COMPARISON OF CRITICALITY BENCHMARK CALCULATIONS ON THE UO_2 AND MOX FUEL ARRAYS USING ENDF/B-V AND ENDF/B-VI DATA

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ABSTRACT

The critical experiments of the UO_2 and MOX fuel rod arrays were selected to validate the cross section libraries based on ENDF/B-V and ENDF/B-VI and the criticality calculation methods of the Monte Carlo code MCNP for the LWR fuel storage and transport package. The MCNP criticality calculations were performed with two different cross section data based on ENDF/B-V and ENDF/B-VI, respectively. The calculational results based on both ENDF/B-V and ENDF/B-VI are in good agreement with most of the benchmark experiments. However, the calculations based on ENDF/B-V predict k-eff's more closely, whereas those based on ENDF/B-VI slightly underestimate k-eff's for thermal LWR fuel lattice experiments. The mean of the calculated k-eff's with ENDF/B-V is 0.99747 for UO_2 and 1.00021 for MOX and that with ENDF/B-VI is 0.99296 for UO_2 and 0.99382 for MOX, respectively. Therefore, the use of the cross section data based on ENDF/B-V is recommended for the thermal LWR fuel criticality analysis instead of the updated version of ENDF/B-VI. Sensitivity calculations show that the underestimation of k-eff's with ENDF/B-VI is primarily due to ^{16}O (increased forward scattering and fast leakage), ^{238}U data (slightly high resonance capture), and additionally ^{239}Pu for MOX fuel cases.

I. INTRODUCTION

The criticality analysis methods and such related data as cross section library should be verified

by the appropriate means to validate the calculated results.[1] The validation is essential to ensure that a system that is evaluated to be subcritical is indeed subcritical and it is usually done by the benchmark calculations on the critical experiments that adequately represent the characteristics of the object system. Through the benchmark calculations, the bias that is a measure of the systematic error between experimental data and calculated results is estimated and the applicability of the analysis methods is defined. The applicability is established by considering the material composition and geometric arrangements, neutron spectrum and other relevant parameters such as heterogeneity, leakage, interaction, absorption, etc.

The most important factors for the criticality analysis are the calculation method and the cross section data. In this paper, two cross section data based on ENDF/B-V and ENDF/B-VI are used in the benchmark calculations to see the influence of cross sections and the Monte Carlo code MCNP4B[2] is selected as the calculational tool. ENDF/B-V (originally issued in 1979 and updated in 1981) has been significantly improved compared with the previous version, but some deficiencies are still included. ENDF/B-VI which updates EDNF/B-V.2 was released in 1990 (Release 0) and 1995 (Release 3). Since the release of ENDF/B-VI, there have been many comparative calculations[3-12] that used ENDF/B-V and ENDF/B-VI to validate ENDF/B-VI. Even though most of the calculations showed somewhat better results with ENDF/B-VI, it was also reported that ENDF/B-V produces better results for some particular benchmark problems.[3-5] The DLC-189 library[13] which provides both cross section data based on ENDF/B-V and ENDF/B-VI is used in the benchmark calculations. Two MCNP calculations with ENDF/B-V and ENDF/B-VI were performed for each critical benchmark experiment and additional sensitivity calculations were performed to see if there is any difference between ENDF/B-V and ENDF/B-VI.

The comparative calculations with ENDF/B-V and ENDF/B-VI in this paper, are mainly for the thermal LWR fuel benchmark experiments that represent the characteristics of the LWR fuel storage and transport package. The critical experiments of the water-moderated UO_2 and MOX fuel arrays are selected from the "International Handbook of Evaluated Criticality Safety Benchmark Experiments"[14] as the reference benchmark experiments. Thus, the application of the calculational results and conclusions of these benchmark calculations are limited to the criticality analysis of the LWR fuel storage or transport package.

Selected benchmark experiments are described in Section II, and Section III gives details of the calculation methods and cross section libraries. The results of the benchmark calculations and the conclusions are followed in Sections IV and V, respectively.

II. DESCRIPTION OF CRITICAL EXPERIMENTS

The critical experiments for the benchmark calculations were taken from reference 14 which was published by the International Criticality Safety Benchmark Evaluation Project (ICSBEP) as an OECD-NEA document. This handbook contains criticality safety benchmark specifications that have been derived from various experiments around the world and the

benchmark specifications are intended for use by criticality safety engineer to validate criticality calculational techniques.

The selected critical experiments represent the characteristics of the LWR fuel storage and transport package. The characteristics of the spent fuel storage facility and/or fuel transport package are as follows:

- UO_2 or (U, Pu)O_2 pellet type fuel encapsulated in the clad
- Square lattice of fuel rods (LWR fuel assembly)
- Separating gap between the fuel clusters
- Moderation by water (in some cases, borated water)
- Fixed neutron absorber plate or steel plate between the fuel clusters
- Metal or uranium reflector around the fuel clusters (transport package)
- Thermal neutron fission system

Total ninety-one experiments were taken from three benchmark experiments for UO_2 fuel rods to reflect the fresh UO_2 fuel assemblies and twenty-seven experiments from four benchmark experiments for MOX fuel rods to reflect the fresh MOX fuel and spent UO_2 fuel assemblies. The detailed information on the critical experiments can be found in reference 14, and the titles of the benchmark critical experiments selected are as follows:

• UO_2 Fuel Lattice Critical Experiments (91 experiments)

- LEU-COMP-THERM-010, “Water-Moderated U(4.31)O_2 Fuel Rods Reflected by Two Lead, Uranium, or Steel Walls” (30 experiments)

- LEU-COMP-THERM-016, “Water-Moderated Rectangular Clusters of U(2.35)O_2 Fuel Rods (2.032-cm Pitch) Separated by Steel, Boral, Copper, Cadmium, Aluminum, or Zircaloy-4 Plates” (32 experiments)

- LEU-COMP-THERM-017, “Water-Moderated U(2.35)O_2 Fuel Rods Reflected by Two Lead, Uranium, or Steel Walls” (29 experiments)

• MOX Fuel Lattice Critical Experiments (27 experiments)

- MIX-COMP-THERM-001, “Water-Reflected Mixed Plutonium-Uranium Oxide (20 wt.% Pu) Pins” (4 experiments)

- MIX-COMP-THERM-002, “Rectangular Arrays of Water-Moderated UO_2-2 Wt.% PuO_2 (8% ^{240}Pu) Fuel Rods” (6 experiments)

- MIX-COMP-THERM-003, “Rectangular Arrays of Water-Moderated UO_2-6.6 Wt.% PuO_2 Fuel Rods” (6 experiments)

- MIX-COMP-THERM-004, “Critical Arrays of Mixed Plutonium-Uranium Fuel Rods with

Water-to-Fuel Volume Ratios Ranging from 2.4 to 5.6" (11 experiments)

The benchmark specifications in reference 14 reflect the results of thorough review and analysis of the original experiments and provide additional data that is ambiguous or not mentioned in the original experiment documents. Thus, it can be considered that the benchmark specifications are more reliable than the originally published experimental data. The simple modified geometry model for the complex structure of experiment with negligible effect on reactivity is suggested in the benchmark specifications, and its feasibility is also proven by the sensitivity analysis in reference 14. Therefore, for geometry modeling and material composition of the benchmark calculations, the benchmark specifications in reference 14 are used rather than the originally published experimental data.

III. CALCULATIONAL METHODS AND CROSS SECTION LIBRARIES

The criticality calculations were performed using the MCNP4B code that solves the problem by the Monte Carlo neutron transport method. The MCNP code directly uses the continuous cross section data from the cross section library. The DLC-189 library that is used in the MCNP calculations provides both continuous cross section data based on ENDF/B-V and ENDF/B-VI. The MCNP calculations were performed for each benchmark experiment with two different cross section libraries based on ENDF/B-V and ENDF/B-VI in DLC-189. Sensitivity calculations were also performed to identify which nuclides cause the difference in the calculated k-eff values between ENDF/B-V and ENDF/B-VI. These were done by simply replacing the cross section data based on ENDF/B-V with its ENDF/B-VI counterpart for the particular nuclides. Sensitivity calculations were performed for ^{235}U, ^{238}U, ^{239}Pu, and ^{16}O because of their importance in the reactivity calculation. In each case of comparative calculations, such input data as geometry modeling and material data are identical except for the cross section data. MCNP4B was run with 500 active generations of 2000 neutrons per each generation after skipping first 50 generations.

IV. RESULTS OF CALCULATIONS

The calculated k-eff values range from 0.99272 to 1.01186 (117 of the 118 benchmarks are within 1% of unity) for the ENDF/B-V data and from 0.98827 to 1.00780 (110 of the 118 benchmarks are within 1% of unity) for the ENDF/B-VI data. The mean and standard deviation of the calculated k-eff's for UO_2 experiments with ENDF/B-V are 0.99747 (~0.25 % Δk underestimation) and 0.00399 and those with ENDF/B-VI are 0.99296 (~0.7 % Δk underestimation) and 0.00786, respectively. The mean and standard deviation of the calculated k-eff's for MOX experiments with ENDF/B-V are 1.00021 (~0.02 % Δk overestimation) and 0.00322 and those with ENDF/B-VI are 0.99382 (~0.62 % Δk underestimation) and 0.00694, respectively. Detailed results are given in Table I (k-eff with ENDF/B-V and ENDF/B-VI) and

Table II (sensitivity calculations).

From the results of Table I, it can be seen that the MCNP calculations with ENDF/B-VI underestimate (~0.0045 Δk for UO_2 and ~0.0065 Δk for MOX) k-eff's than with ENDF/B-V. It appears to be systematic rather than statistical fluctuation due to the characteristics of the calculational method of the Monte Carlo program. The results of sensitivity calculations to identify the nuclides which cause the difference are summarized : the ^{16}O data in ENDF/B-VI tend to decrease the reactivity significantly (~0.003 Δk) and the ^{238}U data in ENDF/B-VI also tend to decrease the reactivity slightly for both UO_2 and MOX cases. Whereas the ^{235}U data in ENDF/B-VI tend to increase the reactivity slightly in both UO_2 and MOX cases but it looks only of minor effect. The ^{239}Pu data in ENDF/B-VI also tend to decrease the reactivity of MOX experiments (~0.002 Δk).

The results of comparisons show a similar trend compared with most of the previous comparative calculations[3-11] but the extent of changes and the cause of difference are somewhat different. It is reported in reference 3 that for UO_2 fuel lattice (core loading) the reactivity difference between ENDF/B-V and ENDF/B-VI results is primarily due to the change in the cross sections for ^{235}U and ^{238}U, and for CANDU cluster the reduction in reactivity is mostly due to ^{16}O and ^{238}U and the effect of ^{235}U is negligible. Reference 4 shows that ^{16}O is principally responsible for the reduction of reactivity with ENDF/B-VI. References 7 and 10 show that the oxygen data in ENDF/B-VI increases both forward scattering and fast leakage. Considering that the selected benchmark experiments are large leakage system, it can be inferred that the oxygen data in ENDF/B-VI would reduce the k-eff. Reference 11 reports that ^{238}U resonance capture is slightly high in ENDF/B-VI and reference 12 shows that 3.4% reduction in the shielded resonance integral of ^{238}U leads to good agreement with measurements. This explains the reduction of k-eff by the ^{238}U data in ENDF/B-VI. In this benchmark calculation of this study, the reactivity reduction with ENDF/B-VI in UO_2 fuel lattice is primarily caused by ^{16}O (increased forward scattering and fast leakage) and ^{238}U (slightly high resonance capture). It is believed that the differences between the results of each reference and these calculations could have been caused by the different characteristics of the considered benchmark experiments and due to the insufficient number of experiments or calculations.

V. CONCLUSIONS

The calculated results based on the ENDF/B-V data estimate k-eff's better and the associated uncertainties are smaller than those based on the ENDF/B-VI data for the thermal LWR fuel lattice benchmark experiments. Therefore, the use of the cross section data based on ENDF/B-V is recommended for the LWR fuel criticality analysis instead of the updated version of ENDF/B-VI. It should, however, be noted that these conclusions are based on the benchmark calculations on the UO_2 and MOX fuels. Therefore, such conclusions should not be extended to such critical configurations as fast critical systems or fissile solution systems.

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REFERENCES

1. "Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors," ANSI/ANS-8.1-1983, American Nuclear Society (1983)

2. "MCNP – A General Monte Carlo N-Particle Transport Code Version 4B" Judith F. Briesmeister, Editor, Los Alamos National Laboratory (1997)

3. R. D. Mosteller, et al., "Data Testing of ENDF/B-VI with MCNP : Critical Experiments, Thermal-Reactor Lattices, and Time-of- Flight Measurements," *Advances in Nuclear Science and Technology*, **24**, 131 (1996)

4. B. M. Capell, et al., "ENDF/B-V and ENDF/B-VI Results for the Russian Criticality-Safety Benchmarks," *Trans. Am. Nucl. Soc.*, **76**. 243 (1997)

5. F. Rahnema and S. M. McKinley, "Comparison of ENDF/B-V and ENDF/B-VI.3 for Light Water Reactor Calculations," *Trans. Am. Nucl. Soc*., **76**. 324 (1997)

6. A. A. Adams, et al., "New Calculations for Critical Assemblies Using MCNP4B," *Trans. Am. Nucl. Soc*., **77**. 230 (1998)

7. J. P. Weinman, "Monte Carlo Cross-Section Testing for Thermal and Intermediate $^{235}U/^{238}U$ Critical Assemblies – ENDF/B-V Versus ENDF/B-VI," *Trans. Am. Nucl. Soc.*, **76**. 325 (1997)

8. A. C. Kahler, "Monte Carlo Eigenvalue Benchmark Calculations of Homogeneous Critical Assemblies with Various ENDF/B Cross-Section data Sets," *Trans. Am. Nucl. Soc.*, **76**. 327 (1997)

9. H. Akkurt and N. M. Abdurrahman, "Benchmark Calculations of ESADA Multi-region MOX Critical Experiments," *Trans. Am. Nucl. Soc.*, **78**. 248 (1998)

10. J. P. Weinman, "Monte Carlo Testing of New Cross-Section Data Sets for Thermal and Intermediate HEU Critical Assemblies," *Trans. Am. Nucl. Soc*., **78**. 175 (1998)

11. R. Q. Wright and L. C. Leal, "Benchmark Testing and Status of ENDF/B-VI Release-3 Evaluations," *Trans. Am. Nucl. Soc*., **77**. 232 (1997)

12. H. Huria and M. Ouisloumen, "ENDF/B-VI: 238U Resonance Integral Reduction – A Closer Look," *Trans. Am. Nucl. Soc*., **76**. 329 (1997)

13. DLC-189, "MCNPXS," Los Alamos National Laboratory (1997)

14. NEA/NSC/DOC(95)03, "International Handbook of Evaluated Criticality Safety Benchmark Experiments," NEA Nuclear Science Committee, Sep. 1998 Edition.

Table I. Calculated k-eff with MCNP Based on ENDF/B-V and ENDF/B-VI Data (1 of 4)

Case	k-eff (ENDF/B-V)	k-eff (ENDF/B-VI)	Δk (ENDF/BV-ENDF/B-VI)
LEU-COMP-THERM-010			
01	1.00754 +/- 0.00070[a]	1.00435 +/- 0.00075	-0.00319
02	1.00885 +/- 0.00072	1.00444 +/- 0.00072	-0.00441
03	1.00697 +/- 0.00071	1.00262 +/- 0.00070	-0.00435
04	0.99455 +/- 0.00073	0.99120 +/- 0.00073	-0.00335
05	0.99834 +/- 0.00071	0.99610 +/- 0.00071	-0.00224
06	1.01186 +/- 0.00072	1.00780 +/- 0.00066	-0.00406
07	0.99957 +/- 0.00068	0.99605 +/- 0.00066	-0.00352
08	0.99584 +/- 0.00070	0.99188 +/- 0.00072	-0.00396
09	1.00034 +/- 0.00073	0.99416 +/- 0.00073	-0.00618
10	1.00069 +/- 0.00073	0.99628 +/- 0.00073	-0.00441
11	1.00198 +/- 0.00076	0.99560 +/- 0.00077	-0.00638
12	0.99803 +/- 0.00076	0.99458 +/- 0.00073	-0.00345
13	0.99634 +/- 0.00074	0.99152 +/- 0.00072	-0.00482
14	0.99898 +/- 0.00079	0.99383 +/- 0.00074	-0.00515
15	0.99791 +/- 0.00077	0.99331 +/- 0.00077	-0.00460
16	0.99867 +/- 0.00071	0.99495 +/- 0.00079	-0.00372
17	0.99886 +/- 0.00077	0.99408 +/- 0.00081	-0.00478
18	0.99817 +/- 0.00078	0.99302 +/- 0.00080	-0.00515
19	0.99639 +/- 0.00071	0.99501 +/- 0.00079	-0.00138
20	1.00057 +/- 0.00081	0.99970 +/- 0.00074	-0.00087
21	1.00167 +/- 0.00078	0.99950 +/- 0.00080	-0.00217
22	0.99894 +/- 0.00076	0.99698 +/- 0.00078	-0.00196
23	0.99695 +/- 0.00079	0.99289 +/- 0.00074	-0.00406
24	0.99652 +/- 0.00077	0.99359 +/- 0.00072	-0.00293
25	0.99591 +/- 0.00073	0.99267 +/- 0.00073	-0.00324
26	0.99743 +/- 0.00076	0.99419 +/- 0.00074	-0.00324
27	0.99652 +/- 0.00071	0.99448 +/- 0.00071	-0.00204
28	0.99785 +/- 0.00074	0.99372 +/- 0.00075	-0.00413
29	0.99785 +/- 0.00073	0.99357 +/- 0.00075	-0.00428
30	0.99429 +/- 0.00074	0.99185 +/- 0.00073	-0.00244
average (deviation)[b]	0.99948 (0.00425)	0.99580 (0.00597)	-0.00368 -

[a] It denotes the standard deviation of the calculated k-eff.
[b] It denotes the standard deviation for the mean value of k-eff.

Table I. Calculated k-eff with MCNP Based on ENDF/B-V and ENDF/B-VI Data (2 of 4)

Case	k-eff (ENDF/B-V)	k-eff (ENDF/B-VI)	Δk (ENDF/BV-ENDF/B-VI)
LEU-COMP-THERM-016			
01	0.99555 +/- 0.00063	0.99136 +/- 0.00065	-0.00419
02	0.99507 +/- 0.00066	0.99048 +/- 0.00065	-0.00459
03	0.99801 +/- 0.00066	0.99022 +/- 0.00066	-0.00779
04	0.99578 +/- 0.00065	0.99081 +/- 0.00062	-0.00497
05	0.99577 +/- 0.00064	0.99152 +/- 0.00065	-0.00425
06	0.99592 +/- 0.00065	0.99166 +/- 0.00065	-0.00426
07	0.99500 +/- 0.00062	0.99074 +/- 0.00063	-0.00426
08	0.99722 +/- 0.00066	0.99086 +/- 0.00065	-0.00636
09	0.99713 +/- 0.00067	0.99309 +/- 0.00068	-0.00404
10	0.99753 +/- 0.00066	0.99104 +/- 0.00066	-0.00649
11	0.99696 +/- 0.00067	0.99146 +/- 0.00069	-0.00550
12	0.99750 +/- 0.00066	0.99252 +/- 0.00067	-0.00498
13	0.99603 +/- 0.00067	0.99047 +/- 0.00063	-0.00556
14	0.99675 +/- 0.00064	0.99112 +/- 0.00064	-0.00563
15	0.99674 +/- 0.00063	0.99128 +/- 0.00067	-0.00546
16	0.99375 +/- 0.00066	0.98959 +/- 0.00064	-0.00416
17	0.99550 +/- 0.00068	0.99032 +/- 0.00066	-0.00518
18	0.99759 +/- 0.00065	0.99253 +/- 0.00061	-0.00506
19	0.99579 +/- 0.00061	0.99096 +/- 0.00068	-0.00483
20	0.99642 +/- 0.00066	0.99268 +/- 0.00068	-0.00374
21	0.99693 +/- 0.00063	0.99112 +/- 0.00068	-0.00581
22	0.99658 +/- 0.00065	0.99093 +/- 0.00064	-0.00565
23	0.99645 +/- 0.00065	0.99087 +/- 0.00064	-0.00558
24	0.99665 +/- 0.00068	0.99019 +/- 0.00066	-0.00646
25	0.99648 +/- 0.00064	0.99182 +/- 0.00063	-0.00466
26	0.99708 +/- 0.00064	0.99272 +/- 0.00066	-0.00436
27	0.99609 +/- 0.00067	0.99263 +/- 0.00066	-0.00346
28	0.99590 +/- 0.00060	0.99046 +/- 0.00063	-0.00544
29	0.99680 +/- 0.00065	0.99156 +/- 0.00063	-0.00524
30	0.99572 +/- 0.00069	0.99147 +/- 0.00064	-0.00425
31	0.99671 +/- 0.00068	0.99249 +/- 0.00065	-0.00422
32	0.99703 +/- 0.00067	0.99015 +/- 0.00062	-0.00688
average (deviation)	0.99639 (0.00377)	0.99129 (0.00890)	-0.00510 -

Table I. Calculated k-eff with MCNP Based on ENDF/B-V and ENDF/B-VI Data (3 of 4)

Case	k-eff (ENDF/B-V)	k-eff (ENDF/B-VI)	Δk (ENDF/BV-ENDF/B-VI)
LEU-COMP-THERM-017			
01	1.00173 +/- 0.00064	0.99804 +/- 0.00070	-0.00369
02	1.00031 +/- 0.00065	0.99670 +/- 0.00062	-0.00361
03	1.00022 +/- 0.00067	0.99330 +/- 0.00063	-0.00692
04	0.99600 +/- 0.00059	0.99173 +/- 0.00064	-0.00427
05	0.99814 +/- 0.00063	0.99424 +/- 0.00064	-0.00390
06	0.99915 +/- 0.00061	0.99450 +/- 0.00067	-0.00465
07	0.99608 +/- 0.00062	0.99533 +/- 0.00063	-0.00075
08	0.99643 +/- 0.00060	0.99050 +/- 0.00063	-0.00593
09	0.99674 +/- 0.00063	0.99081 +/- 0.00064	-0.00593
10	0.99698 +/- 0.00064	0.99179 +/- 0.00064	-0.00519
11	0.99711 +/- 0.00064	0.99289 +/- 0.00070	-0.00422
12	0.99767 +/- 0.00068	0.99043 +/- 0.00066	-0.00724
13	0.99564 +/- 0.00066	0.99266 +/- 0.00065	-0.00298
14	0.99602 +/- 0.00064	0.99139 +/- 0.00069	-0.00463
15	0.99528 +/- 0.00067	0.98827 +/- 0.00066	-0.00701
16	0.99689 +/- 0.00066	0.98994 +/- 0.00070	-0.00695
17	0.99658 +/- 0.00068	0.99151 +/- 0.00074	-0.00507
18	0.99371 +/- 0.00067	0.98937 +/- 0.00066	-0.00434
19	0.99576 +/- 0.00069	0.99116 +/- 0.00068	-0.00460
20	0.99469 +/- 0.00068	0.98992 +/- 0.00065	-0.00477
21	0.99443 +/- 0.00066	0.99000 +/- 0.00067	-0.00443
22	0.99305 +/- 0.00069	0.98920 +/- 0.00067	-0.00385
23	0.99863 +/- 0.00069	0.99464 +/- 0.00070	-0.00399
24	0.99882 +/- 0.00069	0.99452 +/- 0.00066	-0.00430
25	0.99478 +/- 0.00071	0.99127 +/- 0.00064	-0.00351
26	0.99272 +/- 0.00067	0.98878 +/- 0.00065	-0.00394
27	0.99554 +/- 0.00065	0.99041 +/- 0.00073	-0.00513
28	0.99644 +/- 0.00066	0.99062 +/- 0.00068	-0.00582
29	0.99506 +/- 0.00069	0.99078 +/- 0.00068	-0.00428
average (deviation)	0.99657 (0.00409)	0.99189 (0.00860)	-0.00469 -

Table I. Calculated k-eff with MCNP Based on ENDF/B-V and ENDF/B-VI Data (4 of 4)

Case	k-eff (ENDF/B-V)	k-eff (ENDF/B-VI)	Δk (ENDF/BV-ENDF/B-VI)
MIX-COMP-THERM-001			
01	0.99676 +/- 0.00083	0.99329 +/- 0.00083	-0.00347
02	0.99935 +/- 0.00082	0.99402 +/- 0.00085	-0.00533
03	1.00083 +/- 0.00084	0.99434 +/- 0.00084	-0.00649
04	1.00622 +/- 0.00081	0.99770 +/- 0.00077	-0.00852
MIX-COMP-THERM-002[c]			
30	0.99564 +/- 0.00073	0.98934 +/- 0.00078	-0.00729
31	0.99783 +/- 0.00081	0.99151 +/- 0.00073	-0.00721
32	0.99932 +/- 0.00075	0.99431 +/- 0.00072	-0.00739
33	1.00427 +/- 0.00071	1.00170 +/- 0.00074	-0.00497
34	1.00154 +/- 0.00071	0.99714 +/- 0.00068	-0.00818
35	1.00517 +/- 0.00071	1.00235 +/- 0.00071	-0.00571
MIX-COMP-THERM-003			
01	0.99620 +/- 0.00078	0.99058 +/- 0.00081	-0.00562
02	0.99980 +/- 0.00083	0.99153 +/- 0.00085	-0.00827
03	0.99836 +/- 0.00080	0.99108 +/- 0.00084	-0.00728
04	1.00272 +/- 0.00079	0.99524 +/- 0.00083	-0.00748
05	1.00351 +/- 0.00073	0.99658 +/- 0.00079	-0.00693
06	1.00707 +/- 0.00074	0.99864 +/- 0.00073	-0.00843
MIX-COMP-THERM-004			
01	0.99634 +/- 0.00074	0.99102 +/- 0.00072	-0.00532
02	0.99861 +/- 0.00075	0.99177 +/- 0.00077	-0.00684
03	0.99445 +/- 0.00077	0.99179 +/- 0.00072	-0.00266
04	0.99743 +/- 0.00075	0.99167 +/- 0.00075	-0.00576
05	0.99940 +/- 0.00070	0.99223 +/- 0.00068	-0.00717
06	0.99994 +/- 0.00069	0.99209 +/- 0.00076	-0.00785
07	1.00016 +/- 0.00070	0.99420 +/- 0.00070	-0.00596
08	0.99994 +/- 0.00073	0.99381 +/- 0.00068	-0.00613
09	1.00205 +/- 0.00067	0.99639 +/- 0.00067	-0.00566
10	1.00096 +/- 0.00065	0.99627 +/- 0.00066	-0.00469
11	1.00167 +/- 0.00065	0.99575 +/- 0.00065	-0.00592
UO_2 average	**0.99747 (0.00399)**	**0.99296 (0.00786)**	**-0.00450**
MOX average	**1.00021 (0.00322)**	**0.99382 (0.00694)**	**-0.00639**

[c] k-eff of benchmark experiments is not 1.0. The values are normalized to 1.0 by dividing with k-eff of the benchmark experiments.

Table II. Calculated k-eff with MCNP Based on ENDF/B-V and Selected ENDF/B-VI Data (1 of 4)

Case	Oxygen (ENDF/B-VI)[a]		U-238 (ENDF/B-VI)[a]		U-235 (ENDF/B-VI)[a]	
	k-eff	Δk[b]	k-eff	Δk[b]	k-eff	Δk[b]
LEU-COMP-THERM-010						
01	1.00577	-0.00177	1.00594	-0.00160	1.00956	0.00202
02	1.00553	-0.00332	1.00636	-0.00249	1.00841	-0.00044
03	1.00255	-0.00442	1.00479	-0.00218	1.00593	-0.00104
04	0.99279	-0.00176	0.99359	-0.00096	0.99629	0.00174
05	0.99370	-0.00464	0.99630	-0.00204	0.99888	0.00054
06	1.00857	-0.00329	1.01156	-0.00030	1.01433	0.00247
07	0.99710	-0.00247	0.99784	-0.00173	1.00068	0.00111
08	0.99294	-0.00290	0.99470	-0.00114	0.99508	-0.00076
09	0.99831	-0.00203	0.99919	-0.00115	1.00169	0.00135
10	0.99733	-0.00336	0.99846	-0.00223	0.99969	-0.00100
11	0.99755	-0.00443	1.00033	-0.00165	1.00069	-0.00129
12	0.99571	-0.00232	0.99689	-0.00114	0.99852	0.00049
13	0.99162	-0.00472	0.99326	-0.00308	0.99584	-0.00050
14	0.99430	-0.00468	0.99441	-0.00457	0.99897	-0.00001
15	0.99581	-0.00210	0.99811	0.00020	0.99942	0.00151
16	0.99637	-0.00230	0.99680	-0.00187	0.99997	0.00130
17	0.99548	-0.00338	0.99620	-0.00266	1.00110	0.00224
18	0.99560	-0.00257	0.99747	-0.00070	0.99958	0.00141
19	0.99242	-0.00397	0.99481	-0.00158	0.99916	0.00277
20	0.99878	-0.00179	1.00093	0.00036	1.00222	0.00165
21	0.99905	-0.00262	1.00112	-0.00055	1.00377	0.00210
22	0.99703	-0.00191	0.99708	-0.00186	1.00044	0.00150
23	0.99440	-0.00255	0.99609	-0.00086	0.99881	0.00186
24	0.99373	-0.00279	0.99362	-0.00290	0.99691	0.00039
25	0.99430	-0.00161	0.99504	-0.00087	0.99922	0.00331
26	0.99396	-0.00347	0.99532	-0.00211	0.99850	0.00107
27	0.99288	-0.00364	0.99478	-0.00174	0.99812	0.00160
28	0.99632	-0.00153	0.99635	-0.00150	0.99859	0.00074
29	0.99338	-0.00447	0.99522	-0.00263	1.00024	0.00239
30	0.99303	-0.00126	0.99389	-0.00040	0.99588	0.00159
average	0.99654	-0.00294	0.99788	-0.00160	1.00055	0.00107

[a] All cross section data are based on ENDF/B-V except this nuclide based on ENDF/B-VI.
[b] Δk = k-eff (ENDF/B-V) – k-eff (ENDF/B-VI for specified nuclide)

Table II. Calculated k-eff with MCNP Based on ENDF/B-V and Selected ENDF/B-VI Data (2 of 4)

Case	Oxygen (ENDF/B-VI)		U-238 (ENDF/B-VI)		U-235 (ENDF/B-VI)	
	k-eff	Δk	k-eff	Δk	k-eff	Δk
LEU-COMP-THERM-016						
01	0.99307	-0.00248	0.99397	-0.00158	0.99483	-0.00072
02	0.99169	-0.00338	0.99352	-0.00155	0.99535	0.00028
03	0.99455	-0.00346	0.99366	-0.00435	0.99667	-0.00134
04	0.99280	-0.00298	0.99380	-0.00198	0.99415	-0.00163
05	0.99284	-0.00293	0.99498	-0.00079	0.99589	0.00012
06	0.99383	-0.00209	0.99434	-0.00158	0.99642	0.00050
07	0.99379	-0.00121	0.99508	0.00008	0.99653	0.00153
08	0.99356	-0.00366	0.99351	-0.00371	0.99712	-0.00010
09	0.99390	-0.00323	0.99608	-0.00105	0.99640	-0.00073
10	0.99280	-0.00473	0.99469	-0.00284	0.99560	-0.00193
11	0.99442	-0.00254	0.99480	-0.00216	0.99661	-0.00035
12	0.99283	-0.00467	0.99277	-0.00473	0.99738	-0.00012
13	0.99381	-0.00222	0.99397	-0.00206	0.99671	0.00068
14	0.99222	-0.00453	0.99316	-0.00359	0.99731	0.00056
15	0.99301	-0.00373	0.99461	-0.00213	0.99449	-0.00225
16	0.99035	-0.00340	0.99221	-0.00154	0.99334	-0.00041
17	0.99261	-0.00289	0.99501	-0.00049	0.99556	0.00006
18	0.99338	-0.00421	0.99535	-0.00224	0.99623	-0.00136
19	0.99398	-0.00181	0.99557	-0.00022	0.99746	0.00167
20	0.99327	-0.00315	0.99532	-0.00110	0.99617	-0.00025
21	0.99373	-0.00320	0.99527	-0.00166	0.99682	-0.00011
22	0.99388	-0.00270	0.99461	-0.00197	0.99686	0.00028
23	0.99370	-0.00275	0.99480	-0.00165	0.99669	0.00024
24	0.99347	-0.00318	0.99490	-0.00175	0.99708	0.00043
25	0.99359	-0.00289	0.99496	-0.00152	0.99658	0.00010
26	0.99413	-0.00295	0.99463	-0.00245	0.99687	-0.00021
27	0.99285	-0.00324	0.99529	-0.00080	0.99711	0.00102
28	0.99372	-0.00218	0.99480	-0.00110	0.99593	0.00003
29	0.99380	-0.00300	0.99323	-0.00357	0.99607	-0.00073
30	0.99176	-0.00396	0.99480	-0.00092	0.99514	-0.00058
31	0.99338	-0.00333	0.99456	-0.00215	0.99598	-0.00073
32	0.99356	-0.00347	0.99441	-0.00262	0.99617	-0.00086
average	0.99326	-0.00313	0.99446	-0.00193	0.99617	-0.00022

Table II. Calculated k-eff with MCNP Based on ENDF/B-V and Selected ENDF/B-VI Data (3 of 4)

Case	Oxygen (ENDF/B-VI)		U-238 (ENDF/B-VI)		U-235 (ENDF/B-VI)	
	k-eff	Δk	k-eff	Δk	k-eff	Δk
LEU-COMP-THERM-017						
01	1.00089	-0.00084	0.99934	-0.00239	1.00254	0.00081
02	0.99893	-0.00138	1.00073	0.00042	1.00094	0.00063
03	0.99400	-0.00622	0.99676	-0.00346	0.99898	-0.00124
04	0.99198	-0.00402	0.99485	-0.00115	0.99571	-0.00029
05	0.99587	-0.00227	0.99641	-0.00173	0.99890	0.00076
06	0.99589	-0.00326	0.99640	-0.00275	0.99813	-0.00102
07	0.99423	-0.00185	0.99557	-0.00051	0.99812	0.00204
08	0.99423	-0.00220	0.99190	-0.00453	0.99577	-0.00066
09	0.99152	-0.00522	0.99390	-0.00284	0.99399	-0.00275
10	0.99470	-0.00228	0.99346	-0.00352	0.99699	0.00001
11	0.99410	-0.00301	0.99589	-0.00122	0.99777	0.00066
12	0.99495	-0.00272	0.99360	-0.00407	0.99790	0.00023
13	0.99350	-0.00214	0.99404	-0.00160	0.99721	0.00157
14	0.99376	-0.00226	0.99538	-0.00064	0.99718	0.00116
15	0.99193	-0.00335	0.99273	-0.00255	0.99505	-0.00023
16	0.99274	-0.00415	0.99390	-0.00299	0.99651	-0.00038
17	0.99512	-0.00146	0.99565	-0.00093	0.99902	0.00244
18	0.99266	-0.00105	0.99188	-0.00183	0.99684	0.00313
19	0.99224	-0.00352	0.99415	-0.00161	0.99676	0.00100
20	0.99018	-0.00451	0.99134	-0.00335	0.99599	0.00130
21	0.99259	-0.00184	0.99062	-0.00381	0.99511	0.00068
22	0.98994	-0.00311	0.99242	-0.00063	0.99398	0.00093
23	0.99598	-0.00265	0.99698	-0.00165	0.99833	-0.00030
24	0.99703	-0.00179	0.99632	-0.00250	0.99974	0.00092
25	0.99174	-0.00304	0.99420	-0.00058	0.99590	0.00112
26	0.99174	-0.00098	0.98983	-0.00289	0.99223	-0.00049
27	0.99104	-0.00450	0.99133	-0.00421	0.99496	-0.00058
28	0.99269	-0.00375	0.99159	-0.00485	0.99672	0.00028
29	0.99245	-0.00261	0.99180	-0.00326	0.99452	-0.00054
average	0.99375	-0.00283	0.99424	-0.00233	0.99696	0.00039

Table II. Calculated k-eff with MCNP Based on ENDF/B-V and Selected ENDF/B-VI Data (4 of 4)

Case	Oxygen (ENDF/B-VI)		U-238 (ENDF/B-VI)		U-235 (ENDF/B-VI)		Pu-239 (ENDF/B-VI)	
	k-eff	Δk	k-eff	Δk	k-eff	Δk	k-eff	Δk
MIX-COMP-THERM-001								
01	0.99289	-0.00387	0.99667	-0.00009	0.99646	-0.00030	0.99490	-0.00186
02	0.99823	-0.00112	0.99847	-0.00088	1.00102	0.00167	0.99895	-0.00040
03	0.99743	-0.00340	1.00059	-0.00024	1.00145	0.00062	0.99841	-0.00242
04	1.00232	-0.00390	1.00444	-0.00178	1.00587	-0.00035	1.00074	-0.00548
MIX-COMP-THERM-002[c]								
30	0.99253	-0.00312	0.99448	-0.00117	0.99638	0.00074	0.99271	-0.00294
31	0.99574	-0.00209	0.99642	-0.00141	0.99957	0.00174	0.99674	-0.00109
32	0.99581	-0.00351	0.99775	-0.00158	1.00120	0.00188	0.99820	-0.00112
33	1.00241	-0.00186	1.00404	-0.00023	1.00587	0.00160	1.00340	-0.00087
34	0.99842	-0.00313	0.99965	-0.00189	1.00081	-0.00074	0.99811	-0.00344
35	1.00245	-0.00271	1.00315	-0.00201	1.00598	0.00082	1.00228	-0.00288
MIX-COMP-THERM-003								
01	0.99262	-0.00358	0.99577	-0.00043	0.99659	0.00039	0.99456	-0.00164
02	0.99424	-0.00556	0.99672	-0.00308	0.99772	-0.00208	0.99580	-0.00400
03	0.99542	-0.00294	0.99556	-0.00280	0.99932	0.00096	0.99615	-0.00221
04	1.00042	-0.00230	1.00193	-0.00079	1.00339	0.00067	1.00197	-0.00075
05	1.00039	-0.00312	1.00225	-0.00126	1.00508	0.00157	1.00021	-0.00330
06	1.00313	-0.00394	1.00671	-0.00036	1.00778	0.00071	1.00234	-0.00473
MIX-COMP-THERM-004								
01	0.99314	-0.00320	0.99501	-0.00133	0.99668	0.00034	0.99589	-0.00045
02	0.99370	-0.00491	0.99652	-0.00209	0.99693	-0.00168	0.99385	-0.00476
03	0.99370	-0.00075	0.99660	0.00215	0.99870	0.00425	0.99502	0.00057
04	0.99492	-0.00251	0.99701	-0.00042	0.99760	0.00017	0.99452	-0.00291
05	0.99665	-0.00275	0.99764	-0.00176	0.99998	0.00058	0.99704	-0.00236
06	0.99744	-0.00250	0.99784	-0.00210	0.99930	-0.00064	0.99682	-0.00312
07	0.99705	-0.00311	0.99928	-0.00088	0.99922	-0.00094	0.99845	-0.00171
08	0.99856	-0.00138	0.99887	-0.00107	0.99972	-0.00022	0.99985	-0.00009
09	0.99830	-0.00375	1.00003	-0.00202	1.00265	0.00060	0.99883	-0.00322
10	1.00073	-0.00023	1.00082	-0.00014	1.00237	0.00141	0.99945	-0.00151
11	0.99892	-0.00275	1.00081	-0.00086	1.00119	-0.00048	0.99970	-0.00197
UO_2	0.99450	-0.00297	0.99552	-0.00195	0.99787	0.00040	-	-
MOX	0.99732	-0.00289	0.99908	-0.00113	1.00070	0.00049	0.99796	-0.00225

[c] k-eff of benchmark experiments is not 1.0. The values are normalized to 1.0 by dividing with k-eff of the benchmark experiments.