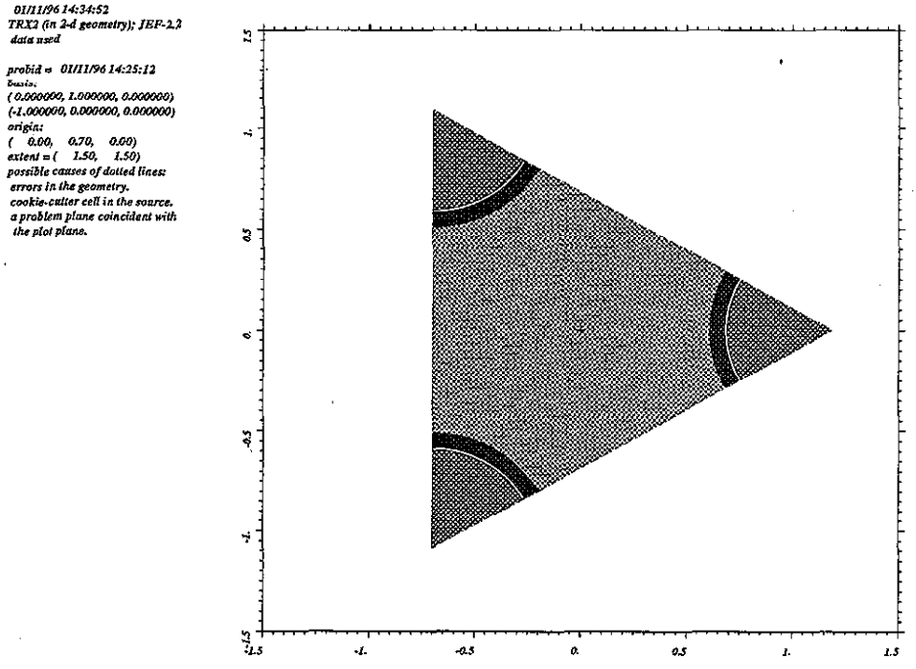

Figure 4.2 *Horizontal cross section through the MCNP4A model of the TRX-2 geometry. Fuel pins are located at the corners of the triangular geometry. The triangular boudaries are modelled as reflecting planes. Note the change of scale compared to fig. 4.1.*

5. RESULTS

5.1 TRX-1

A comparison of measured and calculated values for k_{eff} and spectral indices for the TRX-1 benchmark is given in table 5.1 and 5.2 (JEF-2.2 and JEFF-3.0 data for ^{235}U, respectively).

Table 5.1 *Comparison of measured and calculated values for k_{eff} and spectral indices for the TRX-1 benchmark. JEF-2.2 data for ^{235}U.*

parameter	measured $\pm\sigma$ [%]	calculated $\pm\sigma$ [%]	$C/E \pm \sigma$ [%]
k_{eff}	1.000E+00 ± 0.20	1.0012E+0 ± 0.03	1.0012E+0 ± 0.20
ρ^{28}	1.320E+00 ± 1.52	1.340E+00 ± 0.13	1.015E+00 ± 1.52
δ^{25}	9.870E−02 ± 1.01	9.844E−02 ± 0.11	9.973E−01 ± 1.02
δ^{28}	9.460E−02 ± 4.33	9.566E−02 ± 0.14	1.011E+00 ± 4.34

Table 5.2 *Comparison of measured and calculated values for k_{eff} and spectral indices for the TRX-1 benchmark. JEFF-3.0 data for ^{235}U.*

parameter	measured $\pm\sigma$ [%]	calculated $\pm\sigma$ [%]	$C/E \pm \sigma$ [%]
k_{eff}	1.000E+00 ± 0.20	0.9990E+0 ± 0.03	0.9990E+0 ± 0.20
ρ^{28}	1.320E+00 ± 1.52	1.344E+00 ± 0.13	1.018E+00 ± 1.52
δ^{25}	9.870E−02 ± 1.01	9.772E−02 ± 0.11	9.901E−01 ± 1.02
δ^{28}	9.460E−02 ± 4.33	9.574E−02 ± 0.14	1.012E+00 ± 4.34

Table 5.3 *Comparison of calculated values for k_{eff} and spectral indices for the TRX-1 benchmark using JEFF-3.0 and JEF-2.2 data for ^{235}U.*

parameter	JEFF-3.0 $\pm\sigma$ [%]	JEF-2.2 $\pm\sigma$ [%]	JEFF-3.0/JEF-2.2 $\pm\sigma$ [%]
k_{eff}	0.9990E+0 ± 0.03	1.0012E+0 ± 0.03	0.9978E+0 ± 0.04
ρ^{28}	1.344E+00 ± 0.13	1.340E+00 ± 0.13	1.0029E+0 ± 0.18
δ^{25}	9.772E−02 ± 0.11	9.844E−02 ± 0.11	0.9927E+0 ± 0.16
δ^{28}	9.574E−02 ± 0.14	9.566E−02 ± 0.14	1.0008E+0 ± 0.20

From tables 5.1 and 5.2 it is clear, that both with JEF-2.2 data for ^{235}U and with JEFF-3.0 data for ^{235}U a good description is given of measured values of k_{eff} and spectral indices. The total fission rate is slightly reduced when JEFF-3.0 data for ^{235}U are used. From table 5.3 could be deduced, that the use of JEFF-3.0 data for ^{235}U mainly decreases the epithermal fission rate in ^{235}U.

5.2 TRX-2

A comparison of measured and calculated values for k_{eff} and spectral indices for the TRX-2 benchmark is given in table 5.4 and 5.5 (JEF-2.2 and JEFF-3.0 data for ^{235}U, respectively).

Table 5.4 *Comparison of measured and calculated values for k_{eff} and spectral indices for the TRX-2 benchmark. JEF-2.2 data for ^{235}U.*

parameter	measured $\pm\sigma$ [%]			calculated $\pm\sigma$ [%]			$C/E \pm \sigma$ [%]		
k_{eff}	1.000E+00	$\pm$	0.20	1.0013E+0	$\pm$	0.03	1.0013E+0	$\pm$	0.20
ρ^{28}	8.370E−01	$\pm$	1.91	8.420E−01	$\pm$	0.23	1.006E+00	$\pm$	1.93
δ^{25}	6.140E−02	$\pm$	1.30	6.065E−02	$\pm$	0.18	9.879E−01	$\pm$	1.32
δ^{28}	6.930E−02	$\pm$	5.05	6.962E−02	$\pm$	0.19	1.005E+00	$\pm$	5.05

Table 5.5 *Comparison of measured and calculated values for k_{eff} and spectral indices for the TRX-2 benchmark. JEFF-3.0 data for ^{235}U.*

parameter	measured $\pm\sigma$ [%]			calculated $\pm\sigma$ [%]			$C/E \pm \sigma$ [%]		
k_{eff}	1.000E+00	$\pm$	0.20	0.9998E+0	$\pm$	0.03	0.9998E+0	$\pm$	0.20
ρ^{28}	8.370E−01	$\pm$	1.91	8.432E−01	$\pm$	0.23	1.007E+00	$\pm$	1.93
δ^{25}	6.140E−02	$\pm$	1.30	6.022E−02	$\pm$	0.18	9.808E−01	$\pm$	1.32
δ^{28}	6.930E−02	$\pm$	5.05	6.980E−02	$\pm$	0.19	1.007E+00	$\pm$	5.05

Table 5.6 *Comparison of calculated values for k_{eff} and spectral indices for the TRX-2 benchmark using JEFF-3.0 and JEF-2.2 data for ^{235}U.*

parameter	JEFF-3.0 $\pm\sigma$ [%]			JEF-2.2 $\pm\sigma$ [%]			JEFF-3.0/JEF-2.2 $\pm\sigma$ [%]		
k_{eff}	0.9998E+0	$\pm$	0.03	1.0013E+0	$\pm$	0.03	0.9985E+0	$\pm$	0.04
ρ^{28}	8.432E−01	$\pm$	0.23	8.420E−01	$\pm$	0.23	1.0014E+0	$\pm$	0.18
δ^{25}	6.022E−02	$\pm$	0.18	6.065E−02	$\pm$	0.18	0.9929E+0	$\pm$	0.16
δ^{28}	6.980E−02	$\pm$	0.19	6.962E−02	$\pm$	0.19	1.0026E+0	$\pm$	0.20

Analogously to the TRX-1 benchmark, from tables 5.4 and 5.5 it is clear, that in the case of the TRX-2 benchmark a good description is given of measured values of k_{eff} and spectral indices, both with JEF-2.2 data for ^{235}U and with JEFF-3.0 data for ^{235}U. Like in the TRX-1 benchmark, the total fission rate is reduced when JEFF-3.0 data for ^{235}U are used. Again (from table 5.6) could be deduced, that the use of JEFF-3.0 data for ^{235}U mainly decreases the epithermal fission rate in ^{235}U.

6. CONCLUSIONS

In this report the results are presented of a Monte Carlo analysis of the TRX-1 and TRX-2 benchmarks. The analysis was performed with MCNP4A using JEF-2.2 based data from the EJ2-MCNPlib library.

Two sets of calculations were performed:

- one in which JEF-2.2 based data for ^{235}U were used
- one in which (preliminary) JEFF-3.0 based data for ^{235}U were used.

A comparison shows that there are only slight differences: a good description is given of k_{eff} and the spectral indices ρ^{28}, δ^{25} and δ^{28}, both with JEF-2.2 based data and with JEFF-3.0 based data for ^{235}U.

The use JEFF-3.0 data for ^{235}U results in a reduced total fission rate. It appears, that mainly the epithermal fission rate in ^{235}U is reduced.

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