# STATUS OF THE INTERNATIONAL CRITICALITY SAFETY BENCHMARK EVALUATION PROJECT

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## ABSTRACT

*The International Criticality Safety Benchmark Evaluation Project (ICSBEP) has continued its work generating evaluations of new and historical criticality benchmark experiments since the last update to the nuclear criticality safety community at the 11th International Conference on Nuclear Criticality Safety (ICNC 2019) in Paris, France. Three additional versions of the ICSBEP Handbook have been published since that update, and the Technical Review Group (TRG) held two in-person (in 2019 and 2023) and three virtual (2020 and 2021) meetings to review and approve additional benchmarks. The 2019 edition of the ICSBEP Handbook included five new evaluations with 79 new configurations, the 2020 version of the ICSBEP Handbook contained five new evaluations totaling 76 new configurations, and the 2021 version of the ICSBEP handbook contained five new evaluations with a total of 57 different configurations. The ICSBEP TRG met in October and December 2021, to review benchmarks for potential inclusion in the 2022 ICSBEP Handbook, with seven evaluations receiving provisional approval pending resolution of review group comments. Final comment resolution for some of these evaluations is currently underway and handbook publication should be completed soon. The ICSBEP TRG met again in person in April 2023 to review benchmarks for the 2023 ICSBEP Handbook, provisionally approving 7 new evaluations. The ICSBEP continues to deliver high-quality, peer reviewed evaluations of experiments relevant to the nuclear criticality safety community.*

## KEYWORDS

*ICSBEP, Integral Experiments, Critical Experiments, Benchmarks*

## 1. INTRODUCTION

The International Criticality Safety Benchmark Evaluation Project (ICSBEP) and its associated handbook [1] of evaluated benchmark experiments is the premiere source of trusted benchmarks for criticality safety calculation validation worldwide. The ICSBEP is an official activity of the Organisation for Economic Co-operation and Development (OECD) Nuclear Energy Agency (NEA), which coordinates the Technical Review Group (TRG) participation amongst NEA member countries and publishes the handbook. The handbook represents the technical contributions from hundreds of dedicated individuals from 28 different countries over an almost 30 year period.

Since the last update to the nuclear criticality safety community at the 11th International Conference on Nuclear Criticality Safety (ICNC 2019) in Paris, France, three additional versions of the ICSBEP

Handbook have been published. The 2019 edition of the ICSBEP Handbook included five new evaluations with 79 new configurations, the 2020 version of the ICSBEP Handbook contained five new evaluations totaling 76 new configurations, and the 2021 version of the ICSBEP handbook contained five new evaluations with a total of 57 different configurations. A number of evaluations were revised, including five major revisions. All revised and new evaluations published in the 2019-2021 are further described in Sections 2 and 3 of this paper.

The ICSBEP TRG met in October and December 2021, to review benchmarks for potential inclusion in the 2022 ICSBEP Handbook, with seven evaluations receiving provisional approval pending resolution of review group comments. An overview of the seven evaluations is provided in Section 4. Final comment resolution for these evaluations is currently underway and handbook publication should be completed soon. In April 2023, the ICSBEP TRG met again in person for the first time since October 2019 to review benchmarks for the 2023 ICSBEP Handbook, provisionally approving 7 new evaluations. An overview of the seven evaluations is provided in Section 5.

## 2. NEW PUBLISHED EVALUATIONS: 2019, 2020, 2021 EDITIONS

The 2019, 2020, and 2021 editions of the handbooks contain a total of 15 new evaluations representing 210 different experimental benchmark configurations. A summary of the 2021 handbook contents (which includes all prior approved configurations) and the contributions from the 2019-2021 handbook contents are shown in Table I.

| ICSBEP Type | New Configurations in 2019-2021 Handbooks | Total Configurations in 2021 Handbook |
|---|---|---|
| PU | 60 | 801 |
| HEU | 7 | 1443 |
| IEU | 0 | 278 |
| LEU | 121 | 1822 |
| U233 | 0 | 244 |
| MIX (Pu/U) | 0 | 536 |
| SPEC (Other Actinides) | 0 | 20 |
| ALARM (Shielding) | 0 | 46 |
| FUND (Physics) | 22 | 238 |

### 2.1 New Plutonium Evaluations

Three new plutonium (Pu) evaluations were added to the handbooks in 2019-2021. A description of the new Pu evaluations is provided, below.

**PU-MET-MIXED-002:** This evaluation documents five experiments performed in 2017 and 2018 at the US National Criticality Experiments Research Center (NCERC) representing the plutonium baseline critical experiment configurations of the United States Nuclear Criticality Safety Program's (US NCSP) Thermal/Epithermal eXperiments (TEX) program. These experiments used plutonium/aluminum metal alloy fuel plates from the Zero Power Physics Reactor (ZPPR) program moderated to varying degrees with polyethylene to cover five different fission energy regimes with varying fractions of thermal, intermediate, and fast fissions [2]. As such, cross-reference evaluation identifications include PU-MET-FAST-048 (Case 1) and PU-MET-THERM-002 (Cases 4 and 5). The benchmark reports calculations with MCNP6.1, COG11, and MORET5.D and nuclear data libraries ENDF/B-VII.1 and ENDF/B-VIII.0. Cases 3 (mixed case with 0.43 intermediate fission fraction) and 5 (thermal case) fell outside of 2σ uncertainty for ENDF/B-VIII.0 cross sections, but all cases fell within 2σ with ENDF/B-VII.1 cross sections. Case 3, which had 43% of its fissions occurring the intermediate energy regime, was the worst predicted case, falling outside of 3 σ with ENDF/B-VIII.0 cross sections.

**PU-MET-MIXED-003:** This evaluation documents five experiments that were performed at NCERC in 2018 as part of the TEX program, taking the five baseline configurations evaluated as PU-MET-MIXED-003 and adding a layer of tantalum on top of each Pu layer. Polyethylene was used to moderate the experiments such that of the five configurations, two are considered fast neutron spectra, two mixed, and one thermal [2]. The benchmark reports calculations with MCNP6.1 and MORET5.D and nuclear data libraries ENDF/B-VII.1, ENDF/B-VIII.0, JEFF-3.1.1 and JEFF-3.3. For the MCNP6.1 calculations, Cases 1 and 2 (fast cases) fell outside of 3σ uncertainty for ENDF/B-VIII.0 cross sections, case 3 fell within 3σ, Case 4 was within 2σ, and Case 5 (thermal case) within 1σ.

**PU-SOL-THERM-041:** This evaluation documents forty plutonium-solution benchmark experiments that were performed at the Valduc Facility by Commissariat à l'Energie Atomique (CEA) in France between 1964 and 1965 [3]. The fissile solution was contained within an annular cylinder with inner and outer diameters of 20 and 50 cm, respectively. The central volume contained either air or water. The outside and bottom of the annular tank was reflected by water. Plutonium concentrations ranged between approximately 20 and 190 g/L, with $^{240}$Pu content of approximately 3%. Extensive sample calculations were performed to investigate computational results from current nuclear data and codes; these results are provided within the benchmark evaluation report.

### 2.2 New Highly Enriched Uranium Evaluations

Two new highly enriched uranium (HEU) evaluations were added to the handbook in 2019-2021. A description of the new HEU evaluations is provided, below.

**HEU-MET-FAST-101:** This evaluation documents five critical configurations of the Kilopower Reactor Using Stirling TechnologY (KRUSTY) experiment in support of space reactor design and analysis [4]. The experiments were performed in 2017 and 2018 at NCERC with a U-Mo fuel annulus (enriched to ~93.1 wt.% $^{235}$U) reflected by BeO on the Comet vertical lift critical assembly machine. Calculations of the eigenvalues with MCNP-6.2, MC21 9.00.02, or COG 11.3 Monte Carlo codes with ENDF/B-VIII.0 are well within the 1 σ uncertainty range. COG calculations with JEFF-3.3 are similarly comparable. Calculations using ENDF/B-VII.1, however, were between 3-5 σ greater than the benchmark eigenvalues.

**HEU-MET-THERM-004:** This evaluation documents two thermal HEU (~93.2 wt.% $^{235}$U) with Lucite (polymethyl methacrylate) experiments that were performed on the Planet vertical lift machine at NCERC in December 2019. The experiments consisted of a stack of HEU foils (generally referred to as the class foils) with thick interstitial Lucite moderator and a Lucite reflector. A number of other benchmarks have used the same HEU foils with interstitial polyethylene as the moderator. The two configurations differed slightly in total HEU mass. Sample calculations performed with MCNP6.2 using ENDF/B-VIII.0 cross section data are 6 – 7 σ higher than the benchmark eigenvalues.

### 2.3 New Low Enriched Uranium Evaluations

The majority of the new evaluations and configurations published in ICSBEP have used Low Enriched Uranium (LEU) as the fissile material. An overview of the nine new LEU evaluations are provided, below.

**LEU-COMP-THERM-099:** This evaluation documents seventeen extrapolated critical configurations that were performed at the Sandia Critical Experiments Facility (SCXF) in the US in 2017 and 2018. The experiments were performed to test the effects of titanium and/or aluminum sleeves in water-reflected, water-moderated, triangular-pitched lattices of Zr-4-clad $UO_2$ fuel (4.31 wt.% enriched $^{235}$U)

[5]. The benchmark reports calculations with SCALE6.2, MCNP6.2, and MORET5.D.1 and provided a comparison of ENDF/B-VII.0 with -VII.1 and JEFF-3.1.1 with -3.3 neutron cross section libraries. Calculations with the more recent nuclear data sets indicated definite improvements in the titanium cross sections, with final calculations within 1 to 2 σ of the benchmark eigenvalues.

**LEU-COMP-THERM-101:** Twenty-two experiments were performed at SCXF using the Seven Percent Critical Experiment (7uPCX) to evaluate partially-reflected, water-moderated $UO_2$ fuel (6.90 wt.% enriched $^{235}U$) rod lattices with 0.52 fuel-to-water volume ratio (0.855 cm pitch) [5]. The initial baseline experiment consisted of a full cylindrical critical array of 2025 fuel rods. Subsequent critical loadings consisted of various configuration variants that separated the cylindrical array into two or four smaller subarrays of fuel rods with water channels between the subarrays. The reactivity was controlled by varying the water height in the tank. Numerous sample calculations are provided using various contemporary nuclear codes and data.

**LEU-COMP-THERM-102:** Twenty-seven experiments were performed at SCXF using the Seven Percent Critical Experiment (7uPCX) to evaluate partially-reflected, water-moderated LEU-$O_2$ fuel (enriched to 6.90 $^{235}U$) rod lattices with varying pitches [6]. The purpose of the experiments was to measure the effects of decreasing the fuel-to-water volume ratio on the critical array size. The fuel rod pitch variations changed the configurations from strongly undermoderated to slightly overmoderated. The fuel pitches ranged between 0.80 and 1.71 cm. The total evaluated 1 σ uncertainty in the benchmark eigenvalues ranged between 65 and 121 pcm. The benchmark reports calculations with SCALE6.2, MCNP6.2, and MORET5.D.1 and provided results for ENDF/B-VII.1 and -VIII.0 and JEFF-3.1.1 and -3.3 neutron cross section libraries. Large differences were seen between the two versions of both libraries, and ENDF/B-VIII.0 had the most cases calculate outside of the 1 σ uncertainty.

**LEU-COMP-THERM-103:** This evaluation documents three critical configurations conducted in 2016 at the Brazilian IPEN/MB-01 research reactor with water-moderated, square-pitched lattices of stainless steel 304-clad $UO_2$ fuel (4.326 wt% enriched $^{235}U$) surrounding a central aluminum-clad UMo fuel (19.80 wt.% enriched $^{235}U$) plate test region [7]. The experiments were performed to provide nuclear data validation cases for the UMo fuel. The benchmark reports calculations with MCNP5 and ENDF/B-VII.0 cross sections, which agreed with the benchmark eigenvalues within 1 σ.

**LEU-COMP-THERM-104:** This evaluation documents the KRITZ-1 experiments, which were performed in Sweden in 1970-1971 using water moderated and reflected rectangular arrays of Zr-2-clad $UO_2$ (1.35 wt.% enriched $^{235}U$) Marviken Boiling Heavy Water Reactor (BHWR) fuel rods [8]. The measurements were conducted to measure material buckling as a function of temperature. The evaluation consists of 37 critical configurations from four different experimental series that varied the core configurations and boron concentrations with temperatures ranging from 20.4 to 243.6 °C. Sample calculations were performed with SCALE6.2.3 using ENDF/B-VII.1 cross sections and MCNP6.2 using ENDF/B-VIII.0, with computed eigenvalues within 2-4 σ of the benchmark values. This benchmark is also published in the 2019 edition of the International Handbook of Evaluated Reactor Physics Benchmark Experiments (IRPhEP Handbook) with the identifier KRITZ-LWR-RESR-004 and includes benchmark specifications for additional reactivity effects and coefficient measurements [9].

**LEU-COMP-THERM-106:** The Matériaux Interaction Réflexion Toutes Epaisseurs (MIRTE, translated in English as Materials, Interaction, Reflection, All Thickness) program was carried out between 2008 and 2013 at the CEA Valduc Center in France [10]. The purpose of this program was to measure integral reactivity characteristics for various structural materials, providing benchmark validation data for modern nuclear codes and data utilized in criticality safety and reactor physics applications. MIRTE-2.2 from this series of experiments was evaluated, which includes material screens made of sodium chloride, rhodium sulfide, polyvinylchloride (PVC), molybdenum, chromium resin, and manganese resin. The total evaluated 1 σ uncertainty for these six configurations ranges between 61 and 87 pcm. Most sample calculations using contemporary nuclear data and codes fall within 3σ of the benchmark eigenvalues. Numerous sample calculations are provided.

**SUB-LEU-COMP-THERM-003:** A series of water-moderated subcritical experiments was performed at the IPEN/MB-01 research reactor facility in São Paulo, Brazil, in 2018 [11]. For these experiments, the moderator was doped with soluble boric acid to achieve subcriticality in square-pitched rod arrangements of near optimal 1.5 cm. One critical and seven subcritical configurations were evaluated as acceptable benchmark experiments. Boron content ranged from approximately 50 to 300 ppm. Sample calculations using MCNP5 with ENDF/B-VII.0 nuclear data were within 2 σ of the benchmark values.

**LEU-SOL-THERM-012:** Numerous critical and transient experiments were performed in 2001 using the Transient Experiment Critical Facility (TRACY) at the Tokai Research Establishment of Japan Atomic Energy Agency (JAEA) in Japan. TRACY serves as a supercritical reactor to simulate criticality accidents in fuel processing facilities. One of the critical configurations supporting pulse withdrawal supercritical experiments [12] was evaluated as a benchmark and the information is provided in detail in LEU-SOL-THERM-013. The evaluated critical configuration is an unreflected annular tank containing 10 % enriched ($^{235}$U) uranyl nitrate solution. A boron carbide transient rod was inserted into the central portion of the annulus. This benchmark accompanies the critical and subcritical configurations without the transient rod provided in LEU-SOL-THERM-012. All continuous-energy calculations, using a variety of modern nuclear codes and data, overpredict $k_{eff}$ by more than the 3 σ uncertainty for this benchmark configuration.

### 2.4 New Fundamental Physics Evaluations

**FUND-NCERC-PU-HE3-MULT-003**: This evaluation documents seventeen subcritical configurations measured in December 2016 at NCERC as part of the Subcritical Copper-Reflected α-Plutonium (SCRaP) experiments [13]. In the experiments, a SS304-clad alpha phase plutonium (~94 wt.% $^{239}$Pu) sphere was reflected by various arrangements and thicknesses of copper and/or polyethylene reflectors. The subcritical multiplication was approximated using time correlated neutron data from an $^{3}$He neutron detector system. Computed results using MCNP6.2 with ENDF/B-VII.1 and -VIII.0 were typically within approximately 5 % of the benchmark subcritical parameters although some calculations were discrepant up to 20 %.

**FUND-LLNL-ALPHAN-U235-MULT-001:** This evaluation documents five subcritical measurements performed with the Inherently Safe Subcritical Assembly (ISSA) [8] at Lawrence Livermore National Laboratory (LLNL) in the US in 2017 and 2018. The purpose of this experiment was to collect time-tagged neutron count data corresponding to configurations with multiplication ranging from approximately 2 to 10. The five configurations were arrays of 1, 2, 4, 6, or 9 HEU Materials Test Reactor (MTR) fuel assemblies fully immersed in water. $^{3}$He proportional neutron detectors were used to collect list-mode neutron data and compute the leakage multiplication of the system. Sample calculations performed using COG11.3 with ENDF/B-VII.1 and ENDF/B-VIII.0 were within 12 % of the benchmark values. Calculations performed using MORET5 with ENDF/B-VII.1 and JEFF3.2 were within 12 %.

## 3. REVISED EVALUATIONS: 2019, 2020, 2021 EDITIONS

The 2019, 2020, and 2021 editions of the handbook saw 5 significant revisions and 25 minor revisions to existing, approved benchmarks. Minor revision to existing benchmark evaluations typically include rectifying minor errors such as incorrect information placed in figures, adding a needed clarification, or inclusion of information necessary to complete the benchmark evaluation that was accidently excluded. Minor revisions do not significantly impact the final results of the benchmark evaluation itself. More significant revisions impact the overall results or incur changes to the benchmark model description. Users of benchmarks are strongly encouraged to update their benchmark suite in light of a major revision. Significant revisions to benchmarks are detailed in Table II and minor revisions are detailed in Table III.

**Table II. Details of Significant Benchmark Revisions in the 2019-2021 ICSBEP Handbooks**

| ICSBEP Identifier | Significant Revision Notes |
|---|---|
| PU-MET-FAST-001 | • Revision of simple benchmark model description due to updates in nickel cross section library data in ENDF/B-VIII.0. |
| LEU-COMP-THERM-073 | • Improved quality of Figures 4 and 12.<br>• Updated uncertainty analysis (minor effect).<br>• Updated Section 4 sample calculations. |
| LEU-SOL-THERM-012 | • Errors in the tank geometry uncertainty analysis were identified during the review of LEU-SOLTHERM-013. They were found common to this evaluation and corrected. |
| FUND-NCERC-PU-HE3-MULT-003 | • Female polyethylene hemishell atom densities corrected in Table 113. |
| FUND-LLNL-ALPHAN-HE3-MULT-001 | • Updated uncertainty analysis. Reduced uncertainty in aluminum components and total uncertainty. |

**Table III. Details of Minor Benchmark Revisions in the 2019-2021 ICSBEP Handbooks**

| ICSBEP Identifier | Minor Revision Notes |
|---|---|
| PU-MET-FAST-001 | • On page 79, replaced the text defining full insertion of the rectangular part as being centered within the length of the channel within “upper part M2” to indicate correctly “upper part M3”.<br>• Replaced the “-6” exponents with “6” in the EALF and AFGE columns of Table C.2. |
| PU-MET-FAST-003 | • Removed bad KENO inputs from Appendix A.1 and accompanying subfolder on the handbook. |
| PU-MET-FAST-045 | • Removed bad KENO inputs from Appendix A.1 and accompanying subfolder on the handbook. |
| PU-SOL-THERM-023 | • The MCNP input decks providing in the benchmark subdirectory were incorrect, and they have been removed. |
| PU-SOL-THERM-028 | • On page 2, replaced "- 50/20 cm diam., 3.0 % 240Pu: PU-SOL-THERM-041," with "- 50/20 cm diam.,19 % 240Pu : PU-SOL-THERM-031,".<br>• The hyperlink also points to the correct benchmark. |
| PU-SOL-THERM-029 | • On page 2, replaced "- 50/20 cm diam., 3.0 % 240Pu: PU-SOL-THERM-041," with "- 50/20 cm diam.,19 % 240Pu : PU-SOL-THERM-031,".<br>• The hyperlink also points to the correct benchmark. |
| HEU-MET-FAST-085 | • In Section 1.1, revised to indicate that only six of the 13 evaluated configurations were determined to be acceptable benchmark experiments.<br>• In Table 18, renumbered the cases properly as Cases 1 through 6. |
| HEU-MET-FAST-096 | • Input decks for Cases 7 and 14 revised and updated in Appendix A.<br>• Results for detailed and simple models recalculated and updated in Section 4 results. |
| HEU-MET-THERM-012 | • Figure 18 was replaced; the value of 36.46932 cm was changed to 36.5125 cm. |
| HEU-MET-THERM-032 | • MCNP sample input decks were revised to be compatible with modern versions of the code. |
| IEU-COMP-THERM-013 | • Added note in Section 1.0 pointing users to NRAD-FUND-RESR-002 for the upgraded NRAD core.<br>• Reassessed how the uncertainty in the water saturation of the graphite reflector blocks was treated using additional information (Section 2.1.6.1). |

| ICSBEP Identifier | Minor Revision Notes |
|---|---|
| | However, the resultant uncertainties had no significant impact upon the total benchmark uncertainty (Tables 2.63 and 2.64).<br>• Added additional discussion regarding the treatment of the water saturation of the graphite reflector blocks in Section 3.1.1.1.<br>• Minor correction to MCNP input lattice planes to ensure they will run in modern versions of the code. Changes to inputs provided in Appendices A and C and in the Input directory of the handbook.<br>• Updated Section 4 sample calculations. |
| IEU-MET-FAST-010 | • Provided detailed MCNP model of the as-built experiment with ENDF/B-VIII.0 results in Appendix E. |
| IEU-MET-FAST-020 | • Updated Section 4 to include sample calculations demonstrating the improvement in Fe and Cu cross sections from ENDF/B-VIII.0.<br>• Updated Appendix A sample inputs and provided new sample inputs on the Handbook.<br>• Revised Figures 147a and 147b to clarify benchmark model description.<br>• Original sample calculations moved to Appendix C. |
| IEU-MET-FAST-021 | • Updated Section 4 to include sample calculations demonstrating the improvement in Fe and Cu cross sections from ENDF/B-VIII.0.<br>• Updated Appendix A sample inputs and provided new sample inputs on the Handbook.<br>• Original sample calculations moved to Appendix D. |
| IEU-MET-FAST-022 | • Updated Section 4 to include sample calculations demonstrating the improvement in Fe and Cu cross sections from ENDF/B-VIII.0.<br>• Updated Appendix A sample inputs and provided new sample inputs on the Handbook.<br>• Revised Figures 121, 122, 123, 126, 127, 133, and 134 to more clearly represent the benchmark model description. |
| IEU-SOL-THERM-001 | • Table 18 was added to Section 4 on page 30 to provide sample MCNP calculations attributed to Kermit Bunde (DOE-IE).<br>• MCNP sample input decks are now provided in the benchmark subdirectory. |
| LEU-COMP-THERM-039 | • Updated sample calculation results in Section 4. |
| LEU-COMP-THERM-048 | • KENO input decks in Appendix A.2 are incorrect; text revised to point user to correct input decks found in subfolder on the handbook. |
| LEU-COMP-THERM-071 | • Additional clarification provided based upon uncertainty analyses updated in LEU-COMP-THERM-073. |
| LEU-COMP-THERM-072 | • Additional clarification provided based upon uncertainty analyses updated in LEU-COMP-THERM-073. |
| LEU-COMP-THERM-078 | • Updated Figures 15-29 in Section 1 to fix an error and also so it conforms with similar modern benchmarks. |
| LEU-COMP-THERM-104 | • Evaluation report was missing from the 2019 release of the ICSBEP Handbook. It was added with the 2020 edition. |
| U233-COMP-THERM-004 | • Updated Section 3 Table 20 and Figure 24 to clarify benchmark model description for modeling fuel rod end fittings. |
| MIX-COMP-THERM-004 | • MCNP sample input decks are now provided in the benchmark subdirectory. |
| MIX-SOL-THERM-012 | • Table 23 updated to indicate that there are seven cases, not six. |

## 4. PREPARATIONS FOR THE 2022 EDITION OF THE HANDBOOK

The ICSBEP TRG met in October and December 2021 to review benchmarks for inclusion in the 2022 ICSBEP Handbook. Seven evaluations received provisional approval, pending the resolution of all TRG comments. The approved evaluations are listed below and should be included in the upcoming 2022 edition of the ICSBEP handbook.

**PU-MET-FAST-047:** The purpose of the Jupiter experiments was to measure lead void reactivity worth in a fast plutonium system. ZPPR plutonium fuel plates were arranged in stacks with lead and aluminum within the copper Zeus reflectors on the Comet vertical-lift assembly at NCERC [14].

**HEU-MET-INTER-011:** The Critical Unresolved Region Integral Experiment (CURIE) was also performed on Comet using the Zeus copper reflector at NCERC. It was designed to provide a test nuclear data in the $^{235}$U unresolved resonance region (URR) [14].

**HEU-MET-MIXED-021** (also cross listed as HEU-MET-FAST-103, HEU-MET-INTER-012, and HEU-MET-THERM-036): TEX-HEU experiments were performed using Jemima plates and varying thicknesses of polyethylene to baseline uranium experiments across the neutron fission spectra [2]. Because the dominant fission spectra changed significantly across the five measurements, this benchmark is cross listed with three additional identifiers to facilitate handbook users in identification of experiments requisite to their specific needs.

**IEU-MET-FAST-025:** This experiment is the Jupiter critical experiment with a mixture of HEU and natural uranium plates with lead in the Zeus copper reflector on Comet [14]. Four experiments were evaluated, again using a reference configuration, and then increasing lead voiding via the implementation of aluminum spacers.

**LEU-COMP-THERM-110:** This benchmark is a continuation of the evaluations of MIRTE series using the CEA Valduc Center Apparatus B assembly [10]. The latest contribution surrounds the Zircaloy-4-clad $UO_2$ (4.738 wt.%) rods with steel or copper sleeves in either water or an aluminum block.

**ALARM-CF-CU-SHIELD-001:** The neutron leakage flux through a copper block was evaluated across the energy range of 1.0 to 11.0 MeV using a $^{252}$Cf source to pass neutrons through a copper block. The experiment was a simple geometry integral experiment to support nuclear data testing [15]. The experiment was performed at the Research Centre Řež (RCR, Centrum výzkumu Řež) in the Czech Republic.

**FUND-ORELA-ACC-GRAPH-PNSDT-001:** An experiment was performed to benchmark slowing down characteristics of neutrons in nuclear graphite in the Oak Ridge Electron Linear Accelerator (ORELA) facility [16]. The focus was upon the neutron thermalization process in a graphite block.

## 5. PREPARATIONS FOR THE 2023 EDITION OF THE HANDBOOK

Most recently, the ICSBEP TRG met in April 2023 to review benchmarks for inclusion into the 2023 ICSBEP Handbook. The comments generated by this review are being addressed by the evaluators, and the 2023 handbook edition will be published in the near future.

**PU-MET-THERM-004:** This TEX-Pu variant, completed at NCERC, was designed with thick polyethylene and Lucite moderators to be sensitive to thermal scattering laws [2].

**PU-MET-THERM-005:** This experiment, the Chlorine Worth Study, was designed to provide a validation case for various concentrations of Pu chloride solutions [17]. The experiment was conducted at NCERC with stacks of Pu/Al alloy ZPPR plates, polyethylene moderators, and polyvinyl chloride or chlorinated polyvinyl chloride absorber plates.

**HEU-MET-FAST-102:** This experiment used HEU Jemima plates stacked with interstitial lead, reflected by the Zeus copper and measured on Planet at NCERC, to measure lead void reactivity worth [14].

**HEU-MET-FAST-104:** This benchmark evaluates the critical configurations for the Measurement of Uranium Subcritical and Critical (MUSiC) experiments, which measured a range of subcritical and critical configurations of bare HEU nesting shells on the Planet machine at NCERC [18].

**LEU-COMP-THERM-111:** The experiments described in this benchmark were performed at SCXF to test the effects of molybdenum sleeves in water-reflected, water-moderated, triangular-pitched lattices of $UO_2$ fuel (6.9 wt.% enriched $^{235}$U).

**ALARM-CF-NI-SHIELD-001 (Cross listed as ALARM-CF-FE-SHIELD-002):** This evaluation benchmarks two neutron leakage measurements from a $^{252}$Cf source placed in the center of a 50 cm iron sphere and a similar nickel sphere [15]. The experiments were performed at RCR in the Czech Republic.

**ALARM-CF-SST-SHIELD-002:** This evaluation benchmarks a neutron leakage measurement from a $^{252}$Cf source placed in the center of large stainless steel 321 (SS321) block [15]. The experiments were performed at RCR in the Czech Republic.

## 6. CONCLUSIONS

The ICSBEP continues to deliver high-quality, reviewed evaluations of experiments relevant to the nuclear criticality safety community. As seen in the recently published and soon-to-be-published ICSBEP edition content, the last decade has seen a renewed interest in benchmarking new integral experiments and the ICSBEP content has shifted from evaluations of historical experiments to contemporaneous benchmarking of recently completed experiments.

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