Criticality safety benchmark calculations with MCNP-4C3 using JEFF-3.1 nuclear data

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Abstract

Criticality safety benchmark calculations were performed with MCNP-4C3 using the new JEFF-3.1 nuclear data library. The benchmarks used were almost all taken from the International Criticality Safety Benchmark Evaluation Project (ICSBEP). Additional benchmarks were a Proteus core, a Dimple core, two Kritz cores, and two TRX cores. The results of these calculations are reported in tabular and graphical form.

Keywords

MCNP-4C3
JEFF-3.1
nuclear data
criticality safety benchmarks

Contents

1. Introduction

In May 2005 a new version of the JEFF general purpose nuclear data library was released: JEFF-3.1. Over the last several years there has been a concerted effort by many people in several countries to bring the quality of this nuclear data library to a new, higher level. Especially the underprediction of k_{eff} for many criticality safety benchmark with a thermal spectrum has received much attention.

In this report, the results of many criticality safety benchmark runs are presented. The results show, among other things, that when using JEFF-3.1 nuclear data, the prediction of k_{eff} for the thermal spectrum benchmarks is much closer to the benchmark value.

All results reported in this report were obtained by use of the Monte Carlo neutronics code MCNP, version 4C3 [1].

2. Brief description of the criticality benchmarks

Almost all benchmarks were taken from the *International Handbook of Evaluated Criticality Safety Benchmark Experiments* from the OECD-NEA project ICSBEP [2]. In Ref. [2], these benchmarks are subdivided in main categories according to three criteria.

1. The main fissionable isotope. The systems containing uranium-235 are subdivided according to the enrichment in ^{235}U: there is low enriched uranium (LEU: wt% ^{235}U < 10), intermediate enriched (IEU: $10 <$ wt% ^{235}U < 60) and high enriched (HEU: wt% ^{235}U > 60). There are also plutonium systems (PU), mixed uranium/plutonium systems (MIX), and ^{233}U systems (U233).
2. The physical form of the fissile material: there are metal systems (MET), compound (COM), solution (SOL) and miscellaneous systems.
3. The neutron spectrum: if more than half of the fissions occurs for neutrons with energy below 0.625 eV the spectrum is thermal (THERM), if more than half occurs between 0.625 eV and 100 keV it is intermediate (INTER), and if more than half occurs over 100 keV it is fast (FAST). If none of these applies, the spectrum is classified as MIXED.

The benchmark series identifier consists of the three components mentioned above, plus an additional sequence number.

For each of the benchmark series for which calculations have been performed, a brief description is given below.

2.1 HEU benchmarks

2.1.1 Fast spectrum

heu-met-fast-001 (1 case, 'Godiva')

- A bare sphere of highly enriched uranium (LANL, 1950s).
- The uranium enrichment was 94% ^{235}U.
- The isotopes in this benchmark model are U-{234,235,238}.

heu-met-fast-005 (6 cases)

- Cores of uranium metal alloy and reflectors of molybdenum and beryllium (Obninsk, 1987). The amount of reflector material (Be-9) and the amount of molybdenum between fuel and reflector was varied.
- The uranium enrichment was 90% ^{235}U.
- The isotopes in these benchmark models are C-nat, Al-27, Si-{28−30}, Ti-{46−50}, Cr-{50,52−54}, Mn-55, Fe-{54,56−58}, Ni-{58,60−62,64}, Mo-{92,94−98,100}, and U-{234,235,236,238}.
  In cases 2 − 6 Be-9 is also present.

heu-met-fast-007 (43 cases)

- Uranium metal slabs moderated with polyethylene, plexiglas and teflon (ORNL, 1960s). Some of the polyethylene moderated experiments also had a polyethylene reflector. The H/^{235}U ratio was varied between 0 and 5.
- The uranium enrichment was 93% ^{235}U.
- The isotopes in these benchmark models are H-1, C-nat, U-{234,235,236,238}. In cases 27−31 O-16 is also used, and in cases 32−34 F-19 is also used.

heu-met-fast-022 (1 case)

- A sphere of highly enriched uranium with C, Fe and W impurities, reflected by duraluminum (VNIIEF, Russia, 1962).
- The uranium enrichment was 90% ^{235}U.
- The isotopes in this benchmark model are C-nat, Al-27, Fe-{54,56−58}, Cu-{63,65}, W-{182−184,186}, U-{234,235,238}.

heu-met-fast-027 (1 case)

- A sphere of highly enriched uranium with C, Fe and W impurities, reflected by lead (VNIIEF, Russia, 1962).
- The uranium enrichment was 90% ^{235}U.
- The isotopes in this benchmark model are C-nat, Fe-{54,56−58}, W-{182−184,186}, Pb-{206−208}, U-{234,235,238}.

heu-met-fast-028 (1 case, 'Topsy', 'Flattop-25')

- A sphere of highly enriched uranium reflected by normal uranium (LANL, 1960s).
- The uranium enrichment was 93% ^{235}U.
- The isotopes in this benchmark model are U-{234,235,238}.

heu-met-fast-057 (6 cases)

- Uranium metal spheres and cylinders, reflected by lead (LLNL, 1950s).
- The uranium enrichment was 93% ^{235}U.
- The isotopes in these benchmark models are Be-9, Ca-{40,42−44,46,48}, Fe-{54,56−58}, Ni-{58,60−62,64}, Pb-{204,206−208}, U-{234,235,238}.

heu-met-fast-060 (1 case)

- A cylindrical assembly of uranium metal and tungsten, with aluminum reflectors (ZPR-9 assembly 4, ANL, 1960s).
- The uranium enrichment was 93% ^{235}U.
- The isotopes in this benchmark model are H-1, C-nat, F-19, Mg-{24−26}, Al-27, Si-{28−30}, Cl-{35,37}, Ti-{46−50}, Cr-{50,52−54}, Mn-55, Fe-{54,56−58}, Ni-{58,60−62,64}, Cu-{63,65}, Mo-{92,94−98,100}, W-{182−184,186}, U-{234,235,236,238}.

heu-met-fast-064 (3 cases)

- Three cylinders of lead reflected highly enriched uranium (VNIITF, Russia, 1991).
- The uranium enrichment was 96% ^{235}U.
- The isotopes in these benchmark models are C-nat, Si-{28−30}, Cr-{50,52−54}, Mn-55, Fe-{54,56−58}, W-{182−184,186}, Pb-{204,206−208}, U-{234,235,238}.

heu-met-fast-067 (2 cases)

- Cylindrical assemblies of uranium metal with tungsten, graphite (assembly 5) and aluminum assembly 6), reflected by dense aluminum. (ZPR-9 assemblies 5 and 6, ANL, 1960s).
- The uranium enrichment was 93% ^{235}U.
- The isotopes in these benchmark models are H-1, C-nat, F-19, Mg-{24−26}, Al-27, Si-{28−30}, Cl-{35,37}, Ti-{46−50}, Cr-{50,52−54}, Mn-55, Fe-{54,56−58}, Cu-{63,65}, Ni-{58,60−62,64}, Mo-{92,94−98,100}, W-{182−184,186}, U-{234,235,236,238}.

heu-met-fast-072 (1 case, 'Zeus')

- An iron/HEU core surrounded by a copper reflector in the Los Alamos Critical Experiment Facility (LANL, 2002). In this report only configuration 1 (out of two) was computed.

- The uranium enrichment was 93% ^{235}U.
- The isotopes in these benchmark models are B-{10,11}, C-nat, N-{14,15}, Mg-{24−26}, Al-27, Si-{28−30}, P-31, S-{32−34,36}, Ti-{46−50}, V-nat, Cr-{50,52−54}, Mn-55, Fe-{54,56−58}, Ni-{58,60−62,64}, Cu-{63,65}, Zn-nat, Ga-nat, Mo-{92,94−98,100}, Pb-{204,206−208}, U-{234,235,236,238}.

2.1.2 Intermediate spectrum

heu-comp-inter-004 (1 case)

- A k_∞ experiment at the HECTOR reactor (Winfrith, UK, 1960s): a graphite moderated uranium oxide core. The benchmark model is an infinite medium with a material composition appropriate to the interpolated boron/^{235}U ratio.
- The uranium enrichment was 92% ^{235}U.
- The isotopes in these benchmark models are H-1, B-{10,11}, C-nat, O-16, Ca-{40,42−44,46,48}, U-{234,235,236,238}.

heu-comp-inter-005 (5 cases)

- Several k_∞ experiments at the COBRA facility (Obninsk, Russia, 1980s, 1990s), containing uranium and nickel (KBR-7 assembly), stainless steel (KBR-9), stainless steel and molybdenum (KBR-10), chromium (KBR-15), and zirconium (KBR-16).
- The uranium enrichment was 90% ^{235}U.
- The isotopes in these benchmark models are C-nat, O-16, Si-{28−30}, Ti-{46−50}, Cr-{50,52−54}, Mn-55, Fe-{54,56−58}, Ni-{58,60−62,64}, U-{235,238}. Also used are Co-59 (case 1), Mo-{92,94−98,100} (case 3) and H-1, Zr-{90−92,94,96}, Hf-{174,176−180} (case 5).

heu-met-inter-001 (1 case)

- A cylindrical assembly if uranium and iron, reflected by stainless steel (ZPR-9 assemby 34, ANL, 1979).
- The uranium enrichment was 93% ^{235}U.
- The isotopes in this benchmark model are H-1, C-nat, F-19, Mg-{24−26}, Al-27, Si-{28−30}, Cl-{35,37}, Cr-{50,52−54}, Mn-55, Fe-{54,56−58}, Ni-{58,60−62,64}, Cu-{63,65}, Mo-{92,94−98,100}, U-{234,235,236,238}.

heu-met-inter-006 (4 cases, 'Zeus')

- The inital set of Zeus experiments at the Los Alamos Critical Experiments Facility (LANL, 1999−2001): uranium metal interspersed with graphite plates in a cylindrical stack, surrounded by copper reflector. The C/^{235}U ratio varied between 51.2 to 13.6.
- The uranium enrichment was 93% ^{235}U.
- The isotopes in these benchmark models are C-nat, Mg-{24−26}, Al-27, Si-{28−30}, Ti-{46−50}, Cr-{50,52−54}, Mn-55, Fe-{54,56−58}, Cu-{63,65}, U-{234,235,236,238}.

2.1.3 Thermal spectrum

heu-met-therm-001 (2 cases)

- A polyethylene moderated and reflected uranium system with silicon (LANL, 1999).
- The uranium enrichment was 93% ^{235}U.
- The isotopes in these benchmark models are H-1, C-nat, O-16, Si-{28−30}, U-{234,235,236,238}.

Thermal scattering data for H in CH_2 is used.

heu-met-therm-003 (7 cases)

- Lattices of oralloy cubes in water (LANL, 1955). The number of cubes and their spacing were varied.
- The uranium enrichment was 94% ^{235}U.
- The isotopes in these benchmark models are H-1, C-nat, O-16, U-{234,235,238}.
  Thermal scattering data for H in H_2O is used.

heu-met-therm-006 (23 cases)

- Lattices of SPERT-D fuel elements, reported by ORNL, 1964-65. The fuel elements consisted of plates of a uranium-aluminium alloy. The experiments were water-moderated and water-reflected. In some of the cases uranyl nitrate solution (with and without boron) was substituted for the water. The lattice configuration was varied.
- The uranium enrichment was 93% ^{235}U.
- The isotopes in these benchmark models are H-1, O-16, Mg-{24−26}, Al-27, Si-{28−30}, Ti-{46−50}, Cr-{50,52−54}, Mn-55, Fe-{54,56−58}, Cu-{63,65}, and U-{234,235,238}. Thermal scattering data for H in H_2O is used.
  For cases 17 and 18 Cd-{106,108,110−114,116} is also present, while for cases 4 and 19 − 23 C-nat, N-14, P-31, S-{32−34,36}, and Ni-{58,60−62,64} are present too. Besides, cases 20 − 23 have B-{10,11}.

heu-met-therm-008 (2 cases)

- A polyethylene moderated and reflected uranium system with aluminium (LANL)
- The uranium enrichment was 93% ^{235}U.
- The isotopes in these benchmark models are H-1, C-nat, Mg-{24−26}, Al-27, Si-{28−30}, Ti-{46−50}, Cr-{50,52−54}, Mn-55, Fe-{54,56−58}, Cu-{63,65}, U-{234,235,236,238}.
  Thermal scattering data for H in CH_2 is used.

heu-met-therm-009 (1 case)

- A polyethylene moderated and reflected uranium system with magnesium oxide (LANL, 2001)
- The uranium enrichment was 93% ^{235}U.
- The isotopes in these benchmark models are H-1, Li-{6, B-10, C-nat, O-16, Mg-{24−26}, Al-27, K-{39,40,41}, Ca-{40,42−44,46,48}, Mn-55, Fe-{54,56−58}, Cd-{106,108,110−114,116}, U-{234,235,236,238}.
  Thermal scattering data for H in CH_2 is used.

heu-met-therm-010 (2 cases)

- A polyethylene moderated and reflected uranium system with gadolinium (LANL, 2001). Two thicknesses of Gd foil were used.
- The uranium enrichment was 93% ^{235}U.
- The isotopes in these benchmark models are H-1, C-nat, Gd-{152,154−158,160}, U-{234,235,236,238}.
  Thermal scattering data for H in CH_2 is used.

heu-met-therm-013 (2 cases)

- A polyethylene moderated and reflected uranium system with iron (LANL, ∼2002). Two thicknesses of iron plates were used.

- The uranium enrichment was 93% ^{235}U.
- The isotopes in these benchmark models are H-1, C-nat, Fe-{54,56−58}, U-{234,235,236,238}.
  Thermal scattering data for H in CH_2 is used.

heu-met-therm-014 (1 case)

- 2 × 2 × 23 array of uranium with silicon oxide, moderated and reflected by polyethylene (LANL, ∼2002)
- The uranium enrichment was 93% ^{235}U.
- The isotopes in these benchmark models are H-1, C-nat, O-16, Si-{28−30}, U-{234,235,236,238}.
  Thermal scattering data for H in CH_2 is used.

heu-met-therm-016 (2 cases)

- 2×2×23 array of uranium with Ni-Cr-Mo-Gd alloy, moderated and reflected by polyethylene (LANL)
- The uranium enrichment was 93% ^{235}U.
- The isotopes in these benchmark models are H-1, B-{10,11}, C-nat, O-16, Mg-{24−26}, Al-27, Si-{28−30}, P-31, Ca-{40,42−44,46,48}, Ti-{46−50}, V-nat, Cr-{50,52−54}, Mn-55, Fe-{54,56−58}, Co-59, Ni-{58,60−62,64}, Cu-{63,65}, Br-79, Zr-{90−92,94,96}, Nb-93, Mo-{92,94−98,100}, Ag-{107,109}, Cd-{106,108,110−114,116}, Gd-{152,154−158,160}, Hf-{174,176,177,178,179,180}, Ta-181, W-{182−184,186}, Pb-{204,206−208}, U-{234,235,236,238}.
  Thermal scattering data for H in CH_2 is used.

heu-met-therm-018 (2 cases)

- A polyethylene moderated and reflected uranium system with concrete (LANL, 2003).
- The uranium enrichment was 93% ^{235}U.
- The isotopes in these benchmark models are H-1, Li-{6,7}, B-{10,11}, C-nat, O-16, Na-23, Mg-{24−26}, Al-27, Si-{28−30}, P-31, S-32, K-{39,40,41}, Ca-{40,42−44,46,48}, Sc-45, Ti-{46−50}, Fe-{54,56−58}, Rh-103, Cd-{106,108,110−114,116}, In-{113,115}, Eu-{151,153}, Gd-{152,154−158,160}, U-{234,235,236,238}.
  Thermal scattering data for H in CH_2 is used.

heu-sol-therm-001 (10 cases)

- Cylindrical reflected tank with uranyl nitrate, minimally reflected. The uranium concentration was varied and the critical height was determined.
- The uranium enrichment was 93% ^{235}U.
- The isotopes in these benchmark models are H-1, C-nat, N-14, O-16, Al-27, Si-{28−30}, P-31, S-{32−34,36}, Cr-{50,52−54}, Mn-55, Fe-{54,56−58}, Ni-{58,60−62,64}, Mo-{92,94−98,100}, U-{234,235,236,238}. Thermal scattering data for H in H_2O is used.

heu-sol-therm-002 (14 cases)

- Cylindrical reflected tank with uranyl nitrate, with a concrete reflector. The uranium concentration was varied and the critical height was determined.
- The uranium enrichment was 93% ^{235}U.
- The isotopes in these benchmark models are H-1, C-nat, N-14, O-16, Na-23, Mg-{24−26}, Al-27, Si-{28−30}, S-{32−34,36}, K-{39−41}, Ca-{40,42−44,46,48}, Ti-{46−50}, Cr-

{50,52−54}, Mn-55, Fe-{54,56−58}, and U-{234,235,236,238}. Thermal scattering data for H in H_2O is used.
In cases 5 − 14 there is also Cu-{63,65}, in cases 1 − 4 P-31, Ni-{58,60−62,64}, and Mo-{92,94−98,100}.

heu-sol-therm-004 (6 cases)

- Reflected uranyl-fluoride solutions in heavy water (LANL, 1950s). The D/^{235}U ratio varied from 34 to 431.
- The uranium enrichment was 94% ^{235}U.
- The isotopes in these benchmark models are H-{1,2}, O-16, F-19, Si-{28−30}, Cr-{50,52−54}, Mn-55, Fe-{54,56−58}, Ni-{58,60−62,64}, U-{234,235,238}.
  Thermal scattering data for D in D_2O is used.

heu-sol-therm-009 (4 cases)

- Water reflected 6.4-liter spheres of highly enriched uranium oxyfluoride (UO_2F_2) solutions (ORNL, 1950s). The fuel concentration was varied.
- The uranium enrichment was 93% ^{235}U.
- The isotopes in these benchmark models are H-1, O-16, F-19, Al-27, Si-{28−30}, Mn-55, Cu-{63,65}, U-{234,235,236,238}. Thermal scattering data for H in H_2O is used.

heu-sol-therm-010 (4 cases)

- Water reflected 9.7-liter spheres of highly enriched uranium oxyfluoride (UO_2F_2) solutions (ORNL, 1950s). The fuel concentration and the temprature were varied.
- The uranium enrichment was 93% ^{235}U.
- The isotopes in these benchmark models are H-1, O-16, F-19, Al-27, Si-{28−30}, Mn-55, Cu-{63,65}, U-{234,235,236,238}. Thermal scattering data for H in H_2O is used.

heu-sol-therm-013 (4 cases, 'ORNL-1', . . ., 'ORNL-4')

- Uranyl nitrate solutions poisoned with boric acid in an unreflected sphere (at ORNL, 1950s).
- The uranium enrichment was 93% ^{235}U.
- The isotopes in these benchmark models are H-1, N-14, O-16, Al-27, Si-{28−30}, Mn-55, Cu-{63,65}, U{234,235,236,238}. Thermal scattering data for H in H_2O is used.
  For cases 1 − 3 B-{10,11} are also present.

heu-sol-therm-032 (1 case)

- Unreflected 48-inch sphere of highly enriched uranyl nitrate solution (ORNL, 1950s).
- The uranium enrichment was 93% ^{235}U.
- The isotopes in this benchmark model are H-1, N-14, O-16, Al-27, Si-{28−30}, Mn-55, Fe-{54,56−58}, Cu-{63,65}, U-{233,234,235,236,238}. Thermal scattering data for H in H_2O is used.

heu-sol-therm-038 (30 cases)

- Two interacting slab tanks with highly enriched uranyl nitrate solution with various absorber-reflector plates (LANL, 1988). The absorber-reflector plates were made of poly-ethylene, borated poly-ethylene, boraflex, pyrex, stainless steel, hot rolled steel, lead, beryllium, depleted uranium, or cadmium.
- The uranium enrichment was 93% ^{235}U.
- The isotopes in these benchmark models are H-1, Be-9, B-{10,11}, C-nat, N-14, O-16, Na-23, Mg-{24−26}, Al-27, Si-{28−30}, P-31, S-{32−34,36}, Ti-{46−50}, Cr-

{50,52−54}, Mn-55, Fe-{54,56−58}, Ni-{58,60−62,64}, Cu-{63,65}, Mo-{92,94−98,100}, Cd-{106,108,110−114,116}, Pb-{206−208}, U-{234,235,236,238}. Thermal scattering data for H in H_2O and for H in CH_2 is used.

heu-sol-therm-039 (6 cases)

- Mixture of highly enriched uranium hexafluoride (UF_6) and hydrofluoric acid (HF), low H/U ratio, in a hot-water reflected tank (Valduc, 1960s). The uranium concentration was varied.
- The uranium enrichment was 93% ^{235}U.
- The isotopes in these benchmark models are H-1, C-nat, O-16, F-19, Si-{28−30}, Mn-55, Fe-{54,56−58}, Ni-{58,60−62,64}, Cu-{63,65}, U-{234,235,236,238}. Thermal scattering data for H in H_2O is used.

heu-sol-therm-042 (8 cases)

- Unreflected cylinders (5 ft and 9 ft diameter) of highly enriched uranyl nitrate solution. The uranium concentration was varied.
- The uranium enrichment was 93% ^{235}U.
- The isotopes in these benchmark models are H-1, C-nat, N-14, O-16, Cr-{50,52−54}, Fe-{54,56−58}, Ni-{58,60−62,64}, Mo-{92,94−98,100}, U-{234,235,236,238}. Thermal scattering data for H in H_2O is used.

2.1.4 Mixed spectrum

heu-comp-mixed-003 (1 case)

- Heterogeneous assemblies of uranium dioxide fuel elements in a zirconium hydride moderator block, with beryllium reflector (RCC Kurchatov, 1992−1993).
- The uranium enrichment was 96% ^{235}U.
- The isotopes in these benchmark models are H-1, Be-9, B-{10,11}, C-nat, O-16, Al-27, Si-{28−30}, Ti-{46−50}, Cr-{50,52−54}, Mn-55, Fe-{54,56−58}, Ni-{58,60−62,64}, Zr-{90−92,94,96}, Nb-93, Mo-{92,94−98,100}, Hf-{174,176,177,178,179,180}, W-{182−184,186}, U-{234,235,236,238}.
  Thermal scattering data for H in ZrH is used.

heu-met-mixed-005 (5 cases)

- Critical experiments with heterogeneous compositions of highly enriched uranium, silicon dioxide and polyethylene (Obninsk, 1999).
- The uranium enrichment was 90% ^{235}U.
- The isotopes in these benchmark models are H-1, Li-{6,7}, B-{10,11}, C-nat, N-14, O-16, Na-23, Mg-{24−26}, Al-27, Si-{28−30}, S-32, K-{39,40,41}, Ca-{40,42−44,46,48}, Ti-{46−50}, V-nat, Cr-{50,52−54}, Mn-55, Fe-{54,56−58}, Ni-{58,60−62,64}, Cu-{63,65}, Mo-{92,94−98,100}, Cd-{106,108,110−114,116}, Pb-{206−208}, U-{234,235,236,238}.
  Thermal scattering data for H in H_2O is used.

2.2 IEU benchmarks

2.2.1 Fast spectrum

ieu-met-fast-001 (4 cases, 'Jemima')

- Bare cylindrical configurations of enriched and natural uranium (LANL, 1952−1954).
- The core average uranium enrichment was 36−55% ^{235}U.

- The isotopes in these benchmark models are Mg-{24−26}, Al-27, Cr-{50,52−54}, Mn-55, Fe-{54,56−58}, Ni-{58,60−62,64}, Cu-{63,65}, U-{234,235,238}.

ieu-met-fast-002 (1 case)

- Cylindrical assembly with a core of alternating plates of enriched and natural uranium surrounded by a natural uranium reflector (LANL, 1956).
- The core average uranium enrichment was 16% ^{235}U.
- The isotopes in this benchmark model are U-{234,235,238}.

ieu-met-fast-007 (3 cases, 'Big Ten')

- Three models of a large mixed-uranium-metal cylindrical core with 10% average uranium enrichment, surrounded by a thick depleted uranium reflector (LANL, 1971). The total uranium mass was ten metric tons. This core is modeled in three different benchmark models: detailed, simple and two-zone.
- The core average uranium enrichment was 10% ^{235}U.
- The isotopes in these benchmark models are Si-{28−30}, Cr-{50,52−54}, Mn-55, Fe-{54,56−58}, Ni-{58,60−62,64}, Nb-93, U-{234,235,236,238}.

ieu-met-fast-010 (1 case)

- A cylindrical assembly of uranium metal, 9% average enrichment, with a thick depleted uranium reflector (ANL, ZPR-9, U9 benchmark assembly, 1980).
- The core average uranium enrichment was 9% ^{235}U.
- The isotopes in these benchmark models are H-1, C-nat, F-19, Al-27, Si-{28−30}, Cl-{35,37}, Cr-{50,52−54}, Mn-55, Fe-{54,56−58}, Ni-{58,60−62,64}, Cu-{63,65}, Mo-{92,94−98,100}, U-{234,235,236,238}.

ieu-met-fast-012 (1 case)

- A critical assembly of uranium metal, aluminium and steel, reflected by depleted uranium (ZPR-3 assembly 41, 1962).
- The core average uranium enrichment was 16% ^{235}U.
- The isotopes in this benchmark model are C-nat, Al-27, Si-{28−30}, Cr-{50,52−54}, Mn-55, Fe-{54,56−58}, Ni-{58,60−62,64}, and U-{234,235,236,238}.

ieu-met-fast-014 (2 cases)

- Cylindrical assemblies of uranium metal and tungsten with aluminum reflectors (ANL, ZPR-9 assemblies 2 and 3, 1964). Case 2 (assembly 3) had more tungsten than case 1 (assembly 1).
- The core average uranium enrichment was 16% ^{235}U (case 1) and 21% ^{235}U (case 2).
- The isotopes in these benchmark models are H-1, C-nat, F-19, Mg-{24−26}, Al-27, Si-{28−30}, Cl-{35,37}, Ti-{46−50}, Cr-{50,52−54}, Mn-55, Fe-{54,56−58}, Ni-{58,60−62,64}, Cu-{63,65}, Mo-{92,94−98,100}, W-{182−184,186}, U-{234,235,236,238}.

2.2.2 Intermediate spectrum

ieu-comp-inter-001 (4 cases)

- For k_∞ experiments for combinations of uranium, thorium metal and varying amounts of polyethylene (IPPE, Obninsk, 1990−1994). The H/^{235}U ratio varied from 0 to 70.
- Various combinations of 36% ^{235}U and 90% ^{235}U were used.
- The isotopes in these benchmark models are H-1, C-nat, O-16, Al-27, Si-{28−30}, Ti-{46−50}, Cr-{50,52−54}, Mn-55, Fe-{54,56−58}, Ni-{58,60−62,64}, Th-232, U-{235,238}

2.2.3 Thermal spectrum

ieu-comp-therm-002 (3 cases)

- Stainless steel clad UO_2 fuel rods in a water filled tank (MATR, Russia, 1970-1973). The fuel rods were arranged in a hexagonal lattice, with gadolinium absorber, cadmium absorber or no absorber. Cases 1, 3 and 5 were at room temperature, case 2 was at T=218.4°C, and cases 4 and 6 were at T=150.8°C.
- The uranium enrichment was 17% ^{235}U.
- The isotopes in these benchmark models are H-1, C-nat, O-16, Si-{28−30}, Ti-{46−50}, Cr-{50,52−54}, Mn-55, Fe-{54,56−58}, Ni-{58,60−62,64}, and U-{234,235,238}. Thermal scattering data for H in H_2O is used.
  For case 3 Al-27 and Gd-{152,154−158,160} are also present, for case 5 Al-27 and Cd-{106,108,110−114,116}.

ieu-comp-therm-003 (2 cases)

- Zirconium hydride fuel rods in water, with a graphite reflector (Triga Mark II reactor, Ljubljana, 1991). The two cases differ only in the position of the 7 outermost fuel elements.
- The uranium enrichment was 20% ^{235}U.
- The isotopes in these benchmark models are H-1, B-{10,11}, C-nat, N-14, O-16, Al-27, Si-{28−30}, P-31, S-{32−34,36}, Cr-{50,52−54}, Mn-55, Fe-{54,56−58}, Ni-{58,60−62,64}, Zr-{90−92,94,96}, Mo-{92,94−98,100}, U-{235,238}. Thermal scattering data for graphite, for H in ZrH and for H in H_2O is used.

Proteus (1 case)

- Core 5 of Proteus, a graphite reflected pebble bed reactor, containing uranium-carbon fuel pebbles and graphite moderator pebbles (PSI, 1995−1996) [3].
- The uranium enrichment was 16.7% ^{235}U.
- The isotopes in these benchmark models are H-1, Li-{6,7}, B-{10,11}, C-nat, N-14, O-16, Mg-{24−26}, Al-27, Si-{28−30}, S-{32−34,36}, Cl-{35,37}, Ca-{40,42−44,46,48}, Mn-55, Fe-{54,56−58}, Cu-{63,65}, Ga-nat, Cd-{106,108,110−114,116}, Gd-{154−158,160}, Sm-{144,147−150,152,154}, U-{234,235,236,238}. Thermal scattering data for graphite and for H in H_2O is used.

2.3 LEU benchmarks

2.3.1 Fast spectrum

No benchmark models in this category are available from the ICSBEP handbook.

2.3.2 Intermediate spectrum

No benchmark models in this category are available from the ICSBEP handbook.

2.3.3 Thermal spectrum

leu-comp-therm-001 (8 cases)

- Clusters of aluminium clad UO_2 fuel rods in a water filled tank. The clusters were square, with no absorber plates, reflecting walls, dissolved poison or gadolinium impurities. The number of clusters and the separation between them was varied.

- The uranium enrichment was 2.4% ^{235}U.
- The isotopes in these benchmark models are H-1, C-nat, O-16, Mg-{24−26}, Al-27, Si-{28−30}, Ti-{46−50}, Cr-{50,52−54}, Mn-55, Fe-{54,56−58}, Cu-{63,65}, and U-{234,235,236,238}. Thermal scattering data for H in H_2O and for H in CH_2 is used.

leu-comp-therm-002 (5 cases)

- Water moderated UO_2 fuel rods, aluminium clad, in square arrays (pitch 2.54 cm, Pacific Northwest Laboratories). The shape of the rod cluster was varied, as well as the distance between clusters (for cases 4 and 5).
- The uranium enrichment was 4.31% ^{235}U.
- The isotopes in these benchmark models are H-1, C-nat, O-16, Mg-{24−26}, Al-27, Si-{28−30}, S-{32−34,36}, Ca-{40,42−44,46,48}, Ti-{46−50}, Cr-{50,52−54}, Mn-55, Fe-{54,56−58}, Cu-{63,65}, U-{234,235,236,238}. Thermal scattering data for H in H_2O and for H in CH_2 is used.

leu-comp-therm-003 (22 cases)

- Water moderated UO_2 fuel rods, aluminium clad, in square arrays (pitch 1.684 cm), with gadolinium impurity in water (Pacific Northwest Laboratories). The shape of the rod clusters was varied, as well as the distance between clusters.
- The uranium enrichment was 2.35% ^{235}U.
- The isotopes in these benchmark models are H-1, C-nat, O-16, Mg-{24−26}, Al-27, Si-{28−30}, Ti-{46−50}, Cr-{50,52−54}, Mn-55, Fe-{54,56−58}, Cu-{63,65}, Gd-{152,154−158,160}, U-{234,235,236,238}. Thermal scattering data for H in H_2O and for H in CH_2 is used.

leu-comp-therm-005 (16 cases)

- UO_2 fuel rods, aluminium clad, in water containing dissolved gadolinium (Pacific Northwest Laboratories, early 1980s). The lattice pitch and the gadolinium concentration were varied.
- The uranium enrichment was 2.35% ^{235}U (cases 1−13) and 4.31% ^{235}U (cases 14−16).
- The isotopes in these benchmark models are H-1, C-nat, N-14, O-16, Mg-{24−26}, Al-27, Si-{28−30}, S-{32−34,36} Ca-{40,42−44,46,48}, Ti-{46−50}, Cr-{50,52−54}, Mn-55, Fe-{54,56−58}, Cu-{63,65}, Gd-{152,154−158,160}, U-{234,235,236,238}. Thermal scattering data for H in H_2O and for H in CH_2 is used.

leu-comp-therm-006 (18 cases)

- Arrays of UO_2 fuel rods with water-to-fuel ratios from 1.5 to 3.0 in a Tank-type Critical Assembly (TCA, Japan, 1963−1975). The lattice pitch and the number of fuel rods were varied.
- The uranium enrichment was 2.6% ^{235}U.
- The isotopes in these benchmark models are H-1, O-16, Al-27, U-{234,235,238}. Thermal scattering data for H in H_2O is used.

leu-comp-therm-007 (10 cases)

- Water moderated UO_2 fuel rod arrays (Valduc, 1978). In four cases the arrays were square, with varying pitch. In the other cases the arrays had a triangular pitch, with either hexagonal pr pseudo-cylindrical section, and with varying pitch.
- The uranium enrichment was 4.738% ^{235}U.
- The isotopes in these benchmark models are H-1, B-{10,11}, C-nat, N-14, O-16, Mg-

{24−26}, Al-27, Si-{28−30}, P-31, S-{32−34,36}, Cr-{50,52−54}, Mn-55, Fe-{54,56−58}, Ni-{58,60−62,64}, Zn-nat, U-{234,235,236,238}.
Thermal scattering data for H in H_2O is used.

leu-comp-therm-009 (27 cases)

- Clusters of aluminium-clad UO_2 fuel rods in a large water-filled tank (Pacific Northwest Laboratories, 1977). There were three square-pitched clusters with two absorber plates in between. These plates were stainless steel, borated stainless steel, boral, copper, copper with 1% cadmium, cadmium, aluminium or zircaloy-4.
- The uranium enrichment was 4.3% ^{235}U.
- The isotopes in these benchmark models are H-1, C-nat, O-16, Na-23, Mg-{24−26}, Al-27, Si-{28−30}, S-{32−34,36}, Ca-{40,42−44,46,48}, Ti-{46−50}, Cr-{50,52−54}, Mn-55, Fe-{54,56−58}, Cu-{63,65}, and U-{234,235,236,238}. Thermal scattering data for H in H_2O and for H in CH_2 is used.
  In some cases Na-23 (case 9 − 13) is present, in others B-{10,11} (case 5 − 9, 14, 15), Cd-{106,108,110−114,116} (case 14 − 23), Ni-{58,60−62,64} (cases 1 − 9, 14, 15), Mo-{92,94−98,100} (cases 1 − 8), Sn-{112,114−120,122,124} (cases 14, 15, 26, 27), and Zr-{90−92,94,96} (cases 26, 27).

leu-comp-therm-010 (30 cases)

- Rectangular clusters of water moderated UO_2 fuel rods, reflected by two lead, uranium or steel walls. Also the pitch and the number of fuel rods were varied.
- The uranium enrichment was 4.31% ^{235}U.
- The isotopes in these benchmark models are H-1, C-nat, O-16, Mg-{24−26}, Al-27, Si-{28−30}, P-31, S-{32−34,36}, Ca-{40,42−44,46,48}, Ti-{46−50}, Cr-{50,52−54}, Mn-55, Fe-{54,56−58}, Ni-{58,60−62,64}, Cu-{63,65}, Mo-{92,94−98,100}, Pb-{206−208}, U-{234,235,236,238}. Thermal scattering data for H in H_2O and for H in CH_2 is used.

leu-comp-therm-016 (32 cases)

- Low enriched uranium pin assemblies placed in water and separated by absorber plates. The absorber material was steel, borated steel, boral, copper, copper with cadmium, cadmium, aluminium or zircaloy-4.
- The uranium enrichment was 93% ^{235}U.
- The isotopes in these benchmark models are H-1, C-nat, O-16, Mg-{24−26}, Al-27, Si-{28−30}, Ti-{46−50}, Cr-{50,52−54}, Mn-55, Fe-{54,56−58}, Cu-{63,65}, and U-{234,235,236,238}. Thermal scattering data for H in H_2O and for H in CH_2 is used.
  In some cases B-{10,11} is also present (cases 8 − 14, 20), in others Na-23 (cases 12 − 19), S-{32−34,36} (cases 12 − 19, 28 − 30), Ni-{58,60−62,64} (cases 1 − 14, 20), Zr-{90−92,94,96} (cases 31, 32), Mo-{92,94−98,100} (cases 1 − 11), Cd-{106,108,110−114,116} (cases 20 − 27), and Sn-{112,114−120,122,124} (cases 20, 31, 32).

leu-comp-therm-017 (19 cases)

- Low enriched uranium pin assemblies placed in water and reflected by steel or lead reflector plates. The separation between the clusters and the distance between the fuel and the reflector were varied.
- The uranium enrichment was 2.35% ^{235}U.
- The isotopes in these benchmark models are H-1, C-nat, O-16, Mg-{24−26}, Al-27 Si-{28−30}, Ti-{46−50}, Cr-{50,52−54}, Mn-55, Fe-{54,56−58}, Cu-{63,65} and U-

{234,235,236,238}. Thermal scattering data for H in H_2O and for H in CH_2 is used.
In cases 1−3, 23−25 there is also Pb-{206−208}, in the other cases there P-31, S-{32−34,36}, Ni-{58,60−62,64}, and Mo-{92,94−98,100}.

leu-comp-therm-019 (3 cases)

- Water-moderated hexagonally pitched lattices with low enriched cylindrical fuel rods with stainless steel cladding (RRC Kurchatov Institute, 1961). The pitch of the lattice was varied.
- The uranium enrichment was 5% ^{235}U.
- The isotopes in these benchmark models are H-1, C-nat, O-16, Mg-{24−26}, Al-27, Si-{28−30}, Ti-{46−50}, Cr-{50,52−54}, Mn-55, Fe-{54,56−58}, Ni-{58,60−62,64}, Cu-{63,65}, and U-{234,235,236,238}. Thermal scattering data for H in H_2O is used.

leu-comp-therm-039 (17 cases)

- Incomplete arrays of water moderated and reflected UO_2 fuel rods (Valduc, 1978). All arrays were square, with a varying number of positions not filled.
- The uranium enrichment was 4.738% ^{235}U.
- The isotopes in these benchmark models are H-1, B-{10,11}, C-nat, N-14, O-16, Mg-{24−26}, Al-27, Si-{28−30}, P-31, S-{32−34,36}, Cr-{50,52−54}, Mn-55, Fe-{54,56−58}, Ni-{58,60−62,64}, Zn-nat, U-{234,235,236,238}.
  Thermal scattering data for H in H_2O is used.

leu-comp-therm-051 (19 cases)

- Aluminium-clad uranium oxide in 9 assemblies of 14×14 fuel rods. (Babcock-Wilcox Lynchberg Research Center, 1978-79). The moderator and reflector was borated water, and the absorbers were stainless steel and boron. The loading pattern, water height and boron concentration were varied.
- The uranium enrichment was 2.5% ^{235}U.
- The isotopes in these benchmark models are H-1, B-10, B-11, O-16, Mg-{24−26}, Al-27, Si-{28−30}, Ti-{46−50}, Cr-{50,52−54}, Mn-55, Fe-{54,56−58}, Cu-{63,65}, and U-{234,235,236,238}. Thermal scattering data for H in H_2O is used.
  For cases 2 − 9 there are also: C-nat, P-31, S-{32−34,36}, Co-59, Ni-{58,60−62,64}, and Mo-{92,94−98,100}.

leu-comp-therm-060 (28 cases)

- Configurations of UO_2 fuel assemblies in an RBMK-type graphite moderated reactor. Some configurations had empty channels, some had water in the fuel channels, and some had boron or thorium absorber rods. Also the enrichment was varied.
- The uranium enrichment was 1.8% ^{235}U (cases 1 and 2), 2.4% ^{235}U (cases 5 and 6) or 2.0% ^{235}U (all other cases).
- The isotopes in these benchmark models are H-1, B-{10,11}, C-nat, N-14, O-16, F-19, Mg-{24−26}, Al-27, Si-{28−30}, P-31, S-{32−34,36}, Ca-{40,42−44,46,48}, Ti-{46−50}, V-nat, Cr-{50,52−54}, Mn-55, Fe-{54,56−58}, Ni-{58,60−62,64}, Cu-{63,65}, As-75, Zr-{90−92,94,96}, Nb-93, Mo-{92,94−98,100}, Ag-{107,109}, Cd-{106,108,110−114,116}, Sn-{112,114−120,122,124}, Hf-{174,176−180}, W-{182−184,186}, Au-197, Pb-{206−208}, Bi-209, Th-{230,232}, U-{234,235,236,238}. Thermal scattering data for graphite and for H in H_2O is used.

Dimple (1 case)

- Assembly S01A, a cylindrical arrangement of uranium dioxide fuel pins on a square pitch of 1.32 cm, water moderated and reflected (Winfrith, UK) [4].
- The uranium enrichment was 3% ^{235}U.
- The isotopes in these benchmark models are H-{1,2}, C-nat, N-14 O-16 Mg-{24−26}, Al-27, Si-{28−30}, P-31 S-{32−34,36}, Cl-{35,37}, Ti-{46−50}, V-nat, Cr-{50,52−54}, Mn-55 Fe-{54,56−58}, Co-nat, Ni-{58,60−62,64}, Cu-{63,65}, Sr-{84,86−88}, Nb-93 Mo-{92,94−98,100}, Sn-{112,114−120,122,124}, U-{234,235,236,238}. Thermal scattering data for graphite and for H in H_2O and for H in CH_2 is used.

TRX (2 cases)
- Light-water moderated UO_2 pins with aluminium cladding in a hexagonal lattice [5]. The pitch was 1.806 cm (case 1) or 2.174 cm (case 2).
- The uranium enrichment was 1.3% ^{235}U.
- The isotopes in these benchmark models are H-1, O-16, Al-27, Fe-{54,56−58}, U-{235,238}. Thermal scattering data for graphite and for H in H_2O is used.

leu-met-therm-001 (1 case)
- A natural uranium, heavy water moderated critical assembly (Yugoslavia, 1958).
- The uranium enrichment was 0.72% ^{235}U.
- The isotopes in this benchmark model are H-{1,2}, B-{10,11}, C-nat, N-14, O-16, Mg-{24−26}, Al-27, Si-{28−30}, Ti-{46−50}, Cr-{50,52−54}, Mn-55, Fe-{54,56−58}, Ni-{58,60−62,64}, Cu-{63,65}, Cd-{106,108,110−114,116}, U-{234,235,238}. Thermal scattering data for D in D_2O and for H in H_2O is used.

leu-sol-therm-001 (1 case, 'Sheba-II')
- An unreflected UO_2F_2+H_2O cylindrical assembly (LANL).
- The uranium enrichment was 5% ^{235}U.
- The isotopes in this benchmark model are H-1, N-14, O-16, F-19, Cr-{50,52−54}, Mn-55, Fe-{54,56−58}, Ni-{58,60−62,64}, U-{234,235,236,238}
  Thermal scattering data for H in H_2O is used.

leu-sol-therm-003 (9 cases)
- Full and truncated bare spheres of 10% enriched uranyl nitrate water solutions (Obninsk, 1965). The uranium concentration and the sphere diameters were varied.
- The uranium enrichment was 10% ^{235}U.
- The isotopes in these benchmark models are H-1, N-14, O-16, Si-{28−30}, Ti-{46−50}, Cr-{50,52−54}, Mn-55, Fe-{54,56−58}, Ni-{58,60−62,64}, U-{234,235,238}. Thermal scattering data for H in H_2O is used.

leu-sol-therm-004 (7 cases)
- Water reflected uranyl nitrate solution in a 60 cm cylindrical water tank (STACY, Japan, 1995). The uranium concentration was varied.
- The uranium enrichment was 10% ^{235}U.
- The isotopes in these benchmark models are H-1, C-nat, N-14, O-16, Si-{28−30}, P-31, S-{32−34,36}, Cr-{50,52−54}, Mn-55, Fe-{54,56−58}, Ni-{58,60−62,64}, U-{234,235,236,238}. Thermal scattering data for H in H_2O is used.

leu-sol-therm-007 (5 cases)
- Unreflected uranyl nitrate solution in a 60 cm cylindrical water tank (STACY, Japan, 1995).

The uranium concentration was varied.

- The uranium enrichment was 10% ^{235}U.
- The isotopes in these benchmark models are H-1, C-nat, N-14, O-16, Si-{28−30}, P-31, S-{32−34,36}, Cr-{50,52−54}, Mn-55, Fe-{54,56−58}, Ni-{58,60−62,64}, U-{234,235,236,238}. Thermal scattering data for H in H_2O is used.

leu-sol-therm-016 (7 cases)

- Water reflected slabs (28 cm) of uranyl nitrate solutions (STACY, Japan, 1997). The uranium concentration was varied.
- The uranium enrichment was 10% ^{235}U.
- The isotopes in these benchmark models are H-1, C-nat, N-14, O-16, Si-{28−30}, P-31, S-{32−34,36}, Cr-{50,52−54}, Mn-55, Fe-{54,56−58}, Ni-{58,60−62,64}, U-{234,235,236,238}. Thermal scattering data for H in H_2O is used.

leu-sol-therm-017 (6 cases)

- Unreflected slabs (28 cm) of uranyl nitrate solutions (STACY, Japan, 1997). The uranium concentration was varied.
- The uranium enrichment was 10% ^{235}U.
- The isotopes in these benchmark models are H-1, C-nat, N-14, O-16, Si-{28−30}, P-31, S-{32−34,36}, Cr-{50,52−54}, Mn-55, Fe-{54,56−58}, Ni-{58,60−62,64}, U-{234,235,236,238}. Thermal scattering data for H in H_2O is used.

leu-sol-therm-018 (6 cases)

- Concrete reflected slabs (28 cm) of uranyl nitrate solutions (STACY, Japan, 1997). The thickness of the reflector was varied.
- The uranium enrichment was 10% ^{235}U.
- The isotopes in these benchmark models are H-1, C-nat, N-14, O-16, Na-23, Mg-{24−26}, Al-27, Si-{28−30}, P-31, S-{32−34,36}, Cl-{35,37}, K-{39−41}, Ca-{40,42−44,46,48}, Cr-{50,52−54}, Mn-55, Fe-{54,56−58},Ni-{58,60−62,64}, Cu-{63,65}, and U-{234,235,236,238}. Thermal scattering data for H in H_2O is used.

leu-sol-therm-020 (4 cases)

- Water reflected uranyl nitrate solution in a 80 cm cylindrical water tank (STACY, Japan, 1998−1999). The uranium concentration was varied.
- The uranium enrichment was 10% ^{235}U.
- The isotopes in these benchmark models are H-1, C-nat, N-14, O-16, Si-{28−30}, P-31, S-{32−34,36}, Cr-{50,52−54}, Mn-55, Fe-{54,56−58}, Ni-{58,60−62,64}, U-{234,235,236,238}. Thermal scattering data for H in H_2O is used.

leu-sol-therm-021 (4 cases)

- Unreflected uranyl nitrate solution in a 80 cm cylindrical water tank (STACY, Japan, 1998−1999). The uranium concentration was varied.
- The uranium enrichment was 10% ^{235}U.
- The isotopes in these benchmark models are H-1, C-nat, N-14, O-16, Si-{28−30}, P-31, S-{32−34,36}, Cr-{50,52−54}, Mn-55, Fe-{54,56−58}, Ni-{58,60−62,64}, U-{234,235,236,238}. Thermal scattering data for H in H_2O is used.

2.4 PU benchmarks

2.4.1 Fast spectrum

pu-met-fast-001 (1 case, 'Jezebel')

- A bare sphere of plutonium (LANL, 1950s).
- The plutonium-239 enrichment was 95.2% ^{239}Pu.
- The isotopes in this benchmark model are Ga-nat, Pu-{239,240,241}.

pu-met-fast-002 (1 case, 'Jezebel-240')

- A bare sphere of plutonium (LANL, 1964).
- The plutonium enrichment was 76.4% ^{239}Pu and 20.1% ^{240}Pu.
- The isotopes in this benchmark model are Ga-nat, Pu-{239,240,241,242}.

pu-met-fast-005 (1 case)

- A critical experiment of a plutonium sphere reflected by tungsten (LANL, 1958).
- The isotopes in these benchmark models are Ni-{58,60−62,64}, Cu-{63,65}, Ga-nat, Zr-{90−92,94,96}, W-{182−184,186}, U-{235,238}, Pu-{239,240,241}.

pu-met-fast-006 (1 case, 'Popsy', 'Flattop-Pu')

- A sphere of plutonium reflected by normal uranium (LANL, 1960s).
- The plutonium enrichment was 94.9% ^{239}Pu.
- The isotopes in this benchmark model are Ga-nat, U-{234,235,238}, Pu-{239,240,241}.

pu-met-fast-008 (1 case, 'Thor')

- A sphere of plutonium reflected by thorium (LANL, 1961).
- The plutonium enrichment was 94.9% ^{239}Pu.
- The isotopes in this benchmark model are Ga-nat, Th-232, Pu-{239,240,241}.

pu-met-fast-012 (1 case)

- A cylidrical arrangement of short, close-packed stainless steel clad rods of plutonium metal (97.6 at.%^{239}Pu), reflected on all sides by thick depleted uranium (IPPE, Obninsk, 1956).
- The isotopes in these benchmark models are C-nat, Si-{28−30}, Ti-{46−50}, Cr-{50,52−54}, Mn-55, Fe-{54,56−58}, Ni-{58,60−62,64}, Cu-{63,65}, Ga-nat, U-{235,238}, Pu-{238,239,240,241}.

pu-met-fast-013 (1 case)

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- A cylidrical arrangement of short, close-packed stainless steel clad rods of plutonium metal (97.6 at.%^{239}Pu), reflected on all sides by thick copper reflector (IPPE, Obninsk, 1960).
- The isotopes in these benchmark models are C-nat, Si-{28−30}, Ti-{46−50}, Cr-{50,52−54}, Mn-55, Fe-{54,56−58}, Ni-{58,60−62,64}, Cu-{63,65}, Ga-nat, U-{235,238}, Pu-{238,239,240,241}.

2.4.2 Intermediate spectrum

pu-comp-inter-001 (1 case)

- A k_∞ experiment at the HECTOR reactor (Winfrith, UK, 1960s): a graphite moderated plutonium oxide core (5% ^{240}Pu). The benchmark model is an infinite medium with a material composition appropriate to the interpolated boron/^{239}Pu ratio.
- The isotopes in these benchmark models are H-1, B-{10,11}, C-nat, O-16, Ca-

{40,42−44,46,48}, U-{235,238}, Pu-{239,240,241,242}.
Thermal scattering data for graphite is used.

pu-met-inter-002 (1 case)

- A cylindrical assembly containing plutonium, carbon and stainless steel, reflected by stainless ateel and iron (ANL, ZPR-6 assembly 10, 1981−1982).
- The plutonium enrichment was 95.3% ^{239}Pu.
- The isotopes in these benchmark models are C-nat, Al-27, Si-{28−30}, Cr-{50,52−54}, Co-nat, Mn-55, Fe-{54,56−58}, Ni-{58,60−62,64}, Cu-{63,65}, Mo-{92,94−98,100}, Pu-{238−242}, Am-241.

2.4.3 Thermal spectrum

pu-sol-therm-001 (6 cases)

- Water reflected 11.5 inch diameter spheres of plutonium nitrate solution (Pacific Northwest Laboratories, 1960s). The plutonium concentration was varied.
- The plutonium enrichment was 95% ^{239}Pu.
- The isotopes in these benchmark models are H-1, N-14, O-16, Cr-{50,52−54}, Mn-55, Fe-{54,56−58}, Ni-{58,60−62,64}, Pu-{238,239,240,241,242}. Thermal scattering data for H in H_2O is used.

pu-sol-therm-002 (7 cases)

- Water reflected 12 inch diameter spheres of plutonium nitrate solution (1950s). The plutonium concentration was varied.
- The plutonium enrichment was 96.9% ^{239}Pu.
- The isotopes in these benchmark models are H-1, N-14, O-16, Cr-{50,52−54}, Fe-{54,56−58}, Ni-{58,60−62,64}, Pu-{239,240}. Thermal scattering data for H in H_2O is used.

pu-sol-therm-003 (8 cases)

- Water reflected 13 inch diameter spheres of plutonium nitrate solution (1950s). The plutonium concentration was varied.
- The plutonium enrichment was 98.3% ^{239}Pu (cases 1 and 2) and 96.9% ^{239}Pu (cases 3−7).
- The isotopes in these benchmark models are H-1, N-14, O-16, Al-27, Si-{28−30}, Cr-{50,52−54}, Mn-55, Fe-{54,56−58}, Ni-{58,60−62,64}, Cu-{63,65}, Pu-{239,240}. Thermal scattering data for H in H_2O is used.

pu-sol-therm-004 (13 cases)

- Water reflected 14 inch diameter spheres of plutonium nitrate solution (1950s). The plutonium concentration was varied.
- The plutonium enrichment was 99.5% ^{239}Pu (cases 1−4), 98.25% ^{239}Pu (case 5), and 96.9% ^{239}Pu (cases 6−13).
- The isotopes in these benchmark models are H-1, N-14, O-16, Cr-{50,52−54}, Fe-{54,56−58}, Ni-{58,60−62,64}, Pu-{239,240}. Thermal scattering data for H in H_2O is used.

pu-sol-therm-005 (9 cases)

- Water reflected 14 inch diameter spheres of plutonium nitrate solution (1950s). The plutonium concentration was varied.
- The plutonium enrichment was 96.0% ^{239}Pu (cases 1−7), and 95.6% ^{239}Pu (cases 8 and 9).
- The isotopes in these benchmark models are H-1, N-14, O-16, Cr-{50,52−54}, Fe-

{54,56−58}, Ni-{58,60−62,64}, Pu-{239,240}. Thermal scattering data for H in H_2O is used.

pu-sol-therm-006 (3 cases)

- Water reflected 15 inch diameter spheres of plutonium nitrate solution (1950s). The plutonium concentration was varied.
- The plutonium enrichment was 96.9% ^{239}Pu.
- The isotopes in these benchmark models are H-1, N-14, O-16, Cr-{50,52−54}, Fe-{54,56−58}, Ni-{58,60−62,64}, Pu-{239,240}. Thermal scattering data for H in H_2O is used.

pu-sol-therm-007 (8 cases)

- Water reflected 11.5 inch diameter spheres partly filled with plutonium nitrate solution (Pacific Northwest Laboratories, 1960s). The plutonium concentration was varied.
- The plutonium enrichment was 95% ^{239}Pu.
- The isotopes in these benchmark models are H-1, N-14, O-16, Cr-{50,52−54}, Mn-55, Fe-{54,56−58}, Ni-{58,60−62,64}, Pu-{238,239,240,241,242}. Thermal scattering data for H in H_2O is used.

pu-sol-therm-008 (29 cases)

- Concrete reflected 14 inch diameter spheres of plutonium nitrate solution (Pacific Northwest Laboratories, 1961−2). The geometry and the thickness of the concrete reflector was varied. Some cases had an extra shell of stainless steel outside the solution tank, inside the reflector. some others an extra shell of cadmium at that place.
- The plutonium enrichment was 95% ^{239}Pu.
- The isotopes in these benchmark models are H-1, N-14, O-16, Na-23, Mg-{24−26}, Al-27, Si-{28−30}, K-{39−41}, Ca-{40,42−44,46,48}, Cr-{50,52−54}, Mn-55, Fe-{54,56−58}, Ni-{58,60−62,64}, Cd-{106,108,110−114,116}, Pu-{238,239,240,241,242}. Thermal scattering data for H in H_2O is used.

pu-sol-therm-012 (22 cases)

- Plutonium nitrate solution in a large tank, with and without water reflector (Valduc, 1974). The tank was a right parallelepiped of dimension $130 \times 130 \times 100$ cm^3. The water reflector was either on six sides (cases 2−5), on five sides (cases 6−13), or on no sides (cases 14−23). The plutonium concentration was varied.
- The plutonium enrichment was 74% ^{239}Pu, and 19% ^{240}Pu.
- The isotopes in these benchmark models are H-1, B-10, C-nat, N-14, O-16, Al-27, Si-{28−30}, Cl-{35,37}, Ca-{40,42−44,46,48}, Cr-{50,52−54}, Fe-{54,56−58}, Ni-{58,60−62,64}, Pu-{239,240,241,242}, Am-241. Thermal scattering data for H in H_2O and for H in CH_2 is used.

2.4.4 Mixed spectrum

pu-met-mixed-001 (6 cases)

- Heterogeneous configurations of plutonium, silicon dioxide, and polyethylene (IPPE, Obninsk, 1999−2000). The cores were configured to cover a broad range in neutron spectra.
- The isotopes in these benchmark models are H-1, Li-{6,7}, B-{10,11}, C-nat, N-14, O-16, Na-23, Mg-{24−26}, Al-27, Si-{28−30}, S-32, K-{39,40,41}, Ca-{40,42−44,46,48}, Ti-{46−50}, V-nat, Cr-{50,52−54}, Mn-55, Fe-{54,56−58}, Ni-{58,60−62,64}, Cu-{63,65}, Ga-nat, Mo-{92,94−98,100}, Cd-{106,108,110−114,116}, Pb-{206−208}, U-{235,238}, Pu-

{239,240,241}, Am-241.
Thermal scattering data for H in H_2O is used.

2.5 MIX benchmarks

2.5.1 Fast spectrum

mix-met-fast-011 (4 cases)

- Cylindrical assemblies of mixed fissile plutonium and uranium metal, reflected by graphite (ANL, ZPPR-21 phases B−E, 1990). The ratio of plutonium to uranium was varied.
- The isotopes in these benchmark models are H-1, Li-{6,7}, B-{10,11}, C-nat, N-14, O-16, Na-23, Al-27, Si-{28−30}, Cr-{50,52−54}, Mn-55, Fe-{54,56−58}, Co-nat, Ni-{58,60−62,64}, Cu-{63,65}, Zr-{90−92,94,96}, Mo-{92,94−98,100}, U-{234,235,236,238}, Pu-{238,239,240,241,242}, Am-241.

2.5.2 Intermediate spectrum

No calculations for benchmarks in this category were performed.

2.5.3 Thermal spectrum

mix-comp-therm-012 (33 cases)

- Rectangular parallelepipeds of homogeneous plutonium uranium mixed oxide polystyrene (Pacific Northwest Laboratories, 1970-1972). The cores were either unreflected (cases 20−22 and 31−33) or plexiglas reflected (cases 1−19 and 23−30). The amount of plutonium in the MOX, and the plutonium vector were varied.
- The isotopes in these benchmark models are H-1, C-nat, O-16, U-{235,238}, Pu-{238,239,240,241,242}, Am-241. Thermal scattering data for H in CH_2 is used.

Kritz (2 cases)

- Core 2:19, consisting of light water moderated and reflected square lattices with mixed oxide fuel rods (Studsvik, Sweden, 1970s) [6]. Criticality was obtained at room temperature and at 235.9°C, by adjusting the boron content of the water and by adjusting the water height. The only differences between the cold and the hot case are the densities, the water level, and some slight dimensional changes of the core components.
- The plutonium enrichment was 91% ^{239}Pu.
- The isotopes in these benchmark models are H-1, B-{10,11}, N-14, O-16, Cr-{50,52−54}, Fe-{54,56−58}, Ni-{58,60−62,64}, Zr-{90−92,94,96}, Sn-{112,114−120,122,124}, U-{235,238}, Pu-{239,240,241,242}, Am-241. Thermal scattering data for H in H_2O is used.

mix-sol-therm-001 (3 cases)

- Critical experiments with mixed plutonium and uranium nitrate solutions in a large cylindrical geometry (PNL, 1980s). The concentration of the solution and the U/Pu ratio was varied.
- The isotopes in these benchmark models are H-1, Li-6, B-10, N-14, O-16, Cr-{50,52−54}, Mn-55, Fe-{54,56−58}, Ni-{58,60−62,64}, Cd-{106,108,110−114,116}, Gd-{152,154−158,160}, U-{234,235,236,238}, Pu-{238,239,240,241,242}, Am-241.
  Thermal scattering data for H in H_2O is used.

2.6 U233 benchmarks

2.6.1 Fast spectrum

u233-met-fast-001 (1 case, 'Skidoo', 'Jezebel-233')

- A bare sphere of highly enriched uranium-233 metal (LANL, 1961).
- The uranium enrichment was 98% ^{233}U.
- The isotopes in these benchmark models are U-{233,234,235,238}.

u233-met-fast-005 (2 cases)

- Highly enriched uranium-233 spheres, reflected by beryllium (LANL, 1958). The mass of the uranium-233 core was 10 kg (case 1) and 7.6 kg (case 2).
- The uranium enrichment was 98% ^{233}U.
- The isotopes in these benchmark models are Be-9, O-16, U-{233,234,238}.

u233-met-fast-006 (1 case, 'Flattop-23')

- A highly enriched uranium-233 sphere, reflected by normal uranium (LANL, 1964).
- The uranium enrichment was 98% ^{233}U.
- The isotopes in these benchmark models are U-{233,234,235,238}.

2.6.2 Intermediate spectrum

No calculations for benchmarks in this category were performed.

2.6.3 Thermal spectrum

u233-comp-therm-001 (8 cases)

- Cores of $^{235}UO_2-ZrO_2$ and cores of $^{233}UO_2-ZrO_2$, with blankets of either $^{233}UO_2$ or ThO_2 (BAPL, 1960s). The moderator was light water. Five assemblies were rectangular (cases 1−5) and three hexagonal (cases 6−8).
- The uranium enrichment was 97% ^{233}U for cases 2, 3, 4, 7, and 8, and 93% ^{235}U for cases 1, 5, and 6.
- The isotopes in these benchmark models are H-1, B-10, C-nat, O-16, Cr-{50,52−54}, Mn-55, Fe-{54,56−58}, Ni-{58,60−62,64}, Zr-{90−92,94,96}, Sn-{112,114−120,122,124}, Gd-{152,154−158,160}, Th-232, U-{233,234,235,238}. Thermal scattering data for H in H_2O and for H in CH_2 is used.

u233-sol-001 (5 cases)

- Unreflected spheres of uranium-233 nitrate solutions (ORNL, 1950s). The amount of boron poison and the uranium concentration was varied.
- The uranium enrichment was 98% ^{233}U.
- The isotopes in these benchmark models are H-1, B-{10,11}, N-14, O-16, Al-27, Si-{28−30}, Mn-55, Fe-{54,56−58}, Cu-{63,65}, Th-232, U-{233,234,235,238}. Thermal scattering data for H in H_2O is used.

2.7 Occurrence of elements

In Table 2.1 are listed those elements that are present in *a* material of a benchmark series, either with more than 1 wt% or with more than 1e-4 atoms per barn-cm. Elements that do not show up in the table are either not at all present in the benchmark models, or only in minor fractions.

H in H_2O	(59 benchmark series)
D in D_2O	lmt01, hst04
Be	hcm03
Be in BeO	hcm03
C in graphite	lct60, proteus, ict03, hci04, hmm05, pci01, pmm01
H in ZrH	ict03, hcm03
H in CH_2	(26 benchmark series)
H	(75 benchmark series)
Li	mmf11
Be	hcm03, hst38, hmf05, hmf057, u3mf05
B	(13 benchmark series)
C	(58 benchmark series)
N	(33 benchmark series)
O	(72 benchmark series)
F	hst04, hst09, hst10, hst39, hmf07, lst01
Na	lst18, hmm05, hmt18, hst02, hst38, pmm01, pst08, mcf01
Mg	(30 benchmark series)
Al	(53 benchmark series)
Si	(59 benchmark series)
P	hst02
S	hst02, lct02, lct05, lct09, lct10, lst18
Cl	pst12
K	lst18, hmt18, hmm05, hst02, pmm01, pst08
Ca	(15 benchmark series)
Ti	(14 benchmark series)
Cr	(59 benchmark series)
Mn	(54 benchmark series)
Fe	(77 benchmark series)
Ni	(62 benchmark series)
Co	lct51
Cu	(18 benchmark series)
Ga	pmf01, pmf02, pmf05, pmf06, pmf08, pmf12, pmf13, pmm01
Zr	lct09, lct16, lct60, ict03, hci05, hcm03, pmf05, kritz, mmf11, u3ct01
Nb	lct60, imf07, hcm03
Mo	ict03, hmt16, hst42, hci05, hcm03, hmf05
Cd	lct09, lct16, ict02, hst38, hmt06, hmm05, pst08, pmm01
Sn	lct09, kritz, u3ct01
Gd	ict02, hmt10, hmt16
W	imf14, hmf60, hmf67, hcm03, pmf05
Pb	lct10, lct17, hst38, hmf27, hmf57, hmf64
Th	lct60, ici01, pmf08, u3ct01
U	(87 benchmark series)
Pu	(24 benchmark series)

Table 2.1 A list of elements and the benchmark series in which these elements are present in *a* material, either with more than 1 wt% or with more than 1e-4 atoms per barn-cm.

3. Results of validation calculations

In this Section we report all the k_{eff} results of the calculations. In the following subsections, the results are given in graphical and tabular form. The columns contain the following items.

1. The benchmark value for k_{eff}, and its uncertainty in pcm between brackets. These values were obtained from Refs [2, 3, 4, 5, 6].
2. Results from calculations based on JEFF-3.0
3. The results of the present work, based on JEFF-3.1.
4. The values for the third column divided by the first column (including uncertainty).
5. The benchmark name

3.1 HEU results

3.1.1 Fast spectrum

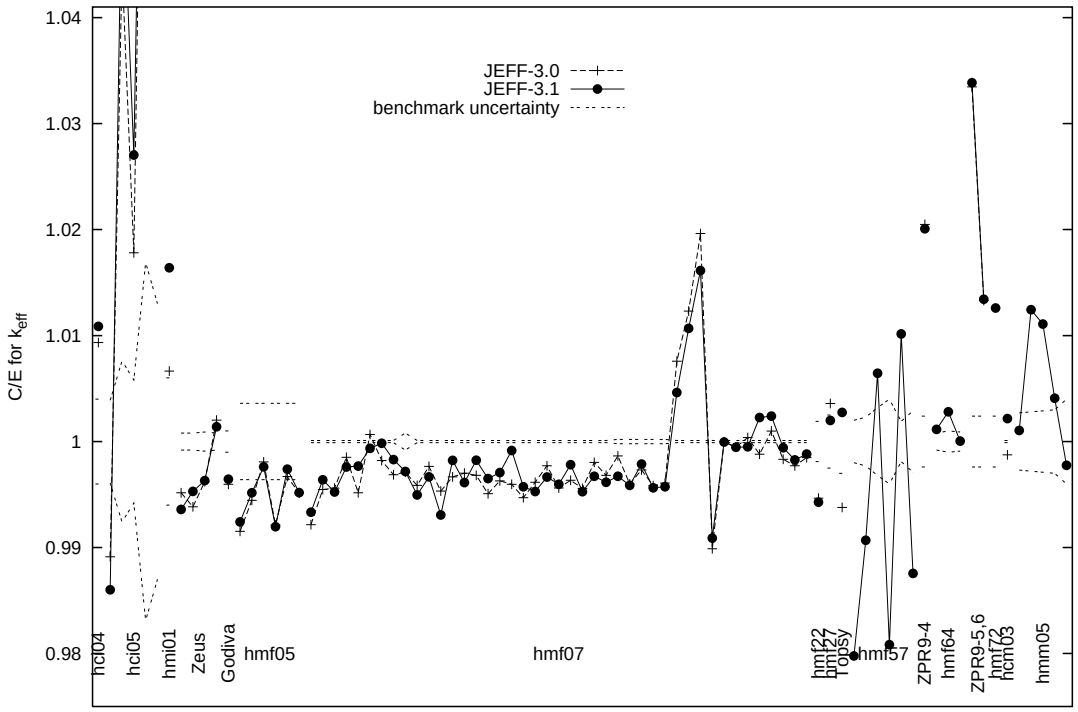

Figure 3.1 Results for the HEU benchmarks with a fast or intermediate spectrum

benchmark	JEFF-3.0	JEFF-3.1	C/E (JEFF-3.1)	name
1.00000(100)	0.99596(40)	0.99644(19)	0.99644(102)	heu-met-fast-001_bare-sphere
1.00000(360)	0.99153(69)	0.99242(72)	0.99242(367)	heu-met-fast-005_case-1
1.00070(360)	0.99515(60)	0.99586(70)	0.99516(367)	heu-met-fast-005_case-2
0.99960(360)	0.99767(80)	0.99721(79)	0.99761(369)	heu-met-fast-005_case-3
0.99890(360)	0.99103(69)	0.99087(87)	0.99196(371)	heu-met-fast-005_case-4
0.99800(360)	0.99470(80)	0.99540(78)	0.99739(369)	heu-met-fast-005_case-5

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benchmark	JEFF-3.0	JEFF-3.1	C/E (JEFF-3.1)	name
0.99870(360)	0.99384(70)	0.99389(71)	0.99518(367)	heu-met-fast-005_case-6
0.99710(10)	0.98927(66)	0.99045(64)	0.99333(65)	heu-met-fast-007_case-1
0.99860(10)	0.99408(63)	0.99500(71)	0.99639(72)	heu-met-fast-007_case-2
1.00120(10)	0.99680(74)	0.99643(74)	0.99524(75)	heu-met-fast-007_case-3
0.99700(10)	0.99551(74)	0.99460(66)	0.99759(67)	heu-met-fast-007_case-4
1.00000(10)	0.99517(70)	0.99768(70)	0.99768(71)	heu-met-fast-007_case-5
1.00280(10)	1.00346(74)	1.00215(70)	0.99935(71)	heu-met-fast-007_case-6
0.99960(10)	0.99781(84)	0.99944(75)	0.99984(76)	heu-met-fast-007_case-7
0.99920(10)	0.99607(79)	0.99750(73)	0.99830(74)	heu-met-fast-007_case-8
1.00170(80)	0.99880(74)	0.99888(76)	0.99718(110)	heu-met-fast-007_case-9
1.00000(10)	0.99587(90)	0.99497(79)	0.99497(80)	heu-met-fast-007_case-10
0.99820(10)	0.99586(89)	0.99487(87)	0.99666(88)	heu-met-fast-007_case-11
0.99510(10)	0.99045(76)	0.98820(90)	0.99307(92)	heu-met-fast-007_case-12
1.00090(10)	0.99756(91)	0.99912(89)	0.99822(90)	heu-met-fast-007_case-13
0.99830(10)	0.99532(87)	0.99444(92)	0.99613(93)	heu-met-fast-007_case-14
0.99780(10)	0.99462(89)	0.99604(95)	0.99824(96)	heu-met-fast-007_case-15
0.99880(10)	0.99389(85)	0.99530(94)	0.99650(95)	heu-met-fast-007_case-16
0.99720(10)	0.99349(90)	0.99429(90)	0.99708(91)	heu-met-fast-007_case-17
0.99910(10)	0.99507(96)	0.99825(98)	0.99915(99)	heu-met-fast-007_case-18
0.99830(10)	0.99301(64)	0.99405(68)	0.99574(69)	heu-met-fast-007_case-19
0.99810(10)	0.99426(79)	0.99339(67)	0.99528(68)	heu-met-fast-007_case-20
0.99870(10)	0.99641(70)	0.99535(79)	0.99665(80)	heu-met-fast-007_case-21
0.99940(10)	0.99502(74)	0.99537(73)	0.99597(74)	heu-met-fast-007_case-22
0.99930(10)	0.99564(70)	0.99711(85)	0.99781(86)	heu-met-fast-007_case-23
1.00010(10)	0.99567(74)	0.99537(72)	0.99527(73)	heu-met-fast-007_case-24
0.99900(10)	0.99703(80)	0.99572(79)	0.99672(80)	heu-met-fast-007_case-25
0.99970(10)	0.99651(85)	0.99586(97)	0.99616(98)	heu-met-fast-007_case-26
0.99650(20)	0.99515(69)	0.99323(76)	0.99672(79)	heu-met-fast-007_case-27
0.99870(20)	0.99471(75)	0.99457(75)	0.99586(78)	heu-met-fast-007_case-28
0.99780(20)	0.99513(72)	0.99567(83)	0.99787(86)	heu-met-fast-007_case-29
0.99810(20)	0.99395(86)	0.99374(83)	0.99563(86)	heu-met-fast-007_case-30
1.00130(20)	0.99737(86)	0.99702(82)	0.99573(85)	heu-met-fast-007_case-31
0.99590(10)	1.00345(61)	1.00051(62)	1.00463(63)	heu-met-fast-007_case-32
0.99950(10)	1.01180(78)	1.01017(62)	1.01068(62)	heu-met-fast-007_case-33
0.99770(10)	1.01727(68)	1.01380(75)	1.01614(75)	heu-met-fast-007_case-34
1.00110(10)	0.99098(88)	0.99198(82)	0.99089(83)	heu-met-fast-007_case-35
0.99990(10)	0.99988(78)	0.99986(89)	0.99996(90)	heu-met-fast-007_case-36
0.99880(10)	0.99828(95)	0.99826(92)	0.99946(93)	heu-met-fast-007_case-37
1.00000(10)	1.00037(99)	0.99950(93)	0.99950(94)	heu-met-fast-007_case-38
1.00180(10)	1.00060(81)	1.00407(78)	1.00227(78)	heu-met-fast-007_case-39

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benchmark	JEFF-3.0	JEFF-3.1	C/E (JEFF-3.1)	name
1.00130(10)	1.00229(88)	1.00370(88)	1.00240(88)	heu-met-fast-007_case-40
0.99940(10)	0.99773(81)	0.99881(108)	0.99941(109)	heu-met-fast-007_case-41
1.00160(10)	0.99931(88)	0.99987(78)	0.99827(79)	heu-met-fast-007_case-42
0.99980(10)	0.99828(93)	0.99862(88)	0.99882(89)	heu-met-fast-007_case-43
1.00000(190)	0.99466(45)	0.99428(42)	0.99428(195)	heu-met-fast-022
1.00000(250)	1.00359(40)	1.00199(40)	1.00199(253)	heu-met-fast-027
1.00000(300)	0.99379(43)	1.00275(51)	1.00275(304)	heu-met-fast-028
1.00000(200)		0.97977(76)	0.97977(215)	heu-met-fast-057_case-1
1.00000(230)		0.99069(65)	0.99069(239)	heu-met-fast-057_case-2
1.00000(320)		1.00645(69)	1.00645(327)	heu-met-fast-057_case-3
1.00000(400)		0.98084(59)	0.98084(404)	heu-met-fast-057_case-4
1.00000(190)		1.01016(63)	1.01016(200)	heu-met-fast-057_case-5
1.00000(290)		0.98755(71)	0.98755(299)	heu-met-fast-057_case-6
0.99550(240)		1.01549(50)	1.02008(246)	heu-met-fast-060
0.99960(80)		1.00075(69)	1.00115(106)	heu-met-fast-064_case-1
0.99960(100)		1.00240(79)	1.00280(127)	heu-met-fast-064_case-2
0.99960(90)		0.99964(73)	1.00004(116)	heu-met-fast-064_case-3
0.99590(240)		1.02962(55)	1.03386(247)	heu-met-fast-067_case-1
0.99380(240)		1.00714(58)	1.01342(248)	heu-met-fast-067_case-2
0.99910(240)		1.01169(74)	1.01260(251)	heu-met-fast-072_case-1

Table 3.1 The results for HEU benchmarks with a fast spectrum

3.1.2 Intermediate spectrum

benchmark	JEFF-3.0	JEFF-3.1	C/E (JEFF-3.1)	name
1.00000(400)	1.00934(52)	1.01087(48)	1.01087(403)	heu-comp-inter-004
1.03200(400)	1.02078(39)	1.01756(33)	0.98601(389)	heu-comp-inter-005_case-1
1.05000(800)	1.09699(44)	1.10783(44)	1.05508(763)	heu-comp-inter-005_case-2
1.03000(600)	1.04833(39)	1.05784(42)	1.02703(584)	heu-comp-inter-005_case-3
1.06400(1800)	1.15813(46)	1.15926(48)	1.08953(1692)	heu-comp-inter-005_case-4
0.99700(1300)	0.91850(42)	0.93460(39)	0.93741(1305)	heu-comp-inter-005_case-5
1.00100(600)	1.00766(46)	1.01742(78)	1.01640(604)	heu-met-inter-001_case-1
0.99770(80)	0.99287(83)	0.99130(78)	0.99359(112)	heu-met-inter-006_case-1
1.00010(80)	0.99394(90)	0.99540(84)	0.99530(116)	heu-met-inter-006_case-2
1.00150(90)	0.99771(87)	0.99780(75)	0.99631(117)	heu-met-inter-006_case-3
1.00160(80)	1.00362(80)	1.00299(76)	1.00139(110)	heu-met-inter-006_case-4

Table 3.2 The results for HEU benchmarks with an intermediate spectrum

3.1.3 Thermal spectrum

benchmark	JEFF-3.0	JEFF-3.1	C/E (JEFF-3.1)	name
1.00100(600)	1.00672(88)	1.00636(84)	1.00535(605)	heu-met-therm-001_simple
1.00100(600)	1.01575(81)	1.00881(90)	1.00780(606)	heu-met-therm-001_detail
1.00000(100)	1.00116(79)	1.00060(78)	1.00060(127)	heu-met-therm-003_case-1

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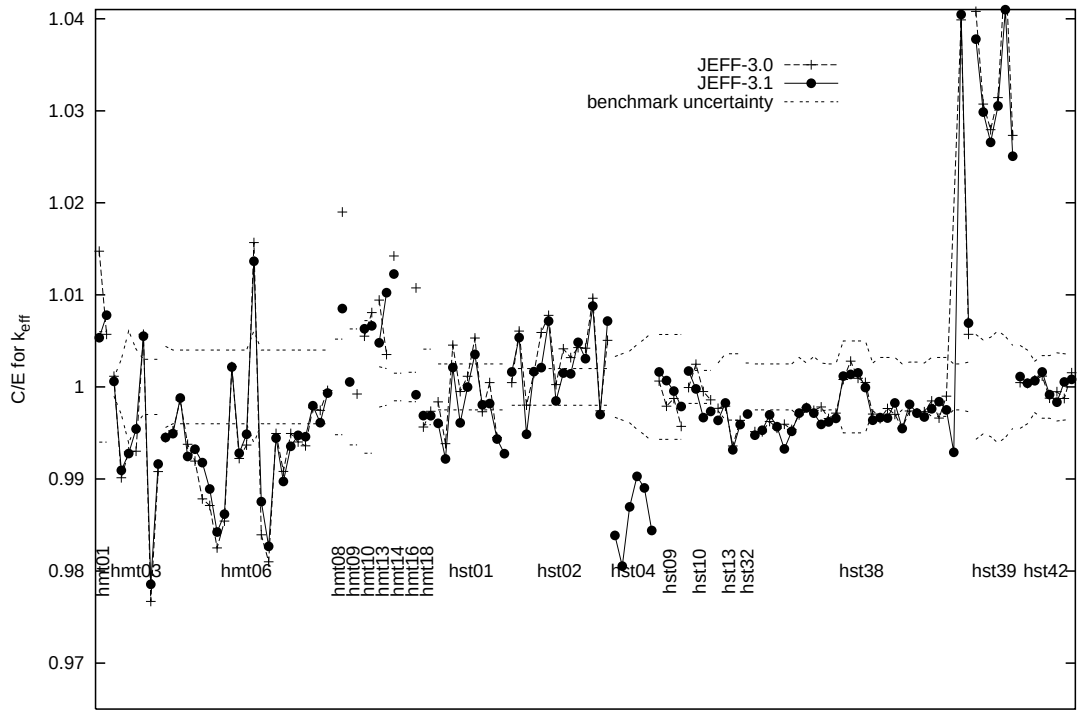

Figure 3.2 Results for the HEU benchmarks with a thermal spectrum

benchmark	JEFF-3.0	JEFF-3.1	C/E (JEFF-3.1)	name
0.99100(300)	0.98122(79)	0.98201(82)	0.99093(314)	heu-met-therm-003_case-2
0.98260(600)	0.97567(91)	0.97550(79)	0.99277(616)	heu-met-therm-003_case-3
0.98760(400)	0.98071(78)	0.98309(92)	0.99543(416)	heu-met-therm-003_case-4
0.99300(300)	0.99867(90)	0.99847(91)	1.00551(316)	heu-met-therm-003_case-5
0.98890(300)	0.96585(94)	0.96769(85)	0.97855(316)	heu-met-therm-003_case-6
0.99190(300)	0.98277(85)	0.98360(87)	0.99163(315)	heu-met-therm-003_case-7
1.00000(440)	0.99450(100)	0.99451(94)	0.99451(450)	heu-met-therm-006_case-1
1.00000(400)	0.99522(90)	0.99492(92)	0.99492(411)	heu-met-therm-006_case-2
1.00000(400)	0.99858(80)	0.99879(92)	0.99879(410)	heu-met-therm-006_case-3
1.00000(400)	0.99376(89)	0.99245(90)	0.99245(410)	heu-met-therm-006_case-4
1.00000(400)	0.99194(89)	0.99324(85)	0.99324(409)	heu-met-therm-006_case-5
1.00000(400)	0.98783(79)	0.99177(83)	0.99177(409)	heu-met-therm-006_case-6
1.00000(400)	0.98712(79)	0.98891(75)	0.98891(407)	heu-met-therm-006_case-7
1.00000(400)	0.98251(79)	0.98424(72)	0.98424(407)	heu-met-therm-006_case-8
1.00000(400)	0.98543(69)	0.98618(77)	0.98618(408)	heu-met-therm-006_case-9
1.00000(400)	1.00221(90)	1.00216(72)	1.00216(406)	heu-met-therm-006_case-10
1.00000(400)	0.99223(89)	0.99279(86)	0.99279(409)	heu-met-therm-006_case-11
1.00000(400)	0.99368(80)	0.99486(78)	0.99486(408)	heu-met-therm-006_case-12
1.00000(610)	1.01568(102)	1.01365(89)	1.01365(616)	heu-met-therm-006_case-13
1.00000(400)	0.98394(89)	0.98754(80)	0.98754(408)	heu-met-therm-006_case-14

continued on next page

benchmark	JEFF-3.0	JEFF-3.1	C/E (JEFF-3.1)	name
1.00000(400)	0.98100(78)	0.98268(88)	0.98268(410)	heu-met-therm-006_case-15
1.00000(400)	0.99494(80)	0.99444(68)	0.99444(406)	heu-met-therm-006_case-16
1.00000(400)	0.99082(89)	0.98973(94)	0.98973(411)	heu-met-therm-006_case-17
1.00000(400)	0.99494(90)	0.99355(92)	0.99355(411)	heu-met-therm-006_case-18
1.00000(400)	0.99402(70)	0.99474(77)	0.99474(407)	heu-met-therm-006_case-19
1.00000(400)	0.99360(80)	0.99459(87)	0.99459(409)	heu-met-therm-006_case-20
1.00000(400)	0.99774(90)	0.99796(77)	0.99796(407)	heu-met-therm-006_case-21
1.00000(400)	0.99746(90)	0.99612(87)	0.99612(409)	heu-met-therm-006_case-22
1.00000(400)	0.99961(90)	0.99933(90)	0.99933(410)	heu-met-therm-006_case-23
1.00090(520)	1.00995(85)	1.00942(90)	1.00851(527)	heu-met-therm-008_detail
1.00320(630)	1.00243(92)	1.00373(82)	1.00053(633)	heu-met-therm-009_simple
1.00300(720)	1.01110(78)	1.00933(87)	1.00631(723)	heu-met-therm-010_7.5mil
1.00260(720)	1.00813(87)	1.00926(92)	1.00664(724)	heu-met-therm-010_15mil
1.00210(220)	1.00563(78)	1.00691(75)	1.00480(232)	heu-met-therm-013_625in
0.99830(200)	1.00771(81)	1.00851(91)	1.01023(220)	heu-met-therm-013_15mil
0.99390(150)	1.00804(99)	1.00609(103)	1.01226(182)	heu-met-therm-014_simple
1.00170(160)	0.99850(101)	1.00084(90)	0.99914(183)	heu-met-therm-016_detail
1.00380(410)	1.00115(83)	1.00067(91)	0.99688(418)	heu-met-therm-018_simple
1.00380(410)	0.99943(88)	1.00065(84)	0.99686(417)	heu-met-therm-018_detail
1.00040(600)	0.99877(118)	0.99645(107)	0.99605(609)	heu-sol-therm-001_case-1
1.00210(720)	0.99592(112)	0.99426(117)	0.99218(728)	heu-sol-therm-001_case-2
1.00030(350)	1.00484(128)	1.00241(114)	1.00211(368)	heu-sol-therm-001_case-3
1.00080(530)	1.00030(123)	0.99690(106)	0.99610(540)	heu-sol-therm-001_case-4
1.00010(490)	1.00125(100)	1.00008(84)	0.99998(497)	heu-sol-therm-001_case-5
1.00020(460)	1.00552(90)	1.00374(100)	1.00354(471)	heu-sol-therm-001_case-6
1.00080(400)	0.99810(110)	0.99886(104)	0.99806(413)	heu-sol-therm-001_case-7
0.99980(380)	1.00027(121)	0.99799(113)	0.99819(397)	heu-sol-therm-001_case-8
1.00080(540)	0.99530(119)	0.99513(107)	0.99433(550)	heu-sol-therm-001_case-9
0.99930(540)		0.99205(99)	0.99274(550)	heu-sol-therm-001_case-10
1.00250(580)	1.00297(110)	1.00412(118)	1.00162(590)	heu-sol-therm-002_case-1
1.00280(580)	1.00888(101)	1.00819(117)	1.00537(590)	heu-sol-therm-002_case-2
1.00330(680)	1.00132(100)	0.99814(127)	0.99486(690)	heu-sol-therm-002_case-3
1.00340(690)	1.00489(111)	1.00507(103)	1.00166(695)	heu-sol-therm-002_case-4
1.00180(440)	1.00772(121)	1.00389(92)	1.00209(449)	heu-sol-therm-002_case-5
1.00230(410)	1.01010(111)	1.00948(108)	1.00716(423)	heu-sol-therm-002_case-6
1.00250(500)	1.00275(120)	1.00097(103)	0.99847(509)	heu-sol-therm-002_case-7
1.00300(550)	1.00715(101)	1.00451(106)	1.00151(558)	heu-sol-therm-002_case-8
1.00120(460)	1.00438(90)	1.00263(92)	1.00143(469)	heu-sol-therm-002_case-9
1.00240(500)	1.00669(91)	1.00726(94)	1.00485(507)	heu-sol-therm-002_case-10
1.00170(380)	1.00592(90)	1.00478(101)	1.00307(392)	heu-sol-therm-002_case-11

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benchmark	JEFF-3.0	JEFF-3.1	C/E (JEFF-3.1)	name
1.00270(500)	1.01237(101)	1.01150(107)	1.00878(510)	heu-sol-therm-002_case-12
1.00250(550)	0.99990(120)	0.99949(105)	0.99700(559)	heu-sol-therm-002_case-13
1.00310(660)	1.00818(101)	1.01028(117)	1.00716(668)	heu-sol-therm-002_case-14
1.00000(330)		0.98387(97)	0.98387(344)	heu-sol-therm-004_case-1
1.00000(360)		0.98053(111)	0.98053(377)	heu-sol-therm-004_case-2
1.00000(390)		0.98696(103)	0.98696(404)	heu-sol-therm-004_case-3
1.00000(460)		0.99029(108)	0.99029(473)	heu-sol-therm-004_case-4
1.00000(520)		0.98902(121)	0.98902(534)	heu-sol-therm-004_case-5
1.00000(590)		0.98441(114)	0.98441(601)	heu-sol-therm-004_case-6
0.99900(430)	0.99963(111)	1.00063(100)	1.00163(442)	heu-sol-therm-009_case-1
1.00000(390)	0.99790(108)	1.00068(96)	1.00068(402)	heu-sol-therm-009_case-2
1.00000(360)	0.99874(97)	0.99955(107)	0.99955(376)	heu-sol-therm-009_case-3
0.99860(350)	0.99432(94)	0.99647(101)	0.99787(365)	heu-sol-therm-009_case-4
1.00000(290)	0.99994(88)	1.00173(98)	1.00173(306)	heu-sol-therm-010_case-1
1.00000(290)	1.00247(91)	0.99978(100)	0.99978(307)	heu-sol-therm-010_case-2
1.00000(290)	0.99949(89)	0.99666(99)	0.99666(307)	heu-sol-therm-010_case-3
0.99920(290)	0.99780(85)	0.99653(104)	0.99733(308)	heu-sol-therm-010_case-4
1.00120(260)	0.99888(60)	0.99757(59)	0.99637(266)	heu-sol-therm-013_case-1
1.00070(360)	0.99861(60)	0.99896(57)	0.99826(364)	heu-sol-therm-013_case-2
1.00090(360)	0.99448(70)	0.99406(58)	0.99317(364)	heu-sol-therm-013_case-3
1.00030(360)	0.99666(70)	0.99622(68)	0.99592(366)	heu-sol-therm-013_case-4
1.00150(260)		0.99855(37)	0.99705(262)	heu-sol-therm-032_case-1
1.00000(250)	0.99514(50)	0.99475(52)	0.99475(255)	heu-sol-therm-038_case-1
1.00000(250)	0.99513(45)	0.99530(51)	0.99530(255)	heu-sol-therm-038_case-2
1.00000(250)	0.99625(48)	0.99696(52)	0.99696(255)	heu-sol-therm-038_case-3
1.00000(250)	0.99551(50)	0.99568(56)	0.99568(256)	heu-sol-therm-038_case-4
1.00000(250)	0.99595(60)	0.99326(61)	0.99326(257)	heu-sol-therm-038_case-5
1.00000(250)	0.99538(55)	0.99518(55)	0.99518(256)	heu-sol-therm-038_case-6
1.00000(320)	0.99697(53)	0.99716(52)	0.99716(324)	heu-sol-therm-038_case-7
1.00000(260)	0.99777(54)	0.99772(47)	0.99772(264)	heu-sol-therm-038_case-8
1.00000(330)	0.99746(48)	0.99715(53)	0.99715(334)	heu-sol-therm-038_case-9
1.00000(260)	0.99782(59)	0.99593(52)	0.99593(265)	heu-sol-therm-038_case-10
1.00000(250)	0.99656(48)	0.99620(56)	0.99620(256)	heu-sol-therm-038_case-11
1.00000(250)	0.99715(59)	0.99658(63)	0.99658(258)	heu-sol-therm-038_case-12
1.00000(500)	1.00081(56)	1.00117(52)	1.00117(503)	heu-sol-therm-038_case-13
1.00000(500)	1.00280(50)	1.00136(61)	1.00136(504)	heu-sol-therm-038_case-14
1.00000(500)	1.00094(50)	1.00153(48)	1.00153(502)	heu-sol-therm-038_case-15
1.00000(500)	1.00049(54)	0.99994(51)	0.99994(503)	heu-sol-therm-038_case-16
1.00000(260)	0.99705(58)	0.99638(57)	0.99638(266)	heu-sol-therm-038_case-17
1.00000(320)	0.99655(56)	0.99667(56)	0.99667(325)	heu-sol-therm-038_case-18

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benchmark	JEFF-3.0	JEFF-3.1	C/E (JEFF-3.1)	name
1.00000(320)	0.99766(64)	0.99662(54)	0.99662(325)	heu-sol-therm-038_case-19
1.00000(320)	0.99702(54)	0.99826(56)	0.99826(325)	heu-sol-therm-038_case-20
1.00000(250)	0.99553(47)	0.99547(50)	0.99547(255)	heu-sol-therm-038_case-21
1.00000(270)	0.99739(52)	0.99811(52)	0.99811(275)	heu-sol-therm-038_case-22
1.00000(270)	0.99718(48)	0.99715(57)	0.99715(276)	heu-sol-therm-038_case-23
1.00000(260)	0.99730(54)	0.99673(46)	0.99673(264)	heu-sol-therm-038_case-24
1.00000(320)	0.99848(49)	0.99763(44)	0.99763(323)	heu-sol-therm-038_case-25
1.00000(320)	0.99661(49)	0.99839(50)	0.99839(324)	heu-sol-therm-038_case-26
1.00000(320)	0.99900(50)	0.99751(53)	0.99751(324)	heu-sol-therm-038_case-27
1.00000(250)		0.99290(58)	0.99290(257)	heu-sol-therm-038_case-28
1.00000(250)	1.03988(55)	1.04047(50)	1.04047(255)	heu-sol-therm-038_case-29
1.00000(270)	1.00572(52)	1.00694(52)	1.00694(275)	heu-sol-therm-038_case-30
1.00000(570)	1.04080(97)	1.03778(100)	1.03778(578)	heu-sol-therm-039_case-1
1.00000(510)	1.03073(93)	1.02986(101)	1.02986(519)	heu-sol-therm-039_case-2
1.00120(540)	1.02917(106)	1.02780(94)	1.02657(547)	heu-sol-therm-039_case-3
1.00180(610)	1.03329(92)	1.03237(97)	1.03052(616)	heu-sol-therm-039_case-4
1.00180(550)	1.04789(94)	1.04286(99)	1.04099(557)	heu-sol-therm-039_case-5
1.00250(450)	1.02990(90)	1.02762(99)	1.02506(459)	heu-sol-therm-039_case-6
0.99570(390)	0.99617(48)	0.99683(47)	1.00113(395)	heu-sol-therm-042_case-1
0.99650(360)	0.99687(53)	0.99690(39)	1.00040(363)	heu-sol-therm-042_case-2
0.99940(280)	1.00016(41)	1.00007(41)	1.00067(283)	heu-sol-therm-042_case-3
1.00000(340)	1.00117(36)	1.00163(40)	1.00163(342)	heu-sol-therm-042_case-4
1.00000(340)	0.99877(29)	0.99916(28)	0.99916(341)	heu-sol-therm-042_case-5
1.00000(370)	0.99948(32)	0.99834(35)	0.99834(372)	heu-sol-therm-042_case-6
1.00000(360)	0.99874(28)	1.00054(23)	1.00054(361)	heu-sol-therm-042_case-7
1.00000(350)	1.00154(24)	1.00082(22)	1.00082(351)	heu-sol-therm-042_case-8

Table 3.3 The results for HEU benchmarks with a thermal spectrum

3.1.4 Mixed spectrum

benchmark	JEFF-3.0	JEFF-3.1	C/E (JEFF-3.1)	name
1.00000(10)	0.99874(77)	1.00217(75)	1.00217(76)	heu-comp-mixed-003_case-5
1.00070(270)		1.00175(88)	1.00105(284)	heu-met-mixed-005_case-1
1.00030(280)		1.01274(85)	1.01244(292)	heu-met-mixed-005_case-2
1.00120(290)		1.01230(90)	1.01109(303)	heu-met-mixed-005_case-3
1.00160(300)		1.00569(81)	1.00408(310)	heu-met-mixed-005_case-4
1.00050(400)		0.99826(86)	0.99776(409)	heu-met-mixed-005_case-5

3.2 IEU results

3.2.1 Fast spectrum

benchmark	JEFF-3.0	JEFF-3.1	C/E (JEFF-3.1)	name
0.99880(90)	0.99636(67)	0.99678(60)	0.99798(108)	ieu-met-fast-001_case-1

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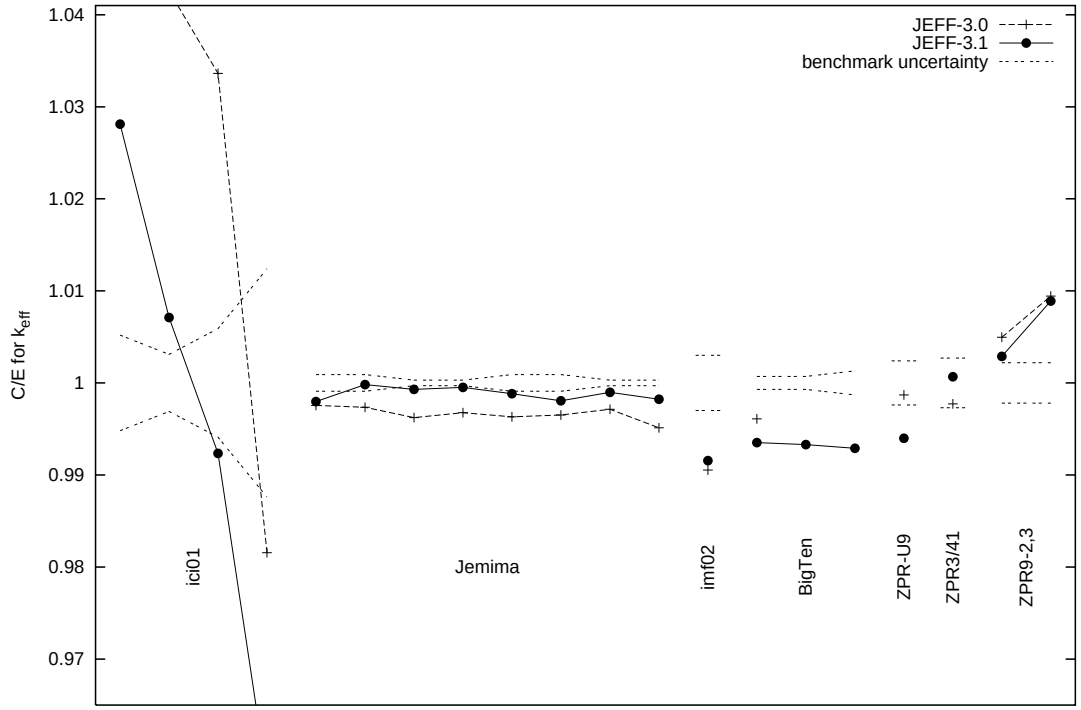

Figure 3.3 Results for the IEU benchmarks with a fast or intermediate spectrum

benchmark	JEFF-3.0	JEFF-3.1	C/E (JEFF-3.1)	name
0.99880(90)	0.99615(62)	0.99861(64)	0.99981(111)	ieu-met-fast-001_case-2
0.99900(30)	0.99523(71)	0.99830(63)	0.99930(70)	ieu-met-fast-001_case-3
0.99900(30)	0.99576(60)	0.99851(70)	0.99951(76)	ieu-met-fast-001_case-4
0.99890(90)	0.99521(72)	0.99773(55)	0.99883(106)	ieu-met-fast-001_case-1i
0.99970(90)	0.99622(67)	0.99775(63)	0.99805(110)	ieu-met-fast-001_case-2i
0.99930(30)	0.99644(59)	0.99828(63)	0.99898(70)	ieu-met-fast-001_case-3i
1.00020(30)	0.99532(70)	0.99843(59)	0.99823(66)	ieu-met-fast-001_case-4i
1.00000(300)	0.99053(59)	0.99156(29)	0.99156(301)	ieu-met-fast-002_case-1
1.00450(70)	1.00058(28)	0.99798(28)	0.99351(75)	ieu-met-fast-007_detail
1.00450(70)		0.99777(27)	0.99330(75)	ieu-met-fast-007_simple
0.99480(130)		0.98774(25)	0.99290(133)	ieu-met-fast-007_twozone
0.99540(240)	0.99411(31)	0.98942(42)	0.99399(245)	ieu-met-fast-010_case-1
1.00070(270)	0.99842(60)	1.00137(63)	1.00067(277)	ieu-met-fast-012_case-1
0.99580(220)	1.00074(27)	0.99868(53)	1.00289(227)	ieu-met-fast-014_case-1
0.99270(220)	1.00206(26)	1.00153(57)	1.00889(229)	ieu-met-fast-014_case-2

Table 3.4 The results for IEU benchmarks with a fast spectrum

3.2.2 Intermediate spectrum

benchmark	JEFF-3.0	JEFF-3.1	C/E (JEFF-3.1)	name
0.96900(500)	1.01364(29)	0.99624(35)	1.02811(517)	ieu-comp-inter-001_case-1
0.98000(300)	1.02175(41)	0.98696(42)	1.00710(309)	ieu-comp-inter-001_case-2

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benchmark	JEFF-3.0	JEFF-3.1	C/E (JEFF-3.1)	name
1.01400(600)	1.04810(56)	1.00623(51)	0.99234(594)	ieu-comp-inter-001_case-3
0.96400(1200)	0.94622(60)	0.92252(64)	0.95697(1247)	ieu-comp-inter-001_case-4

Table 3.5 The results for IEU benchmarks with an intermediate spectrum

3.2.3 Thermal spectrum

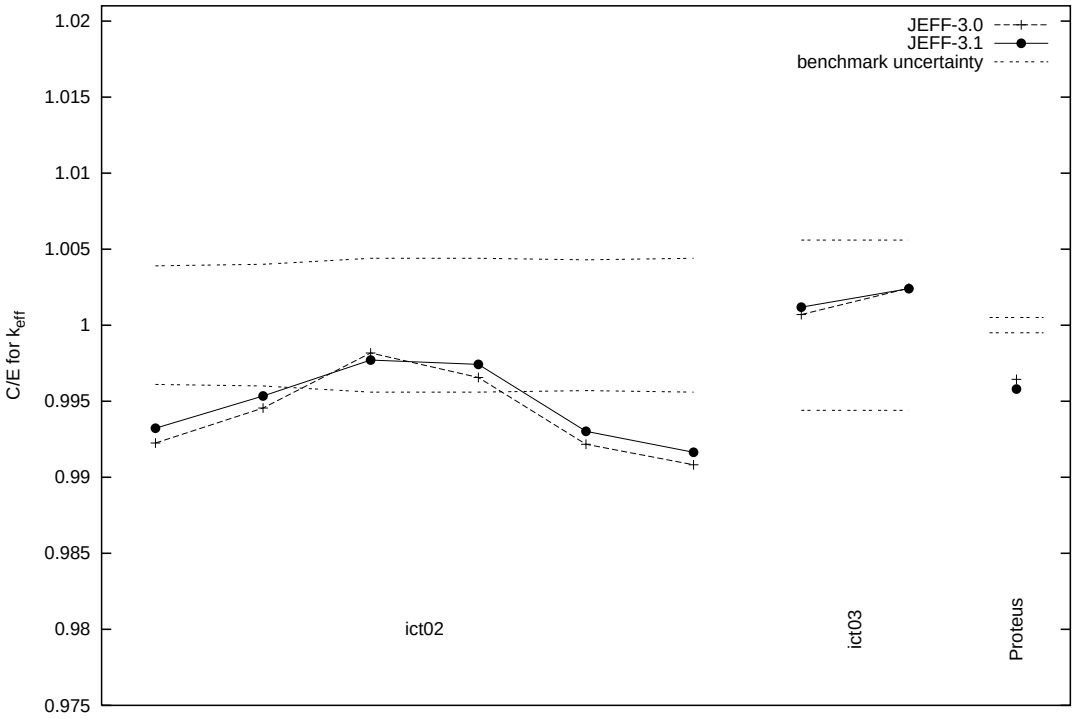

Figure 3.4 Results for the IEU benchmarks with a thermal spectrum

benchmark	JEFF-3.0	JEFF-3.1	C/E (JEFF-3.1)	name
1.00140(390)	0.99364(80)	0.99461(83)	0.99322(398)	ieu-comp-therm-002_case-1
1.00190(400)	0.99644(70)	0.99723(26)	0.99534(400)	ieu-comp-therm-002_case-2
1.00170(440)	0.99987(80)	0.99941(82)	0.99771(447)	ieu-comp-therm-002_case-3
1.00190(440)	0.99845(90)	0.99932(76)	0.99742(446)	ieu-comp-therm-002_case-4
1.00140(430)	0.99356(80)	0.99441(78)	0.99302(437)	ieu-comp-therm-002_case-5
1.00160(440)	0.99241(99)	0.99323(77)	0.99164(446)	ieu-comp-therm-002_case-6
1.00060(560)	1.00130(85)	1.00178(85)	1.00118(566)	ieu-comp-therm-003_core-132
1.00460(560)	1.00704(83)	1.00701(87)	1.00240(564)	ieu-comp-therm-003_core-133
1.01120(50)	1.00760(90)	1.00695(26)	0.99580(56)	ieu-comp-therm-proteus

Table 3.6 The results for IEU benchmarks with a thermal spectrum

3.3 LEU results

3.3.1 Thermal spectrum

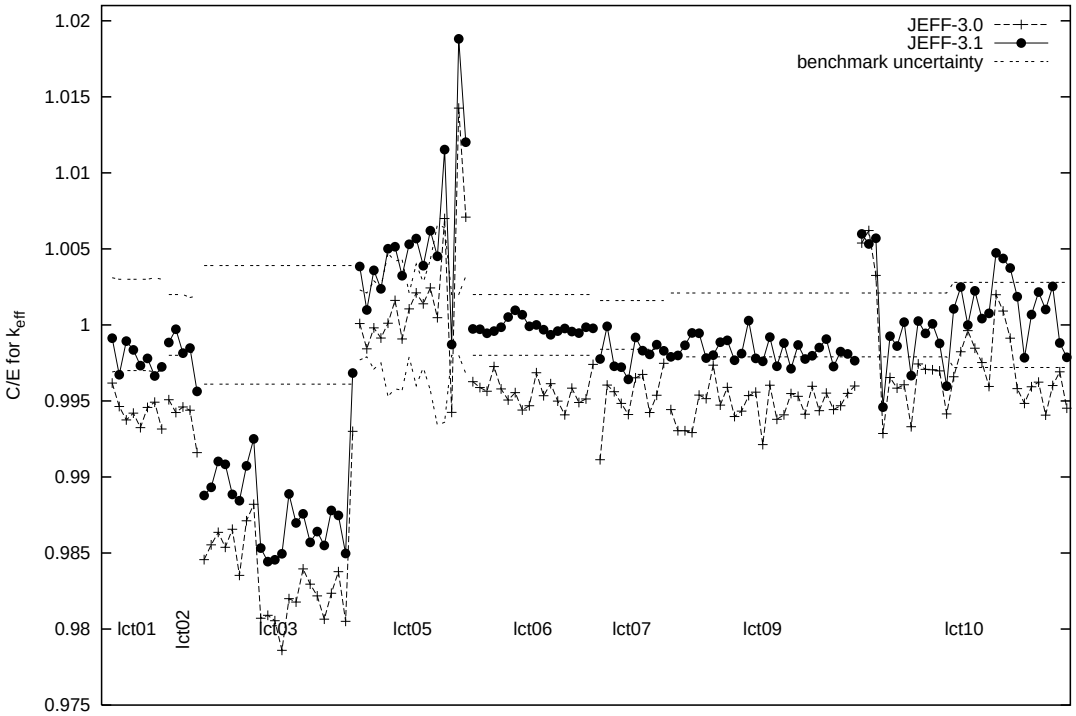

Figure 3.5 Results for the LEU benchmarks with a thermal spectrum

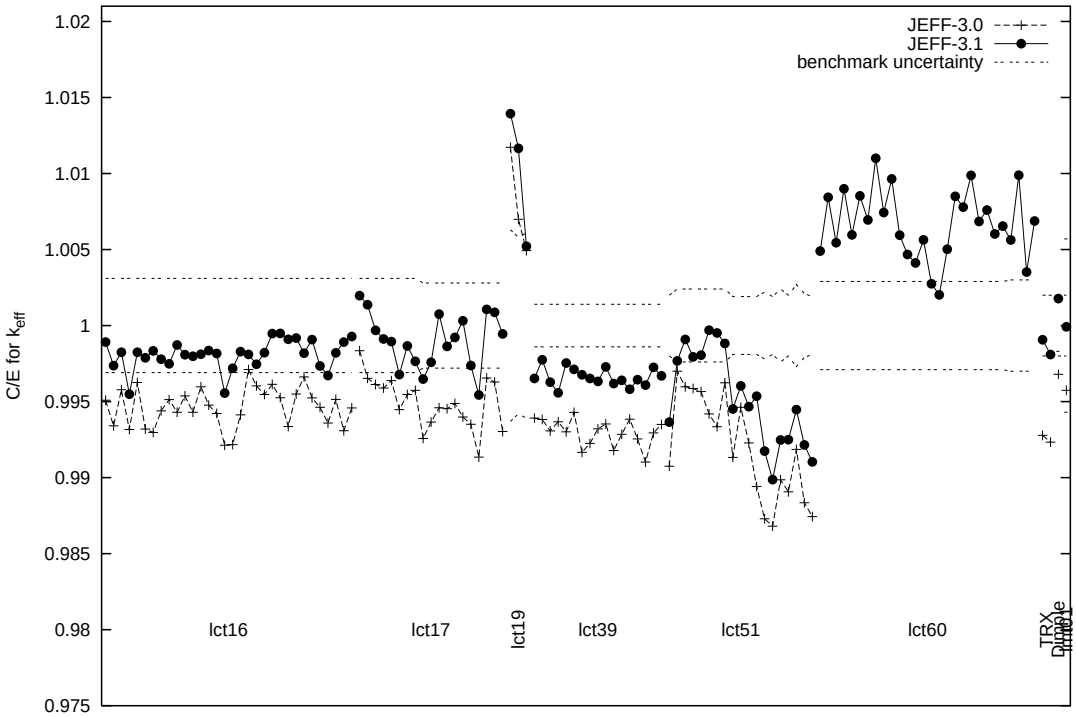

Figure 3.6 Results for the LEU benchmarks with a thermal spectrum (continued)

benchmark	JEFF-3.0	JEFF-3.1	C/E (JEFF-3.1)	name
1.00000(310)	0.99617(70)	0.99913(76)	0.99913(319)	leu-comp-therm-001_case-1

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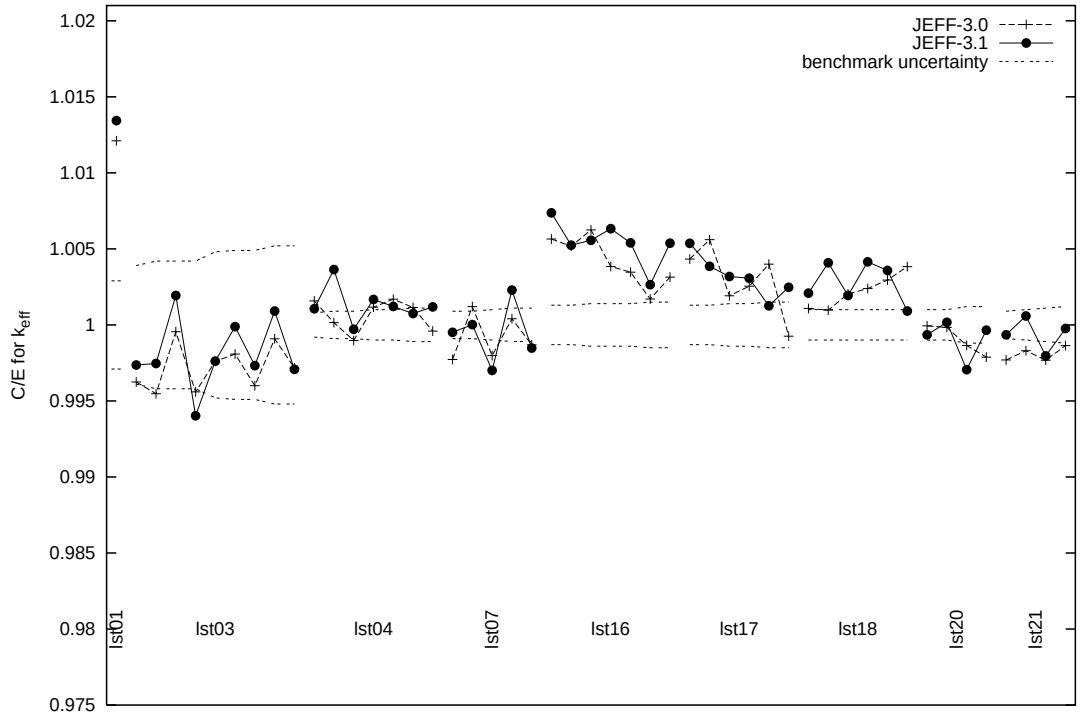

Figure 3.7 Results for the LEU benchmarks with a thermal spectrum (continued)

benchmark	JEFF-3.0	JEFF-3.1	C/E (JEFF-3.1)	name
0.99980(300)	0.99443(70)	0.99652(67)	0.99672(308)	leu-comp-therm-001_case-2
0.99980(300)	0.99355(70)	0.99873(64)	0.99893(307)	leu-comp-therm-001_case-3
0.99980(300)	0.99400(60)	0.99815(68)	0.99835(308)	leu-comp-therm-001_case-4
0.99980(300)	0.99304(70)	0.99712(62)	0.99732(306)	leu-comp-therm-001_case-5
0.99980(300)	0.99437(70)	0.99760(71)	0.99780(308)	leu-comp-therm-001_case-6
0.99980(310)	0.99472(70)	0.99644(67)	0.99664(317)	leu-comp-therm-001_case-7
0.99980(300)	0.99295(70)	0.99704(68)	0.99724(308)	leu-comp-therm-001_case-8
0.99970(200)	0.99478(90)	0.99854(88)	0.99884(219)	leu-comp-therm-002_case-1
0.99970(200)	0.99394(92)	0.99941(81)	0.99971(216)	leu-comp-therm-002_case-2
0.99970(200)	0.99430(82)	0.99784(83)	0.99814(217)	leu-comp-therm-002_case-3
0.99970(180)	0.99409(73)	0.99818(82)	0.99848(198)	leu-comp-therm-002_case-4
0.99970(190)	0.99130(80)	0.99533(78)	0.99563(206)	leu-comp-therm-002_case-5
1.00000(390)	0.98456(80)	0.98878(66)	0.98878(396)	leu-comp-therm-003_case-1
1.00000(390)	0.98554(74)	0.98932(83)	0.98932(399)	leu-comp-therm-003_case-2
1.00000(390)	0.98636(75)	0.99102(72)	0.99102(397)	leu-comp-therm-003_case-3
1.00000(390)	0.98537(77)	0.99083(73)	0.99083(397)	leu-comp-therm-003_case-4
1.00000(390)	0.98656(76)	0.98885(77)	0.98885(398)	leu-comp-therm-003_case-5
1.00000(390)	0.98353(73)	0.98844(78)	0.98844(398)	leu-comp-therm-003_case-6
1.00000(390)	0.98712(76)	0.99073(74)	0.99073(397)	leu-comp-therm-003_case-7
1.00000(390)	0.98820(71)	0.99250(79)	0.99250(398)	leu-comp-therm-003_case-8

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benchmark	JEFF-3.0	JEFF-3.1	C/E (JEFF-3.1)	name
1.00000(390)	0.98071(74)	0.98532(70)	0.98532(396)	leu-comp-therm-003_case-9
1.00000(390)	0.98090(90)	0.98443(74)	0.98443(397)	leu-comp-therm-003_case-10
1.00000(390)	0.98055(74)	0.98455(83)	0.98455(399)	leu-comp-therm-003_case-11
1.00000(390)	0.97860(65)	0.98495(60)	0.98495(395)	leu-comp-therm-003_case-12
1.00000(390)	0.98200(74)	0.98888(71)	0.98888(397)	leu-comp-therm-003_case-13
1.00000(390)	0.98177(81)	0.98698(80)	0.98698(398)	leu-comp-therm-003_case-14
1.00000(390)	0.98395(63)	0.98758(76)	0.98758(398)	leu-comp-therm-003_case-15
1.00000(390)	0.98295(69)	0.98570(69)	0.98570(396)	leu-comp-therm-003_case-16
1.00000(390)	0.98218(77)	0.98641(80)	0.98641(398)	leu-comp-therm-003_case-17
1.00000(390)	0.98065(68)	0.98550(66)	0.98550(396)	leu-comp-therm-003_case-18
1.00000(390)	0.98235(78)	0.98780(74)	0.98780(397)	leu-comp-therm-003_case-19
1.00000(390)	0.98377(77)	0.98747(73)	0.98747(397)	leu-comp-therm-003_case-20
1.00000(390)	0.98051(76)	0.98497(67)	0.98497(396)	leu-comp-therm-003_case-21
1.00000(390)	0.99300(78)	0.99683(69)	0.99683(396)	leu-comp-therm-003_case-22
1.00000(230)	1.00009(25)	1.00384(87)	1.00384(246)	leu-comp-therm-005_case-1
1.00000(210)	0.99843(23)	1.00098(80)	1.00098(225)	leu-comp-therm-005_case-2
1.00000(290)	0.99981(24)	1.00359(74)	1.00359(299)	leu-comp-therm-005_case-3
1.00000(250)	0.99914(23)	1.00237(85)	1.00237(264)	leu-comp-therm-005_case-4
1.00000(470)	1.00011(26)	1.00501(71)	1.00501(475)	leu-comp-therm-005_case-5
1.00000(420)	1.00161(27)	1.00514(93)	1.00514(430)	leu-comp-therm-005_case-6
1.00000(430)	0.99908(27)	1.00323(85)	1.00323(438)	leu-comp-therm-005_case-7
1.00000(210)	1.00105(26)	1.00530(73)	1.00530(222)	leu-comp-therm-005_case-8
1.00000(400)	1.00211(23)	1.00568(85)	1.00568(409)	leu-comp-therm-005_case-9
1.00000(280)	1.00139(24)	1.00389(92)	1.00389(295)	leu-comp-therm-005_case-10
1.00000(430)	1.00243(24)	1.00619(88)	1.00619(439)	leu-comp-therm-005_case-11
1.00000(660)	1.00047(27)	1.00451(76)	1.00451(664)	leu-comp-therm-005_case-12
1.00000(640)	1.00700(25)	1.01153(78)	1.01153(645)	leu-comp-therm-005_case-13
1.00000(200)	0.99425(21)	0.99871(78)	0.99871(215)	leu-comp-therm-005_case-14
1.00000(200)	1.01426(24)	1.01881(80)	1.01881(215)	leu-comp-therm-005_case-15
1.00000(320)	1.00709(23)	1.01202(69)	1.01202(327)	leu-comp-therm-005_case-16
1.00000(200)	0.99627(75)	0.99973(23)	0.99973(201)	leu-comp-therm-006_case-1
1.00000(200)	0.99588(75)	0.99971(24)	0.99971(201)	leu-comp-therm-006_case-2
1.00000(200)	0.99564(78)	0.99945(24)	0.99945(201)	leu-comp-therm-006_case-3
1.00000(200)	0.99726(71)	0.99959(25)	0.99959(202)	leu-comp-therm-006_case-4
1.00000(200)	0.99579(68)	0.99985(24)	0.99985(201)	leu-comp-therm-006_case-5
1.00000(200)	0.99506(79)	1.00051(26)	1.00051(202)	leu-comp-therm-006_case-6
1.00000(200)	0.99555(75)	1.00096(23)	1.00096(201)	leu-comp-therm-006_case-7
1.00000(200)	0.99440(88)	1.00067(26)	1.00067(202)	leu-comp-therm-006_case-8
1.00000(200)	0.99468(82)	0.99991(23)	0.99991(201)	leu-comp-therm-006_case-9
1.00000(200)	0.99685(68)	1.00000(22)	1.00000(201)	leu-comp-therm-006_case-10

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benchmark	JEFF-3.0	JEFF-3.1	C/E (JEFF-3.1)	name
1.00000(200)	0.99534(71)	0.99968(24)	0.99968(201)	leu-comp-therm-006_case-11
1.00000(200)	0.99613(74)	0.99935(22)	0.99935(201)	leu-comp-therm-006_case-12
1.00000(200)	0.99499(73)	0.99959(24)	0.99959(201)	leu-comp-therm-006_case-13
1.00000(200)	0.99409(74)	0.99976(25)	0.99976(202)	leu-comp-therm-006_case-14
1.00000(200)	0.99584(73)	0.99956(23)	0.99956(201)	leu-comp-therm-006_case-15
1.00000(200)	0.99490(70)	0.99946(20)	0.99946(201)	leu-comp-therm-006_case-16
1.00000(200)	0.99513(74)	0.99985(24)	0.99985(201)	leu-comp-therm-006_case-17
1.00000(200)	0.99740(73)	0.99977(22)	0.99977(201)	leu-comp-therm-006_case-18
1.00000(160)	0.99113(88)	0.99776(41)	0.99776(165)	leu-comp-therm-007_case-1
1.00000(160)	0.99604(94)	0.99991(42)	0.99991(165)	leu-comp-therm-007_case-2
1.00000(160)	0.99561(78)	0.99728(39)	0.99728(165)	leu-comp-therm-007_case-3
1.00000(160)	0.99484(66)	0.99722(33)	0.99722(163)	leu-comp-therm-007_case-4
1.00000(160)	0.99411(87)	0.99642(42)	0.99642(165)	leu-comp-therm-007_case-5
1.00000(160)	0.99652(88)	0.99918(45)	0.99918(166)	leu-comp-therm-007_case-6
1.00000(160)	0.99674(84)	0.99830(40)	0.99830(165)	leu-comp-therm-007_case-7
1.00000(160)	0.99424(87)	0.99806(45)	0.99806(166)	leu-comp-therm-007_case-8
1.00000(160)	0.99537(89)	0.99870(38)	0.99870(164)	leu-comp-therm-007_case-9
1.00000(160)	0.99747(81)	0.99829(42)	0.99829(165)	leu-comp-therm-007_case-10
1.00000(210)	0.99443(80)	0.99790(76)	0.99790(223)	leu-comp-therm-009_case-1
1.00000(210)	0.99304(79)	0.99799(71)	0.99799(222)	leu-comp-therm-009_case-2
1.00000(210)	0.99304(79)	0.99866(87)	0.99866(227)	leu-comp-therm-009_case-3
1.00000(210)	0.99292(79)	0.99947(70)	0.99947(221)	leu-comp-therm-009_case-4
1.00000(210)	0.99538(80)	0.99945(79)	0.99945(224)	leu-comp-therm-009_case-5
1.00000(210)	0.99515(80)	0.99782(81)	0.99782(225)	leu-comp-therm-009_case-6
1.00000(210)	0.99735(80)	0.99801(81)	0.99801(225)	leu-comp-therm-009_case-7
1.00000(210)	0.99472(80)	0.99886(83)	0.99886(226)	leu-comp-therm-009_case-8
1.00000(210)	0.99589(85)	0.99898(75)	0.99898(223)	leu-comp-therm-009_case-9
1.00000(210)	0.99397(90)	0.99768(88)	0.99768(228)	leu-comp-therm-009_case-10
1.00000(210)	0.99433(80)	0.99811(79)	0.99811(224)	leu-comp-therm-009_case-11
1.00000(210)	0.99535(70)	1.00028(84)	1.00028(226)	leu-comp-therm-009_case-12
1.00000(210)	0.99558(80)	0.99780(70)	0.99780(221)	leu-comp-therm-009_case-13
1.00000(210)	0.99213(79)	0.99760(77)	0.99760(224)	leu-comp-therm-009_case-14
1.00000(210)	0.99603(80)	0.99920(77)	0.99920(224)	leu-comp-therm-009_case-15
1.00000(210)	0.99379(89)	0.99728(78)	0.99728(224)	leu-comp-therm-009_case-16
1.00000(210)	0.99409(80)	0.99880(72)	0.99880(222)	leu-comp-therm-009_case-17
1.00000(210)	0.99548(70)	0.99712(74)	0.99712(223)	leu-comp-therm-009_case-18
1.00000(210)	0.99530(80)	0.99868(73)	0.99868(222)	leu-comp-therm-009_case-19
1.00000(210)	0.99413(90)	0.99776(84)	0.99776(226)	leu-comp-therm-009_case-20
1.00000(210)	0.99596(80)	0.99797(72)	0.99797(222)	leu-comp-therm-009_case-21
1.00000(210)	0.99436(80)	0.99851(76)	0.99851(223)	leu-comp-therm-009_case-22

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benchmark	JEFF-3.0	JEFF-3.1	C/E (JEFF-3.1)	name
1.00000(210)	0.99552(70)	0.99906(84)	0.99906(226)	leu-comp-therm-009_case-23
1.00000(210)	0.99443(70)	0.99726(80)	0.99726(225)	leu-comp-therm-009_case-24
1.00000(210)	0.99468(70)	0.99824(73)	0.99824(222)	leu-comp-therm-009_case-25
1.00000(210)	0.99550(70)	0.99809(80)	0.99809(225)	leu-comp-therm-009_case-26
1.00000(210)	0.99598(70)	0.99764(78)	0.99764(224)	leu-comp-therm-009_case-27
1.00000(210)	1.00538(82)	1.00598(75)	1.00598(223)	leu-comp-therm-010_case-1
1.00000(210)	1.00620(84)	1.00532(73)	1.00532(222)	leu-comp-therm-010_case-2
1.00000(210)	1.00325(75)	1.00570(79)	1.00570(224)	leu-comp-therm-010_case-3
1.00000(210)	0.99286(85)	0.99459(77)	0.99459(224)	leu-comp-therm-010_case-4
1.00000(210)	0.99654(71)	0.99926(79)	0.99926(224)	leu-comp-therm-010_case-5
1.00000(210)	0.99584(70)	0.99861(72)	0.99861(222)	leu-comp-therm-010_case-6
1.00000(210)	0.99606(74)	1.00018(68)	1.00018(221)	leu-comp-therm-010_case-7
1.00000(210)	0.99330(72)	0.99666(81)	0.99666(225)	leu-comp-therm-010_case-8
1.00000(210)	0.99743(76)	1.00025(82)	1.00025(225)	leu-comp-therm-010_case-9
1.00000(210)	0.99708(75)	0.99944(80)	0.99944(225)	leu-comp-therm-010_case-10
1.00000(210)	0.99705(74)	1.00007(84)	1.00007(226)	leu-comp-therm-010_case-11
1.00000(210)	0.99698(79)	0.99878(76)	0.99878(223)	leu-comp-therm-010_case-12
1.00000(210)	0.99415(74)	0.99597(75)	0.99597(223)	leu-comp-therm-010_case-13
1.00000(280)	0.99659(88)	1.00105(84)	1.00105(292)	leu-comp-therm-010_case-14
1.00000(280)	0.99823(90)	1.00249(77)	1.00249(290)	leu-comp-therm-010_case-15
1.00000(280)	0.99962(86)	0.99999(71)	0.99999(289)	leu-comp-therm-010_case-16
1.00000(280)	0.99847(78)	1.00224(79)	1.00224(291)	leu-comp-therm-010_case-17
1.00000(280)	0.99752(79)	1.00041(84)	1.00041(292)	leu-comp-therm-010_case-18
1.00000(280)	0.99595(78)	1.00076(106)	1.00076(299)	leu-comp-therm-010_case-19
1.00000(280)	1.00199(79)	1.00473(90)	1.00473(294)	leu-comp-therm-010_case-20
1.00000(280)	1.00091(69)	1.00437(87)	1.00437(293)	leu-comp-therm-010_case-21
1.00000(280)	0.99913(80)	1.00374(74)	1.00374(290)	leu-comp-therm-010_case-22
1.00000(280)	0.99581(71)	1.00185(81)	1.00185(291)	leu-comp-therm-010_case-23
1.00000(280)	0.99484(67)	0.99784(92)	0.99784(295)	leu-comp-therm-010_case-24
1.00000(280)	0.99593(78)	1.00068(76)	1.00068(290)	leu-comp-therm-010_case-25
1.00000(280)	0.99624(75)	1.00216(86)	1.00216(293)	leu-comp-therm-010_case-26
1.00000(280)	0.99407(80)	1.00101(78)	1.00101(291)	leu-comp-therm-010_case-27
1.00000(280)	0.99601(83)	1.00253(79)	1.00253(291)	leu-comp-therm-010_case-28
1.00000(280)	0.99691(86)	0.99881(74)	0.99881(290)	leu-comp-therm-010_case-29
1.00000(280)	0.99452(76)	0.99787(83)	0.99787(292)	leu-comp-therm-010_case-30
1.00000(310)	0.99509(70)	0.99891(78)	0.99891(320)	leu-comp-therm-016_case-1
1.00000(310)	0.99341(60)	0.99736(70)	0.99736(318)	leu-comp-therm-016_case-2
1.00000(310)	0.99578(60)	0.99824(77)	0.99824(319)	leu-comp-therm-016_case-3
1.00000(310)	0.99316(60)	0.99548(85)	0.99548(322)	leu-comp-therm-016_case-4
1.00000(310)	0.99626(80)	0.99824(70)	0.99824(318)	leu-comp-therm-016_case-5

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benchmark	JEFF-3.0	JEFF-3.1	C/E (JEFF-3.1)	name
1.00000(310)	0.99319(60)	0.99788(73)	0.99788(319)	leu-comp-therm-016_case-6
1.00000(310)	0.99297(70)	0.99833(71)	0.99833(318)	leu-comp-therm-016_case-7
1.00000(310)	0.99439(70)	0.99779(62)	0.99779(316)	leu-comp-therm-016_case-8
1.00000(310)	0.99513(60)	0.99748(68)	0.99748(317)	leu-comp-therm-016_case-9
1.00000(310)	0.99430(70)	0.99872(78)	0.99872(320)	leu-comp-therm-016_case-10
1.00000(310)	0.99537(80)	0.99808(63)	0.99808(316)	leu-comp-therm-016_case-11
1.00000(310)	0.99430(80)	0.99798(66)	0.99798(317)	leu-comp-therm-016_case-12
1.00000(310)	0.99597(60)	0.99811(73)	0.99811(319)	leu-comp-therm-016_case-13
1.00000(310)	0.99477(70)	0.99835(65)	0.99835(317)	leu-comp-therm-016_case-14
1.00000(310)	0.99422(60)	0.99816(64)	0.99816(317)	leu-comp-therm-016_case-15
1.00000(310)	0.99213(79)	0.99556(72)	0.99556(318)	leu-comp-therm-016_case-16
1.00000(310)	0.99217(70)	0.99719(71)	0.99719(318)	leu-comp-therm-016_case-17
1.00000(310)	0.99413(60)	0.99828(76)	0.99828(319)	leu-comp-therm-016_case-18
1.00000(310)	0.99711(70)	0.99810(68)	0.99810(317)	leu-comp-therm-016_case-19
1.00000(310)	0.99603(80)	0.99745(73)	0.99745(319)	leu-comp-therm-016_case-20
1.00000(310)	0.99546(80)	0.99821(75)	0.99821(319)	leu-comp-therm-016_case-21
1.00000(310)	0.99613(70)	0.99947(72)	0.99947(318)	leu-comp-therm-016_case-22
1.00000(310)	0.99525(80)	0.99948(78)	0.99948(320)	leu-comp-therm-016_case-23
1.00000(310)	0.99336(70)	0.99910(71)	0.99910(318)	leu-comp-therm-016_case-24
1.00000(310)	0.99550(70)	0.99918(71)	0.99918(318)	leu-comp-therm-016_case-25
1.00000(310)	0.99662(70)	0.99818(75)	0.99818(319)	leu-comp-therm-016_case-26
1.00000(310)	0.99524(70)	0.99907(69)	0.99907(318)	leu-comp-therm-016_case-27
1.00000(310)	0.99462(60)	0.99734(64)	0.99734(317)	leu-comp-therm-016_case-28
1.00000(310)	0.99359(70)	0.99671(66)	0.99671(317)	leu-comp-therm-016_case-29
1.00000(310)	0.99514(80)	0.99820(56)	0.99820(315)	leu-comp-therm-016_case-30
1.00000(310)	0.99308(79)	0.99891(64)	0.99891(317)	leu-comp-therm-016_case-31
1.00000(310)	0.99458(70)	0.99928(68)	0.99928(317)	leu-comp-therm-016_case-32
1.00000(310)	0.99834(70)	1.00197(65)	1.00197(317)	leu-comp-therm-017_case-1
1.00000(310)	0.99653(80)	1.00137(68)	1.00137(317)	leu-comp-therm-017_case-2
1.00000(310)	0.99612(60)	0.99968(81)	0.99968(320)	leu-comp-therm-017_case-3
1.00000(310)	0.99589(70)	0.99912(63)	0.99912(316)	leu-comp-therm-017_case-10
1.00000(310)	0.99638(80)	0.99894(73)	0.99894(318)	leu-comp-therm-017_case-11
1.00000(310)	0.99447(60)	0.99677(69)	0.99677(318)	leu-comp-therm-017_case-12
1.00000(310)	0.99546(60)	0.99866(68)	0.99866(317)	leu-comp-therm-017_case-13
1.00000(310)	0.99574(70)	0.99764(74)	0.99764(319)	leu-comp-therm-017_case-14
1.00000(280)	0.99257(70)	0.99648(64)	0.99648(287)	leu-comp-therm-017_case-15
1.00000(280)	0.99365(70)	0.99758(67)	0.99758(288)	leu-comp-therm-017_case-16
1.00000(280)	0.99459(80)	1.00075(61)	1.00075(287)	leu-comp-therm-017_case-17
1.00000(280)	0.99453(70)	0.99863(69)	0.99863(288)	leu-comp-therm-017_case-18
1.00000(280)	0.99488(70)	0.99922(83)	0.99922(292)	leu-comp-therm-017_case-19

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benchmark	JEFF-3.0	JEFF-3.1	C/E (JEFF-3.1)	name
1.00000(280)	0.99398(70)	1.00031(83)	1.00031(292)	leu-comp-therm-017_case-20
1.00000(280)	0.99351(70)	0.99737(80)	0.99737(291)	leu-comp-therm-017_case-21
1.00000(280)	0.99135(79)	0.99543(71)	0.99543(289)	leu-comp-therm-017_case-22
1.00000(280)	0.99655(70)	1.00106(79)	1.00106(291)	leu-comp-therm-017_case-23
1.00000(280)	0.99629(70)	1.00087(65)	1.00087(287)	leu-comp-therm-017_case-24
1.00000(280)	0.99303(60)	0.99945(77)	0.99945(290)	leu-comp-therm-017_case-25
1.00000(630)	1.01172(81)	1.01393(72)	1.01393(634)	leu-comp-therm-019_case-1
1.00000(580)	1.00698(81)	1.01165(85)	1.01165(586)	leu-comp-therm-019_case-2
1.00000(610)	1.00493(50)	1.00521(66)	1.00521(614)	leu-comp-therm-019_case-3
1.00000(140)	0.99391(88)	0.99652(40)	0.99652(146)	leu-comp-therm-039_case-1
1.00000(140)	0.99382(90)	0.99775(48)	0.99775(148)	leu-comp-therm-039_case-2
1.00000(140)	0.99307(93)	0.99628(35)	0.99628(144)	leu-comp-therm-039_case-3
1.00000(140)	0.99367(82)	0.99558(37)	0.99558(145)	leu-comp-therm-039_case-4
1.00000(140)	0.99301(82)	0.99753(46)	0.99753(147)	leu-comp-therm-039_case-5
1.00000(140)	0.99429(86)	0.99712(46)	0.99712(147)	leu-comp-therm-039_case-6
1.00000(140)	0.99166(82)	0.99676(44)	0.99676(147)	leu-comp-therm-039_case-7
1.00000(140)	0.99225(80)	0.99652(40)	0.99652(146)	leu-comp-therm-039_case-8
1.00000(140)	0.99320(80)	0.99633(41)	0.99633(146)	leu-comp-therm-039_case-9
1.00000(140)	0.99353(80)	0.99728(43)	0.99728(146)	leu-comp-therm-039_case-10
1.00000(140)	0.99178(83)	0.99618(41)	0.99618(146)	leu-comp-therm-039_case-11
1.00000(140)	0.99285(83)	0.99640(47)	0.99640(148)	leu-comp-therm-039_case-12
1.00000(140)	0.99384(78)	0.99581(39)	0.99581(145)	leu-comp-therm-039_case-13
1.00000(140)	0.99254(86)	0.99644(42)	0.99644(146)	leu-comp-therm-039_case-14
1.00000(140)	0.99102(95)	0.99608(42)	0.99608(146)	leu-comp-therm-039_case-15
1.00000(140)	0.99294(92)	0.99725(42)	0.99725(146)	leu-comp-therm-039_case-16
1.00000(140)	0.99350(68)	0.99669(39)	0.99669(145)	leu-comp-therm-039_case-17
1.00100(200)	0.99174(69)	0.99464(84)	0.99365(217)	leu-comp-therm-051_case-1
1.00100(240)	0.99800(70)	0.99868(74)	0.99768(251)	leu-comp-therm-051_case-2
1.00100(240)	0.99697(80)	1.00009(69)	0.99909(249)	leu-comp-therm-051_case-3
1.00100(240)	0.99686(70)	0.99894(78)	0.99794(252)	leu-comp-therm-051_case-4
1.00100(240)	0.99666(80)	0.99905(78)	0.99805(252)	leu-comp-therm-051_case-5
1.00100(240)	0.99518(70)	1.00069(70)	0.99969(250)	leu-comp-therm-051_case-6
1.00100(240)	0.99434(70)	1.00051(69)	0.99951(249)	leu-comp-therm-051_case-7
1.00100(240)	0.99724(80)	0.99982(72)	0.99882(250)	leu-comp-therm-051_case-8
1.00100(190)	0.99232(70)	0.99550(79)	0.99451(206)	leu-comp-therm-051_case-9
1.00100(190)	0.99561(70)	0.99703(79)	0.99603(206)	leu-comp-therm-051_case-10
1.00100(190)	0.99327(70)	0.99565(71)	0.99466(203)	leu-comp-therm-051_case-11
1.00100(190)	0.99040(69)	0.99635(74)	0.99535(204)	leu-comp-therm-051_case-12
1.00100(220)	0.98828(79)	0.99273(72)	0.99174(231)	leu-comp-therm-051_case-13
1.00100(190)	0.98779(69)	0.99086(77)	0.98987(205)	leu-comp-therm-051_case-14

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benchmark	JEFF-3.0	JEFF-3.1	C/E (JEFF-3.1)	name
1.00100(240)	0.99085(69)	0.99346(72)	0.99247(250)	leu-comp-therm-051_case-15
1.00100(200)	0.99006(79)	0.99348(78)	0.99249(215)	leu-comp-therm-051_case-16
1.00100(270)	0.99284(70)	0.99546(66)	0.99447(278)	leu-comp-therm-051_case-17
1.00100(210)	0.98934(69)	0.99314(71)	0.99215(222)	leu-comp-therm-051_case-18
1.00100(190)	0.98842(69)	0.99202(66)	0.99103(201)	leu-comp-therm-051_case-19
0.99900(260)		1.00390(59)	1.00490(267)	leu-comp-therm-060_case-1
0.99770(260)		1.00612(65)	1.00844(268)	leu-comp-therm-060_case-2
1.00010(260)		1.00554(73)	1.00544(270)	leu-comp-therm-060_case-3
1.00170(260)		1.01071(78)	1.00899(271)	leu-comp-therm-060_case-4
1.00090(260)		1.00687(64)	1.00596(267)	leu-comp-therm-060_case-5
0.98940(270)		0.99784(81)	1.00853(285)	leu-comp-therm-060_case-6
1.00280(260)		1.00976(61)	1.00694(266)	leu-comp-therm-060_case-7
1.00390(260)		1.01494(79)	1.01100(270)	leu-comp-therm-060_case-8
1.00430(260)		1.01176(61)	1.00743(266)	leu-comp-therm-060_case-9
1.00140(260)		1.01105(72)	1.00964(269)	leu-comp-therm-060_case-10
1.00010(260)		1.00604(68)	1.00594(269)	leu-comp-therm-060_case-11
1.00090(260)		1.00557(64)	1.00467(267)	leu-comp-therm-060_case-12
1.00100(260)		1.00512(76)	1.00412(271)	leu-comp-therm-060_case-13
1.00150(260)		1.00715(79)	1.00564(271)	leu-comp-therm-060_case-14
1.00120(260)		1.00395(68)	1.00275(268)	leu-comp-therm-060_case-15
1.00070(260)		1.00272(67)	1.00202(268)	leu-comp-therm-060_case-16
1.00120(260)		1.00623(70)	1.00502(269)	leu-comp-therm-060_case-17
1.00060(260)		1.00911(73)	1.00850(270)	leu-comp-therm-060_case-18
1.00070(260)		1.00850(71)	1.00779(269)	leu-comp-therm-060_case-19
1.00390(260)		1.01382(68)	1.00988(268)	leu-comp-therm-060_case-20
1.00030(260)		1.00714(65)	1.00684(268)	leu-comp-therm-060_case-21
1.00360(260)		1.01122(73)	1.00759(269)	leu-comp-therm-060_case-22
1.00170(260)		1.00773(58)	1.00602(266)	leu-comp-therm-060_case-23
1.00250(260)		1.00906(64)	1.00654(267)	leu-comp-therm-060_case-24
1.00160(260)		1.00724(62)	1.00563(267)	leu-comp-therm-060_case-25
0.99960(260)		1.00949(77)	1.00989(271)	leu-comp-therm-060_case-26
1.00000(200)	0.99278(17)	0.99906(60)	0.99906(209)	leu-comp-therm-trx_case-1_3d
1.00000(200)	0.99233(18)	0.99809(52)	0.99809(207)	leu-comp-therm-trx_case-2_3d
0.99830(170)	0.99510(50)	1.00007(50)	1.00177(177)	leu-comp-therm-dimple
0.99900(570)	0.99474(60)	0.99892(58)	0.99992(574)	leu-met-therm-001_case-1
0.99910(290)	1.01120(88)	1.01252(86)	1.01343(302)	leu-sol-therm-001
0.99970(390)	0.99595(81)	0.99706(65)	0.99736(396)	leu-sol-therm-003_case-1
0.99930(420)	0.99477(70)	0.99676(69)	0.99746(426)	leu-sol-therm-003_case-2
0.99950(420)	0.99905(69)	1.00143(76)	1.00193(427)	leu-sol-therm-003_case-3
0.99950(420)	0.99510(69)	0.99352(75)	0.99402(427)	leu-sol-therm-003_case-4

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benchmark	JEFF-3.0	JEFF-3.1	C/E (JEFF-3.1)	name
0.99970(480)	0.99730(64)	0.99731(54)	0.99761(483)	leu-sol-therm-003_case-5
0.99990(490)	0.99798(54)	0.99979(63)	0.99989(494)	leu-sol-therm-003_case-6
0.99940(490)	0.99540(54)	0.99672(53)	0.99732(493)	leu-sol-therm-003_case-7
0.99930(520)	0.99839(49)	1.00021(47)	1.00091(522)	leu-sol-therm-003_case-8
0.99960(520)	0.99677(43)	0.99668(45)	0.99708(522)	leu-sol-therm-003_case-9
0.99940(80)	1.00098(68)	1.00046(76)	1.00106(110)	leu-sol-therm-004_case-001
0.99990(90)	1.00005(69)	1.00354(65)	1.00364(111)	leu-sol-therm-004_case-029
0.99990(90)	0.99887(58)	0.99961(70)	0.99971(114)	leu-sol-therm-004_case-033
0.99990(100)	1.00106(59)	1.00157(72)	1.00167(123)	leu-sol-therm-004_case-034
0.99990(100)	1.00159(67)	1.00111(59)	1.00121(116)	leu-sol-therm-004_case-046
0.99940(110)	1.00054(55)	1.00015(54)	1.00075(123)	leu-sol-therm-004_case-051
0.99960(110)	0.99919(65)	1.00078(62)	1.00118(126)	leu-sol-therm-004_case-054
0.99610(90)	0.99384(72)	0.99561(66)	0.99951(112)	leu-sol-therm-007_case-14
0.99730(90)	0.99850(63)	0.99732(79)	1.00002(120)	leu-sol-therm-007_case-30
0.99850(100)	0.99648(64)	0.99551(61)	0.99701(117)	leu-sol-therm-007_case-32
0.99880(110)	0.99920(56)	1.00109(67)	1.00229(129)	leu-sol-therm-007_case-36
0.99830(110)	0.99699(66)	0.99678(64)	0.99848(128)	leu-sol-therm-007_case-49
0.99960(130)	1.00525(84)	1.00697(99)	1.00737(163)	leu-sol-therm-016_case-105
0.99990(130)	1.00507(83)	1.00514(83)	1.00524(154)	leu-sol-therm-016_case-113
0.99940(140)	1.00564(68)	1.00497(81)	1.00557(162)	leu-sol-therm-016_case-125
0.99960(140)	1.00344(70)	1.00593(76)	1.00633(159)	leu-sol-therm-016_case-129
0.99950(140)	1.00297(71)	1.00489(69)	1.00539(156)	leu-sol-therm-016_case-131
0.99920(150)	1.00090(66)	1.00184(68)	1.00264(165)	leu-sol-therm-016_case-140
0.99940(150)	1.00254(68)	1.00477(79)	1.00537(169)	leu-sol-therm-016_case-196
0.99810(130)	1.00242(90)	1.00345(86)	1.00536(156)	leu-sol-therm-017_case-104
0.99860(130)	1.00420(78)	1.00244(78)	1.00385(152)	leu-sol-therm-017_case-122
0.99890(140)	1.00081(82)	1.00208(83)	1.00318(163)	leu-sol-therm-017_case-123
0.99920(140)	1.00174(73)	1.00227(79)	1.00307(161)	leu-sol-therm-017_case-126
0.99870(150)	1.00268(82)	0.99996(71)	1.00126(166)	leu-sol-therm-017_case-130
0.99960(150)	0.99886(68)	1.00207(66)	1.00247(164)	leu-sol-therm-017_case-147
0.99920(100)	1.00028(70)	1.00129(66)	1.00209(120)	leu-sol-therm-018_case-1
0.99960(100)	1.00057(70)	1.00368(64)	1.00408(119)	leu-sol-therm-018_case-2
0.99960(100)	1.00164(80)	1.00153(78)	1.00193(127)	leu-sol-therm-018_case-3
0.99970(100)	1.00209(70)	1.00385(71)	1.00415(123)	leu-sol-therm-018_case-4
0.99920(100)	1.00215(80)	1.00278(64)	1.00358(119)	leu-sol-therm-018_case-5
0.99960(100)	1.00343(70)	1.00051(76)	1.00091(126)	leu-sol-therm-018_case-6
0.99950(100)	0.99944(66)	0.99885(62)	0.99935(118)	leu-sol-therm-020_case-216
0.99960(100)	0.99944(56)	0.99977(62)	1.00017(118)	leu-sol-therm-020_case-217
0.99970(120)	0.99835(59)	0.99676(46)	0.99706(129)	leu-sol-therm-020_case-220
0.99980(120)	0.99768(52)	0.99945(46)	0.99965(129)	leu-sol-therm-020_case-226

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benchmark	JEFF-3.0	JEFF-3.1	C/E (JEFF-3.1)	name
0.99830(90)	0.99600(64)	0.99765(65)	0.99935(111)	leu-sol-therm-021_case-215
0.99850(100)	0.99680(66)	0.99909(59)	1.00059(116)	leu-sol-therm-021_case-218
0.99890(110)	0.99658(58)	0.99686(47)	0.99796(120)	leu-sol-therm-021_case-221
0.99930(120)	0.99794(54)	0.99906(58)	0.99976(133)	leu-sol-therm-021_case-223

Table 3.7 The results for LEU benchmarks with a thermal spectrum

3.4 PU results

3.4.1 Fast spectrum

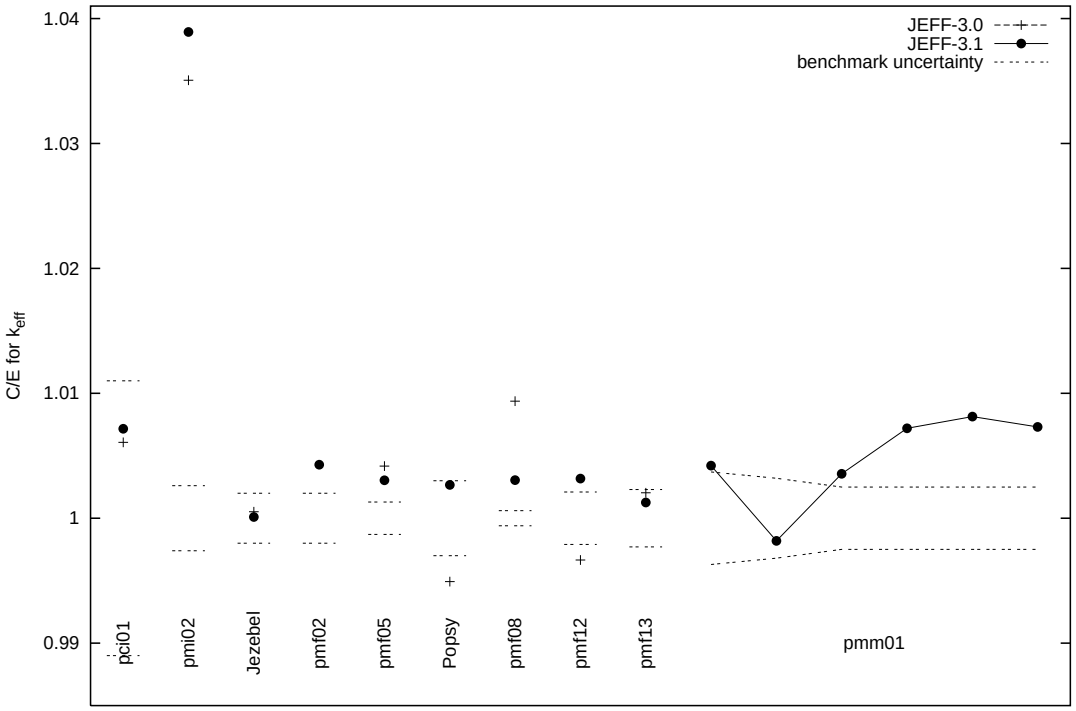

Figure 3.8 Results for the PU benchmarks with a fast, intermediate, or mixed spectrum

benchmark	JEFF-3.0	JEFF-3.1	C/E (JEFF-3.1)	name
1.00000(200)	1.00052(40)	1.00010(19)	1.00010(201)	pu-met-fast-001_bare-sphere
1.00000(200)		1.00428(67)	1.00428(211)	pu-met-fast-002
1.00000(130)	1.00417(73)	1.00304(70)	1.00304(148)	pu-met-fast-005
1.00000(300)	0.99492(44)	1.00267(43)	1.00267(303)	pu-met-fast-006
1.00000(60)	1.00937(45)	1.00305(35)	1.00305(69)	pu-met-fast-008_case-1
1.00090(210)	0.99756(71)	1.00407(67)	1.00317(220)	pu-met-fast-012
1.00340(230)	1.00545(72)	1.00466(80)	1.00126(243)	pu-met-fast-013

Table 3.8 The results for PU benchmarks with a fast spectrum

3.4.2 Intermediate spectrum

benchmark	JEFF-3.0	JEFF-3.1	C/E (JEFF-3.1)	name
1.00000(1100)	1.00608(57)	1.00716(44)	1.00716(1101)	pu-comp-inter-001
0.98690(260)	1.02150(47)	1.02532(73)	1.03893(273)	pu-met-inter-002_case-1

Table 3.9 The results for PU benchmarks with an intermediate spectrum

3.4.3 Thermal spectrum

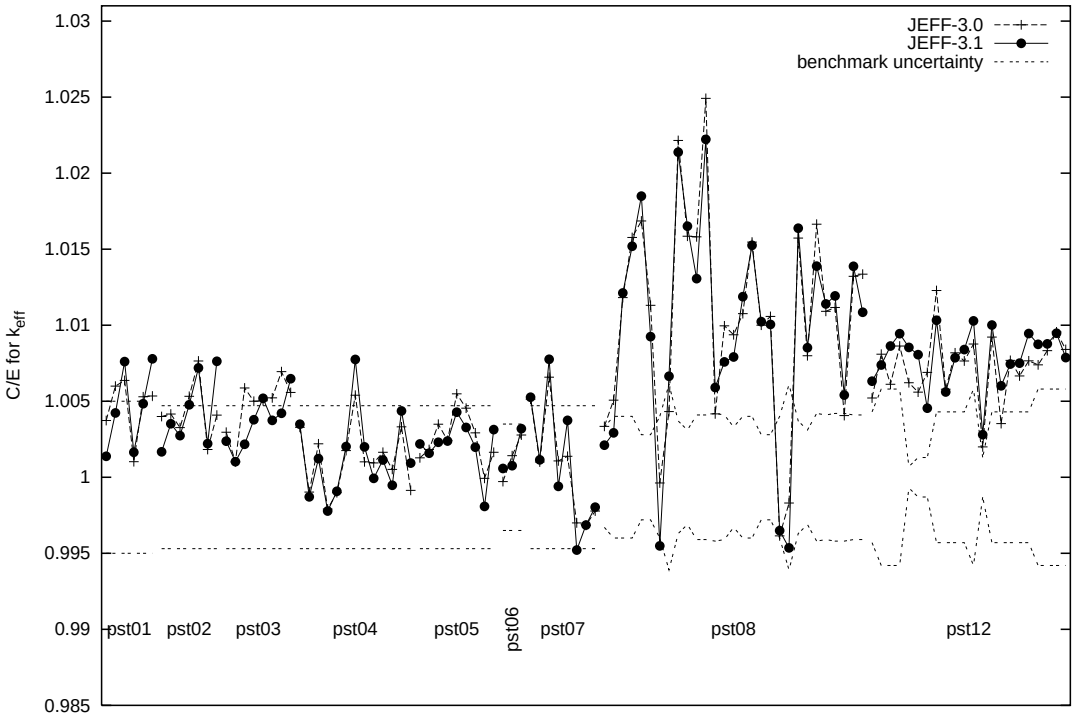

Figure 3.9 Results for the PU benchmarks with a thermal spectrum

benchmark	JEFF-3.0	JEFF-3.1	C/E (JEFF-3.1)	name
1.00000(500)	1.00373(95)	1.00138(95)	1.00138(509)	pu-sol-therm-001_case-1
1.00000(500)	1.00599(108)	1.00423(95)	1.00423(509)	pu-sol-therm-001_case-2
1.00000(500)	1.00637(102)	1.00760(87)	1.00760(507)	pu-sol-therm-001_case-3
1.00000(500)	1.00102(96)	1.00164(104)	1.00164(511)	pu-sol-therm-001_case-4
1.00000(500)	1.00529(94)	1.00484(106)	1.00484(511)	pu-sol-therm-001_case-5
1.00000(500)	1.00534(95)	1.00779(102)	1.00779(510)	pu-sol-therm-001_case-6
1.00000(470)	1.00399(87)	1.00167(97)	1.00167(480)	pu-sol-therm-002_case-1
1.00000(470)	1.00416(91)	1.00352(87)	1.00352(478)	pu-sol-therm-002_case-2
1.00000(470)	1.00326(90)	1.00274(95)	1.00274(479)	pu-sol-therm-002_case-3
1.00000(470)	1.00532(101)	1.00476(86)	1.00476(478)	pu-sol-therm-002_case-4
1.00000(470)	1.00765(91)	1.00719(92)	1.00719(479)	pu-sol-therm-002_case-5
1.00000(470)	1.00182(92)	1.00221(93)	1.00221(479)	pu-sol-therm-002_case-6
1.00000(470)	1.00409(106)	1.00762(97)	1.00762(480)	pu-sol-therm-002_case-7
1.00000(470)	1.00296(86)	1.00237(92)	1.00237(479)	pu-sol-therm-003_case-1

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benchmark	JEFF-3.0	JEFF-3.1	C/E (JEFF-3.1)	name
1.00000(470)	1.00101(89)	1.00102(93)	1.00102(479)	pu-sol-therm-003_case-2
1.00000(470)	1.00587(80)	1.00217(91)	1.00217(479)	pu-sol-therm-003_case-3
1.00000(470)	1.00500(85)	1.00378(88)	1.00378(478)	pu-sol-therm-003_case-4
1.00000(470)	1.00503(90)	1.00519(103)	1.00519(481)	pu-sol-therm-003_case-5
1.00000(470)	1.00522(89)	1.00374(96)	1.00374(480)	pu-sol-therm-003_case-6
1.00000(470)	1.00695(91)	1.00421(87)	1.00421(478)	pu-sol-therm-003_case-7
1.00000(470)	1.00558(93)	1.00648(87)	1.00648(478)	pu-sol-therm-003_case-8
1.00000(470)	1.00328(89)	1.00349(74)	1.00349(476)	pu-sol-therm-004_case-1
1.00000(470)	0.99903(82)	0.99871(86)	0.99871(478)	pu-sol-therm-004_case-2
1.00000(470)	1.00220(85)	1.00123(70)	1.00123(475)	pu-sol-therm-004_case-3
1.00000(470)	0.99791(75)	0.99778(87)	0.99778(478)	pu-sol-therm-004_case-4
1.00000(470)	0.99898(82)	0.99908(88)	0.99908(478)	pu-sol-therm-004_case-5
1.00000(470)	1.00175(79)	1.00202(94)	1.00202(479)	pu-sol-therm-004_case-6
1.00000(470)	1.00539(87)	1.00775(84)	1.00775(477)	pu-sol-therm-004_case-7
1.00000(470)	1.00101(71)	1.00200(75)	1.00200(476)	pu-sol-therm-004_case-8
1.00000(470)	1.00094(85)	0.99993(90)	0.99993(479)	pu-sol-therm-004_case-9
1.00000(470)	1.00164(90)	1.00113(86)	1.00113(478)	pu-sol-therm-004_case-10
1.00000(470)	1.00052(90)	0.99947(91)	0.99947(479)	pu-sol-therm-004_case-11
1.00000(470)	1.00331(80)	1.00436(78)	1.00436(476)	pu-sol-therm-004_case-12
1.00000(470)	0.99914(84)	1.00093(77)	1.00093(476)	pu-sol-therm-004_case-13
1.00000(470)	1.00128(79)	1.00219(75)	1.00219(476)	pu-sol-therm-005_case-1
1.00000(470)	1.00182(83)	1.00158(81)	1.00158(477)	pu-sol-therm-005_case-2
1.00000(470)	1.00349(84)	1.00230(99)	1.00230(480)	pu-sol-therm-005_case-3
1.00000(470)	1.00242(89)	1.00238(93)	1.00238(479)	pu-sol-therm-005_case-4
1.00000(470)	1.00548(85)	1.00428(89)	1.00428(478)	pu-sol-therm-005_case-5
1.00000(470)	1.00454(101)	1.00327(85)	1.00327(478)	pu-sol-therm-005_case-6
1.00000(470)	1.00292(86)	1.00198(69)	1.00198(475)	pu-sol-therm-005_case-7
1.00000(470)	0.99993(84)	0.99808(84)	0.99808(477)	pu-sol-therm-005_case-8
1.00000(470)	1.00164(89)	1.00313(92)	1.00313(479)	pu-sol-therm-005_case-9
1.00000(350)	0.99971(89)	1.00058(81)	1.00058(359)	pu-sol-therm-006_case-1
1.00000(350)	1.00142(84)	1.00076(86)	1.00076(360)	pu-sol-therm-006_case-2
1.00000(350)	1.00278(74)	1.00319(75)	1.00319(358)	pu-sol-therm-006_case-3
1.00000(470)	1.00513(92)	1.00526(95)	1.00526(479)	pu-sol-therm-007_case-2
1.00000(470)	1.00100(97)	1.00114(90)	1.00114(479)	pu-sol-therm-007_case-3
1.00000(470)	1.00658(99)	1.00776(103)	1.00776(481)	pu-sol-therm-007_case-5
1.00000(470)	1.00107(104)	0.99940(91)	0.99940(479)	pu-sol-therm-007_case-6
1.00000(470)	1.00138(90)	1.00374(85)	1.00374(478)	pu-sol-therm-007_case-7
1.00000(470)	0.99700(101)	0.99521(94)	0.99521(479)	pu-sol-therm-007_case-8
1.00000(470)	0.99683(99)	0.99686(93)	0.99686(479)	pu-sol-therm-007_case-9
1.00000(470)	0.99778(107)	0.99803(89)	0.99803(478)	pu-sol-therm-007_case-10

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benchmark	JEFF-3.0	JEFF-3.1	C/E (JEFF-3.1)	name
1.00000(330)	1.00335(91)	1.00211(95)	1.00211(343)	pu-sol-therm-008_case-1
1.00000(400)	1.00507(86)	1.00292(96)	1.00292(411)	pu-sol-therm-008_case-2
1.00000(400)	1.01181(100)	1.01212(88)	1.01212(409)	pu-sol-therm-008_case-3
1.00000(400)	1.01577(85)	1.01519(103)	1.01519(413)	pu-sol-therm-008_case-4
1.00000(280)	1.01685(82)	1.01849(81)	1.01849(291)	pu-sol-therm-008_case-5
1.00000(280)	1.01131(80)	1.00925(90)	1.00925(294)	pu-sol-therm-008_case-7
1.00000(400)	0.99962(86)	0.99549(89)	0.99549(410)	pu-sol-therm-008_case-8
1.00000(610)	1.00432(102)	1.00664(106)	1.00664(619)	pu-sol-therm-008_case-9
1.00000(370)	1.02215(90)	1.02138(85)	1.02138(379)	pu-sol-therm-008_case-10
1.00000(310)	1.01585(83)	1.01651(83)	1.01651(321)	pu-sol-therm-008_case-11
1.00000(410)	1.01581(101)	1.01306(111)	1.01306(424)	pu-sol-therm-008_case-12
1.00000(410)	1.02492(98)	1.02222(90)	1.02222(419)	pu-sol-therm-008_case-13
1.00000(420)	1.00417(93)	1.00590(100)	1.00590(432)	pu-sol-therm-008_case-14
1.00000(410)	1.00996(87)	1.00758(108)	1.00758(424)	pu-sol-therm-008_case-15
1.00000(330)	1.00937(97)	1.00791(72)	1.00791(338)	pu-sol-therm-008_case-16
1.00000(400)	1.01076(81)	1.01187(81)	1.01187(408)	pu-sol-therm-008_case-17
1.00000(400)	1.01546(95)	1.01525(99)	1.01525(412)	pu-sol-therm-008_case-18
1.00000(280)	1.01000(94)	1.01023(92)	1.01023(294)	pu-sol-therm-008_case-19
1.00000(280)	1.01058(92)	1.01005(82)	1.01005(292)	pu-sol-therm-008_case-20
1.00000(400)	0.99615(93)	0.99649(91)	0.99649(410)	pu-sol-therm-008_case-21
1.00000(610)	0.99831(97)	0.99535(113)	0.99535(620)	pu-sol-therm-008_case-22
1.00000(370)	1.01573(81)	1.01638(87)	1.01638(380)	pu-sol-therm-008_case-23
1.00000(310)	1.00799(90)	1.00852(88)	1.00852(322)	pu-sol-therm-008_case-24
1.00000(420)	1.01664(100)	1.01388(105)	1.01388(433)	pu-sol-therm-008_case-25
1.00000(410)	1.01091(102)	1.01140(104)	1.01140(423)	pu-sol-therm-008_case-26
1.00000(420)	1.01116(95)	1.01192(114)	1.01192(435)	pu-sol-therm-008_case-27
1.00000(420)	1.00406(105)	1.00540(90)	1.00540(429)	pu-sol-therm-008_case-28
1.00000(410)	1.01321(110)	1.01387(71)	1.01387(416)	pu-sol-therm-008_case-29
1.00000(410)	1.01335(86)	1.01085(97)	1.01085(421)	pu-sol-therm-008_case-30
1.00000(430)	1.00521(63)	1.00632(50)	1.00632(433)	pu-sol-therm-012_case-2
1.00000(580)	1.00809(60)	1.00738(56)	1.00738(583)	pu-sol-therm-012_case-3
1.00000(580)	1.00611(52)	1.00863(51)	1.00863(582)	pu-sol-therm-012_case-4
1.00000(580)	1.00863(49)	1.00944(54)	1.00944(582)	pu-sol-therm-012_case-5
1.00000(70)	1.00622(97)	1.00854(100)	1.00854(121)	pu-sol-therm-012_case-6
1.00000(130)	1.00560(94)	1.00806(100)	1.00806(164)	pu-sol-therm-012_case-7
1.00000(130)	1.00689(89)	1.00454(97)	1.00454(162)	pu-sol-therm-012_case-8
1.00000(430)	1.01228(87)	1.01032(83)	1.01032(438)	pu-sol-therm-012_case-9
1.00000(430)	1.00579(78)	1.00561(78)	1.00561(437)	pu-sol-therm-012_case-10
1.00000(430)	1.00818(74)	1.00786(72)	1.00786(436)	pu-sol-therm-012_case-11
1.00000(430)	1.00765(64)	1.00840(65)	1.00840(435)	pu-sol-therm-012_case-12

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benchmark	JEFF-3.0	JEFF-3.1	C/E (JEFF-3.1)	name
1.00000(580)	1.00876(48)	1.01028(54)	1.01028(582)	pu-sol-therm-012_case-13
1.00000(130)	1.00200(100)	1.00280(85)	1.00280(155)	pu-sol-therm-012_case-14
1.00000(430)	1.00922(81)	1.01001(86)	1.01001(438)	pu-sol-therm-012_case-15
1.00000(430)	1.00353(70)	1.00601(75)	1.00601(436)	pu-sol-therm-012_case-16
1.00000(430)	1.00769(88)	1.00744(76)	1.00744(437)	pu-sol-therm-012_case-17
1.00000(430)	1.00666(69)	1.00750(60)	1.00750(434)	pu-sol-therm-012_case-18
1.00000(430)	1.00766(59)	1.00945(68)	1.00945(435)	pu-sol-therm-012_case-19
1.00000(580)	1.00739(55)	1.00874(51)	1.00874(582)	pu-sol-therm-012_case-20
1.00000(580)	1.00832(56)	1.00877(52)	1.00877(582)	pu-sol-therm-012_case-21
1.00000(580)	1.00956(49)	1.00947(41)	1.00947(581)	pu-sol-therm-012_case-22
1.00000(580)	1.00841(49)	1.00787(44)	1.00787(582)	pu-sol-therm-012_case-23

Table 3.10 The results for PU benchmarks with a thermal spectrum

3.4.4 Mixed spectrum

benchmark	JEFF-3.0	JEFF-3.1	C/E (JEFF-3.1)	name
1.00020(370)		1.00441(99)	1.00421(383)	pu-met-mixed-001_case-1
1.00020(320)		0.99839(83)	0.99819(331)	pu-met-mixed-001_case-2
1.00050(250)		1.00406(98)	1.00356(268)	pu-met-mixed-001_case-3
1.00000(250)		1.00720(91)	1.00720(266)	pu-met-mixed-001_case-4
1.00010(250)		1.00823(83)	1.00813(263)	pu-met-mixed-001_case-5
1.00030(250)		1.00761(87)	1.00731(264)	pu-met-mixed-001_case-6

3.5 MIX results

3.5.1 Fast spectrum

benchmark	JEFF-3.0	JEFF-3.1	C/E (JEFF-3.1)	name
0.98660(230)	0.98388(49)	0.98997(47)	1.00342(238)	mix-comp-fast-001
0.98970(230)	0.98783(48)	0.99002(70)	1.00032(243)	mix-met-fast-011_case-1
0.99980(230)	0.99274(44)	0.99539(46)	0.99559(235)	mix-met-fast-011_case-2
1.00180(240)	0.99749(49)	0.99852(47)	0.99673(244)	mix-met-fast-011_case-3
1.00120(240)	0.99842(53)	1.00128(42)	1.00008(243)	mix-met-fast-011_case-4

Table 3.11 The results for MIX benchmarks with a fast spectrum

3.5.2 Thermal spectrum

benchmark	JEFF-3.0	JEFF-3.1	C/E (JEFF-3.1)	name
1.00520(670)	0.97599(51)	0.97597(53)	0.97092(669)	mix-comp-therm-012_case-1
1.00520(670)	0.97668(58)	0.97812(60)	0.97306(669)	mix-comp-therm-012_case-2
1.00520(670)	0.97475(65)	0.97389(52)	0.96885(669)	mix-comp-therm-012_case-3
1.00520(670)	0.97976(50)	0.97874(51)	0.97368(669)	mix-comp-therm-012_case-4
1.00520(670)	0.97589(53)	0.97640(62)	0.97135(670)	mix-comp-therm-012_case-5
1.00520(750)	0.98124(59)	0.98007(60)	0.97500(749)	mix-comp-therm-012_case-6

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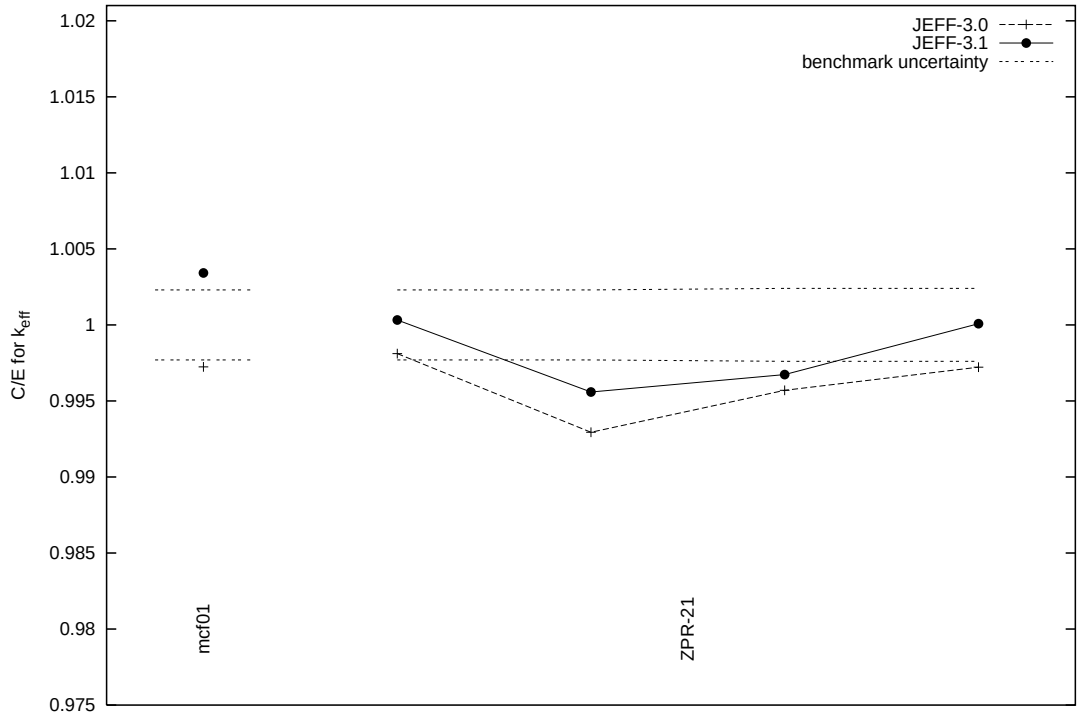

Figure 3.10 Results for the MIX benchmarks with a fast spectrum

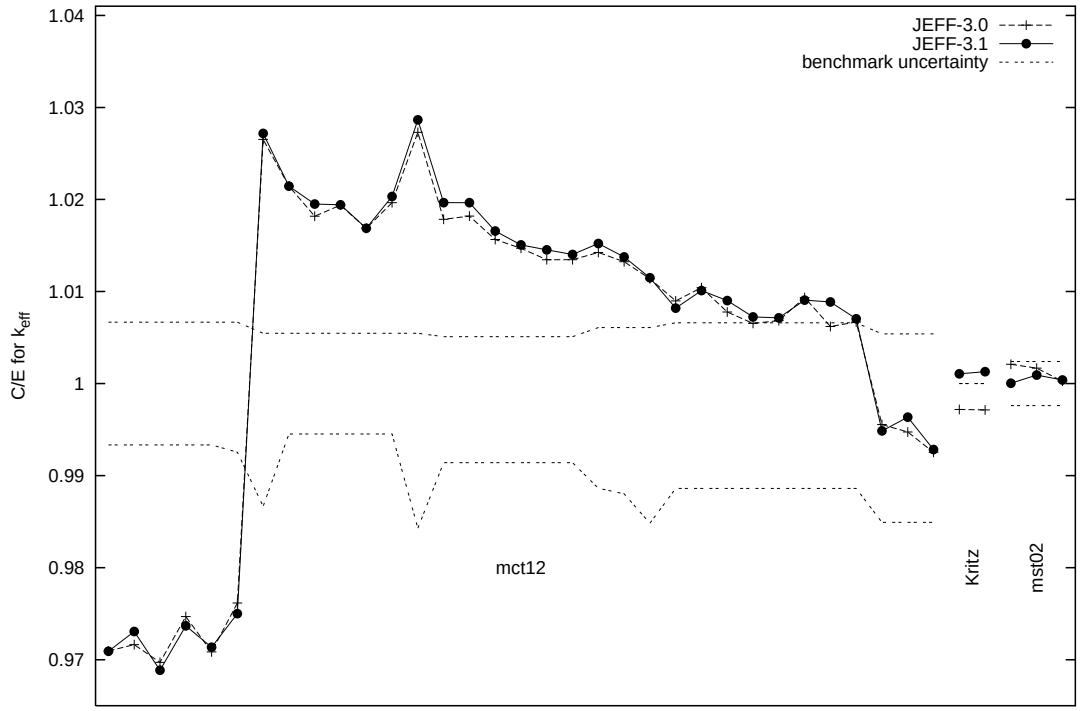

Figure 3.11 Results for the MIX benchmarks with a thermal spectrum

benchmark	JEFF-3.0	JEFF-3.1	C/E (JEFF-3.1)	name
1.00530(1340)	1.03196(51)	1.03261(53)	1.02717(1334)	mix-comp-therm-012_case-7

continued on next page

benchmark	JEFF-3.0	JEFF-3.1	C/E (JEFF-3.1)	name
1.00530(550)	1.02686(56)	1.02685(49)	1.02144(549)	mix-comp-therm-012_case-8
1.00530(550)	1.02358(55)	1.02491(46)	1.01951(549)	mix-comp-therm-012_case-9
1.00530(550)	1.02479(54)	1.02482(58)	1.01942(550)	mix-comp-therm-012_case-10
1.00530(550)	1.02224(55)	1.02227(51)	1.01688(549)	mix-comp-therm-012_case-11
1.00530(550)	1.02506(50)	1.02574(56)	1.02033(550)	mix-comp-therm-012_case-12
1.00530(1580)	1.03273(55)	1.03410(52)	1.02865(1572)	mix-comp-therm-012_case-13
1.00120(860)	1.01907(52)	1.02087(67)	1.01965(861)	mix-comp-therm-012_case-14
1.00120(860)	1.01942(62)	1.02087(65)	1.01965(861)	mix-comp-therm-012_case-15
1.00120(860)	1.01687(56)	1.01779(53)	1.01657(861)	mix-comp-therm-012_case-16
1.00120(860)	1.01591(63)	1.01628(57)	1.01506(861)	mix-comp-therm-012_case-17
1.00120(860)	1.01467(62)	1.01575(58)	1.01453(861)	mix-comp-therm-012_case-18
1.00120(860)	1.01467(57)	1.01524(56)	1.01402(861)	mix-comp-therm-012_case-19
1.00140(1140)	1.01567(55)	1.01664(70)	1.01522(1140)	mix-comp-therm-012_case-20
1.00140(1200)	1.01466(71)	1.01517(68)	1.01375(1200)	mix-comp-therm-012_case-21
1.00140(1520)	1.01281(63)	1.01292(67)	1.01150(1519)	mix-comp-therm-012_case-22
1.00070(1140)	1.00969(56)	1.00890(64)	1.00819(1141)	mix-comp-therm-012_case-23
1.00070(1140)	1.01113(68)	1.01082(64)	1.01011(1141)	mix-comp-therm-012_case-24
1.00070(1140)	1.00849(64)	1.00973(61)	1.00902(1141)	mix-comp-therm-012_case-25
1.00070(1140)	1.00724(57)	1.00795(55)	1.00724(1141)	mix-comp-therm-012_case-26
1.00070(1140)	1.00754(64)	1.00784(48)	1.00714(1140)	mix-comp-therm-012_case-27
1.00070(1140)	1.01006(66)	1.00978(60)	1.00907(1141)	mix-comp-therm-012_case-28
1.00070(1140)	1.00690(68)	1.00958(64)	1.00887(1141)	mix-comp-therm-012_case-29
1.00070(1140)	1.00738(62)	1.00773(52)	1.00703(1140)	mix-comp-therm-012_case-30
1.00170(1510)	0.99723(78)	0.99655(68)	0.99486(1509)	mix-comp-therm-012_case-31
1.00170(1510)	0.99643(61)	0.99804(64)	0.99635(1509)	mix-comp-therm-012_case-32
1.00170(1510)	0.99421(73)	0.99452(66)	0.99283(1509)	mix-comp-therm-012_case-33
1.00000(0)	0.99718(22)	1.00105(22)	1.00105(22)	mix-comp-therm-kritz_core-2.19cold
1.00000(0)	0.99713(7)	1.00129(22)	1.00129(22)	mix-comp-therm-kritz_core-2.19hot
1.00000(240)	1.00209(58)	1.00003(47)	1.00003(245)	mix-sol-therm-002_exp-58
1.00000(240)	1.00167(61)	1.00092(53)	1.00092(246)	mix-sol-therm-002_exp-59
1.00000(240)	1.00026(45)	1.00038(49)	1.00038(245)	mix-sol-therm-002_exp-61

Table 3.12 The results for MIX benchmarks with a thermal spectrum. † The benchmark value and its uncertainty is still under investigation for Kritz.

3.6 U233 results

3.6.1 Fast spectrum

benchmark	JEFF-3.0	JEFF-3.1	C/E (JEFF-3.1)	name
1.00000(100)	1.01359(38)	1.00445(37)	1.00445(107)	u233-met-fast-001
1.00000(90)	1.00895(41)	1.00099(36)	1.00099(97)	u233-met-fast-005_case-1
1.00000(60)	1.00710(49)	1.00033(48)	1.00033(77)	u233-met-fast-005_case-2
1.00000(140)	1.00391(53)	1.00608(44)	1.00608(147)	u233-met-fast-006

Table 3.13 The results for U233 benchmarks with a fast spectrum

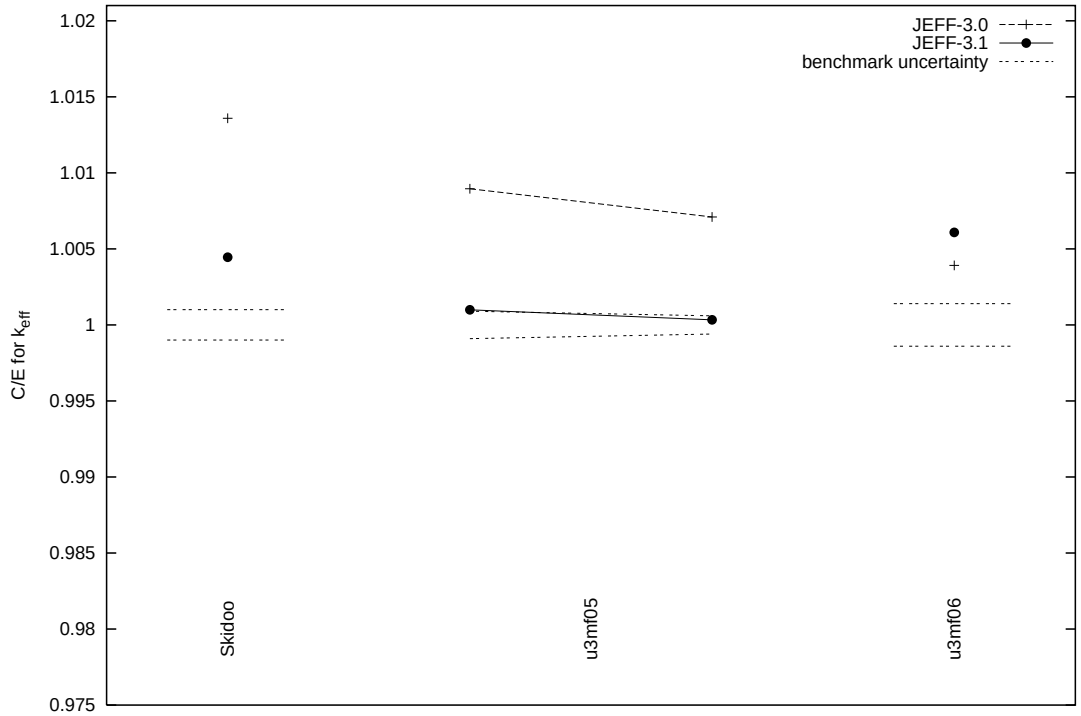

Figure 3.12 Results for the U233 benchmarks with a fast spectrum

3.6.2 Thermal spectrum

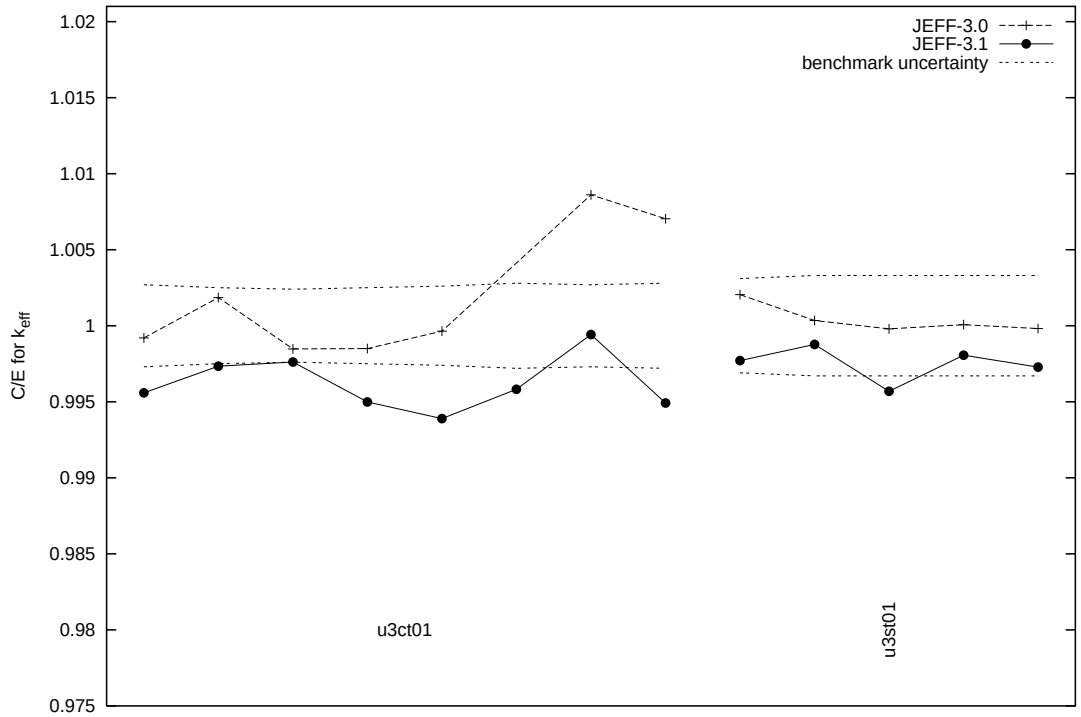

Figure 3.13 Results for the U233 benchmarks with a thermal spectrum

benchmark	JEFF-3.0	JEFF-3.1	C/E (JEFF-3.1)	name
1.00060(270)	0.99980(123)	0.99619(98)	0.99559(287)	u233-comp-therm-001_case-1
1.00150(250)	1.00335(106)	0.99884(99)	0.99734(269)	u233-comp-therm-001_case-2
1.00000(240)	0.99848(112)	0.99761(112)	0.99761(265)	u233-comp-therm-001_case-3
1.00070(250)	0.99920(85)	0.99569(80)	0.99499(262)	u233-comp-therm-001_case-4
1.00150(260)	1.00114(76)	0.99538(89)	0.99389(275)	u233-comp-therm-001_case-5
1.00150(280)		0.99731(102)	0.99582(298)	u233-comp-therm-001_case-6
0.99950(270)	1.00811(112)	0.99892(102)	0.99942(289)	u233-comp-therm-001_case-7
1.00040(280)	1.00744(112)	0.99532(90)	0.99492(294)	u233-comp-therm-001_case-8
1.00000(310)	1.00205(61)	0.99771(53)	0.99771(315)	u233-sol-therm-001_case-1
1.00050(330)	1.00084(62)	0.99927(80)	0.99877(339)	u233-sol-therm-001_case-2
1.00060(330)	1.00039(63)	0.99629(58)	0.99569(335)	u233-sol-therm-001_case-3
0.99980(330)	0.99987(59)	0.99786(69)	0.99806(337)	u233-sol-therm-001_case-4
0.99990(330)	0.99972(62)	0.99718(60)	0.99728(335)	u233-sol-therm-001_case-5

Table 3.14 The results for U233 benchmarks with a thermal spectrum

3.7 Summary

In the previous subsections, results for many benchmarks were presented. The number of benchmarks in each of the ICSBEP main categories is summarized in Table 3.15.

	COMP				MET				SOL	total
	therm /	inter /	fast /	mixed	therm /	inter /	fast /	mixed	therm	
LEU	257 /	/	/		1 /	/	/		49	307
IEU	9 /	4 /	/		/	/	16 /			29
HEU	/	6 /	/		42 /	5 /	66 /	5	87	211
MIX	35 /	/	1 /	1	/	/	4 /		3	44
PU	/	1 /	/		/	1 /	7 /	6	105	120
U233	8 /	/	/		/	/	4 /		5	17
total	309 /	11 /	1 /	1	43 /	6 /	97 /	11	249	728

Table 3.15 The number of benchmarks per main ICSBEP category for thermal/intermediate/fast neutron spectrum.

For a specific situation, it can be useful to compute averages of those benchmark cases that are most applicable to that situation. Here, however, we only give average values for $C/E-1$ for the main ICSBEP categories, see Table 3.16.

Closer inspection of individual benchmarks wil reveal deviations from the average. For various of these cases it may well be that the nuclear data library can, at a later date, still be improved further to yield better results. A detailed discussion of these problems, and the possibilities to solve them, is beyond the scope of the present paper.

	COMP				MET				SOL
	therm /	inter /	fast /	mixed	therm /	inter /	fast /	mixed	therm
LEU	−98 /	/	/		−7 /	/	/		145
IEU	−359 /	−376 /	/		/	/	−197 /		
HEU	/	1915 /	/	217	−308 /	60 /	−116 /	528	66
MIX	512 /	/	336 /		/	/	−182 /		44
PU	/	716 /	/		/	3842 /	251 /	476	568
U233	−380 /	/	/		/	/	296 /		−249

Table 3.16 The average values for $C/E-1$ (in pcm) per main ICSBEP benchmark category.

References

[1] J.F. Briesmeister (Ed.), *MCNP - A General Monte Carlo N-Particle Transport Code, Version 4C,* Technical Report LA-13709-M, Los Alamos National Laboratory, USA (2000)
J.S. Hendricks, *MCNP4C3*, Report X-5:RN(U)-JSH-01-17, Los Alamos National Laboratory, USA (2001)

[2] J. Blair Briggs (ed.), *International Handbook of Evaluated Criticality Safety Benchmark Experiments,* NEA/NSC/DOC(95)03/I, Nuclear Energy Agency, Paris (September 2004 Edition)

[3] T. Williams, M. Rosselet, and W. Scherer (Eds.), *Critical Experiments and Reactor Physics Calculations for Low-Enriched High Temperature Gas Cooled Reactors*, IAEA Tecdoc 1249 (advance electronic version, 2001)

[4] A. D. Knipe, *Specifications of the Dimple S01 Benchmark Assemblies*, Report AEA TSD 0375 (JEF/DOC-504), AEA Technology (1994)

[5] J. Hardy, D. Klein and J. J. Volpe, *A study of physics parameters in several H_2O-moderated lattices of slightly enriched and natural uranium*, Nuc. Sci. Eng. **40** (1970) 101;
Cross section evaluation working group (CSEWG), *Benchmark Specifications*, ENDF-202 (1986)

[6] I. Remec, J. C. Gehin, and R. J. Ellis, *KRITZ-2:19 experiment on regular H2O/fuel pin lattices with mixed oxide fuel at temperatures up to 245°C, A Study (Draft) by the OECD/NEA Working Party on Scientific Issues of Reactor Systems (WPRS)*, To be published as part of the International Reactor Physics Benchmark Project.

[7] S.C. van der Marck, A. Hogenbirk, and R. Klein Meulekamp, *New temperature interpolation in MCNP*, Proc. M&C-2005, Avignon (France), 2005