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 benchmark experiments since the last update to the nuclear criticality safety (NCS) community at the 12th International Conference on Nuclear Criticality Conference held in 2023. One additional version of the ICSBEP Handbook has been published since that update, and the Technical Review Group (TRG) held two in-person meetings to review and approve additional benchmarks. The 2022 and 2023 editions of the handbook were combined into one release (published in November 2024) and contained 13 new evaluations with 46 different configurations and two major revisions to existing evaluations. The 2024 version of the handbook, currently under publication review, will contain two new evaluations with 15 new configurations and one major revision to HEU-MET-FAST-028, the evaluation of Flattop with a uranium core. The ICSBEP TRG met again in person in April 2025 to review benchmarks for the 2025 ICSBEP Handbook and final comment resolution is currently ongoing. Many of the new benchmarks represent contemporaneous experiments that have been specifically optimized to provide validation cases relevant to the NCS community. One major area of focus for new critical experiments is to target the sparsely populated intermediate energy (or resonance) region. Another focus of many of the new benchmarks is to provide experiments sensitive to different materials, such as chlorine, hafnium, tantalum, titanium, molybdenum, chromium, and polymethyl methacrylate (PMMA, or Lucite). The ICSBEP continues to deliver high-quality, peer reviewed evaluations of integral experiments relevant to the nuclear data community.

Key Words: 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 Organization 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 American nuclear criticality safety community at the 2022 Nuclear Criticality Safety Division Topical in Anaheim, California, one edition of the ICSBEP Handbook has been published. The 2022/2023 handbook edition was released in November 2024 and was a combined release representing two years of evaluation review and approval and included 13 new evaluations with a total of 42 new configurations. Two evaluations underwent major revisions. All revised and new evaluations published in the 2022/2023 edition are further described in Sections 2 and 3 of this paper.

In April 2024, the ICSBEP TRG met Livermore, California to review benchmarks for inclusion in the 2024 ICSBEP Handbook, and two new evaluations and one major revision to an existing evaluation from that meeting have been finalized for publication. Additionally, the TRG met in April of 2025 in Ljubljana, Slovenia to review benchmarks for inclusion in the 2025 ICSBEP Handbook, provisionally approving 8 new evaluations. An overview of the 2024 and 2025 approved evaluations is provided in Sections 4 and 5 of this paper.

2 NEW PUBLISHED EVALUATIONS: 2022/2023 EDITION

The 2022/2023 editions of the handbooks contain a total of 13 new evaluations representing 42 different experimental benchmark configurations. A summary of the new 2022/2023 handbook contents and the total handbook contents Table I.

Table I: New and Total Contents of the 2022/2023 ICSBEP Handbook Edition

ICSBEP Type	New Configurations for 2022/2023	Total Configurations in Handbook
PU	7	805
HEU	15	1452
IEU	4	278
LEU	11	1827
U233	0	244
MIX (Pu/U)	0	536
SPEC (Other Actinides)	0	20
ALARM (Shielding)	4	51
FUND (Physics)	1	238

2.1 New Plutonium Evaluations

Two new plutonium (Pu) evaluations were added to the handbook. Descriptions of the new Pu evaluations are provided, below.

PU-MET-THERM-004 : This experiment was the third in the Thermal Epithermal eXperiments (TEX) series using Zero Power Physics Reactor (ZPPR) plutonium/aluminum alloy plates. This TEX-Pu variant, completed at National Criticality Experiments Research Center (NCERC), was designed with thick polyethylene and polymethyl methacrylate (PMMA, or Lucite) moderators to be sensitive to thermal scattering laws [2]. Two thicknesses of each moderator were used for a total of four configurations.

PU-MET-THERM-005: This experiment, the Chlorine Worth Study, was designed to provide a validation case for various concentrations of Pu chloride solutions [3]. The experiment was conducted at NCERC with stacks of plutonium/aluminum alloy ZPPR plates, polyethylene moderators, and polyvinyl chloride or chlorinated polyvinyl chloride absorber plates. Three configurations, each targeting a different concentration of Pu chloride solution were evaluated.

2.2 New Highly Enriched Uranium Evaluations

Four new highly enriched uranium (HEU) evaluations were added to the 2022/2023 handbook. Descriptions of the new HEU evaluations are provided, below.

HEU-MET-FAST-102: This experiment was a collaboration between the Japan Atomic Energy Agency (JAEA) and Los Alamos National Laboratory to test the void reactivity worth for lead for fast reactors. Thin HEU Jemima plates were stacked with interstitial lead, reflected by the Zeus copper, and measured on Comet at NCERC [4]. Three experiments were evaluated, one being a reference configuration and the other two with increasing lead void via the implementation of aluminum spacers.

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 [5]. The goal of this experiment was to produce a modern, high precision bare HEU benchmark. Evaluation of the subcritical configurations as fundamental physics benchmarks are planned for the future.

HEU-MET-INTER-011: The Critical Unresolved Region Integral Experiment (CURIE) was performed on Comet using the Zeus copper reflector at NCERC. It was designed to provide a test for nuclear data in the ^{235}U unresolved resonance region (URR) [4]. Polytetrafluoroethylene (PTFE, or Teflon) was used as an interstitial material between the Jemima plates to slightly moderate the neutrons into the URR and thus also provides a test for fluorine in this energy region.

HEU-MET-MIXED-021 (also cross listed as HEU-MET-FAST-103, HEU-MET-INTER-012, and HEU-MET-THERM-036): The TEX-HEU experiments were performed using Jemima plates and varying thicknesses of interstitial polyethylene to tune the neutron fission spectra from fast to thermal [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.

2.3 New Intermediate Enriched Uranium Evaluations

IEU-MET-FAST-025: This experiment was a collaboration between the Japan Atomic Energy Agency (JAEA) and LANL to test the void reactivity worth for lead for fast reactors. The experiments used a mixture of HEU and natural uranium plates (targeting an intermediate uranium enrichment) with interstitial lead stacked inside the Zeus copper reflector on the Comet vertical assembly machine [4]. Four experiments were evaluated, one being a reference configuration and the other three with increasing lead void via the implementation of aluminum spacers.

2.4 New Low Enriched Uranium Evaluations

Two new evaluations published in ICSBEP used Low Enriched Uranium (LEU) as the fissile material. Overviews of the new LEU evaluations are provided, below.

LEU-COMP-THERM-110: 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 Commissariat à l'Energie Atomique (CEA) Valduc Center in France [6]. 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. This benchmark contains six critical configurations in the third experimental MIRTE series and the Zircaloy-4-clad UO_2 (4.738 wt.%) rods were surrounded by steel or copper sleeves in either water or an aluminum block with varying degrees of moderation.

LEU-COMP-THERM-111: The experiments described in this benchmark were performed at the Sandia Critical Experiments Facility (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) [7]. Five benchmark configurations that varied in the number and placement of molybdenum sleeves around fuel rods were included.

2.5 New Alarm/Shielding Evaluations

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 [8]. The experiment was performed at the Research Centre Řež (RCR, Centrum výzkumu Řež) in the Czechia.

ALARM-CF-NI-SHIELD-001 (also 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 [8]. The experiments were performed at RCR in Czechia.

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 [8]. The experiments were performed at RCR in Czechia.

2.6 New Fundamental Physics Evaluations

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 [9]. Neutron pulses from ORELA were injected into a rectangular reactor-grade graphite pile that approximated a 70 cm cube. The time-dependent reaction rate of neutrons from the graphite pile was counted by a lithium glass scintillation detector that was placed above the pile.

3 REVISED EVALUATIONS: 2022/2023 EDITION

The 2022/2023 edition of the handbook saw 2 significant revisions to existing, approved benchmarks. Minor revisions 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. Major 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.

Table II. Details of Significant Benchmark Revisions in the 2022/2023 ICSBEP Handbook

ICSBEP Identifier	Significant Revision Notes
PU-MET-MIXED-002	• Revision to expected benchmark values and benchmark uncertainties for detailed and simplified models. • Updated figures in Section 3 to correct typographical errors • Changed many instances of “weight fraction” and “weight percent” to “mass fraction” in tables and text. • Minor change to benchmark input files for the Y+/Y- dimension of aluminum fins that does not impact k_{eff} calculation. • SCALE Keno results and input files added.
PU-SOL-THERM-028	• Revision of solution chemistry uncertainties • Added additional information about measurements • No changes to benchmark models • Added many additional sample results for updated nuclear data libraries.

4 PREPARATIONS FOR THE 2024 EDITION OF THE HANDBOOK

The ICSBEP TRG met at LLNL in Livermore, CA in April 2024 to review benchmarks for inclusion in the 2024 ICSBEP Handbook. Two new evaluations were approved and have since been finalized after resolution of all TRG comments. The approved evaluations are listed below and will be included in the upcoming 2024 edition of the ICSBEP handbook.

HEU-MET-INTER-013 (also cross listed as HEU-MET-FAST-105, HEU-MET-MIXED-022, and HEU-MET-THERM-037): This benchmark evaluates the second series of TEX-HEU experiments performed at NCERC. This series introduced hafnium plates as an interstitial diluent to the experimental stacks of HEU Jemima plates and varying thicknesses of polyethylene. Additionally, one fast unmoderated configuration was reflected on top and bottom by the hafnium plates [10]. 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.

FUND-LLNL-DT-PE-PNDA-001 (also cross listed as FUND-LLNL-DT-PE-PMMA-001): This evaluation benchmarked a series of pulsed-neutron die-away (PNDA) experiments completed at LLNL, with the goal of providing a validation for thermal neutron scattering laws. The experiment used a pulsed deuterium-tritium (D-T) neutron generator impinging on a moderating target. The neutrons scattered and thermalized within the target and were counted as a function of time using ^{3}He detectors surrounding the target. These data provide a time-decay profile of the neutron population which can be fitted to a simple exponential decay equation, with the benchmark quantity being the decay constant from the exponent, α [11]. Four high density polyethylene (HDPE) and four polymethyl methacrylate (PMMA, or Lucite) targets were evaluated.

One evaluation underwent a major revision for the 2024 handbook. The evaluation for the HEU core in the Flattop critical assembly, HEU-MET-FAST-028, underwent significant revision based on new, modern measurements and contains much more detail than the previous version of the benchmark. It is recommended to update any validation library with the new evaluation and models.

Table III. Details of Significant Benchmark Revisions in the 2024 ICSBEP Handbook

ICSBEP Identifier	Significant Revision Notes
HEU-MET-FAST-028	• Revision to expected benchmark values and benchmark uncertainties, addition of new detailed and simplified model. • Significant update to the benchmark geometry based on new measurements and data

5 PREPARATIONS FOR THE 2025 EDITION OF THE HANDBOOK

Most recently, the ICSBEP TRG met at the Jožef Stefan Institute in Ljubljana, Slovenia in April 2025 to review benchmarks for inclusion into the 2025 ICSBEP Handbook. Eight evaluations received conditional approval from the TRG, pending resolution of the comments from the meeting. The comments are currently being addressed by the evaluators, and the 2025 handbook edition will be published in the near future. The benchmarks receiving conditional approval at the April 2025 meeting are briefly described, below:

PU-MET-FAST-050: This evaluation focuses on the second series of Jupiter experiments conducted with JAEA by LANL and replaces some of the Pu/Al ZPPR plates with plates that contained a higher fraction of ^{240}Pu [11]. Like previous experiments, the goal was to measure the lead void reactivity of the assembly, which consisted of Pu/Al plates with interstitial lead reflected by copper.

HEU-MET-FAST-106: The Cerberus series of experiments used HEU Jemima plates stacked with interstitial copper surrounded by the Zeus copper reflector, measured on Comet at NCERC [13]. The experiment was designed to provide a validation case to test copper neutron scattering cross sections and the benchmark presented three cases that vary on the thickness of interstitial copper between HEU layers.

HEU-MET-THERM-038 (also cross listed as HEU-MET-INTER-014): This benchmark evaluated the third in the series of TEX-HEU experiments performed at NCERC. The TEX-Cl assemblies used the HEU Jemima plates stacked with varying levels of polyethylene moderator and plates filled with packed sodium chloride salt. The motivation for the experiments was to provide validation cases for chlorine absorption for electrorefining operations and molten salt fuel forms [14].

LEU-COMP-THERM-112: The experiments described in this benchmark were performed at SCXF to test the effects of tantalum rods in a central test region driven by a water-reflected, water-moderated, triangular-pitched lattices of UO_2 fuel (6.9 wt.% enriched ^{235}U). The experiments were a collaboration between Oak Ridge National Laboratory (ORNL) and Sandia and were designed to achieve significant sensitivity to tantalum neutron capture in the epithermal/intermediate energy range [15].

ALARM-CF-PTFE-SHIELD-001: This evaluation benchmarks a neutron leakage measurement from a ^{252}Cf source placed in the center of polytetrafluoroethylene (PTFE, or Teflon) block. Activation foils were placed at various depths inside the PTFE block and the leakage spectrum was measured using the proton recoil method [8]. The motivation for the measurements was to study neutron scattering in fluorine, particularly due to the usage of FLiNa and FLiBe salts in various nuclear applications and UF_6 being very important for uranium enrichment. The experiment was performed at the RCR.

ALARM-CF-AL-SHIELD-001: This evaluation benchmarks a neutron leakage measurement from a ^{252}Cf source placed in the center of an aluminum block. Activation foils were placed at various depths inside the block and the leakage spectrum was measured using the proton recoil method [8]. The motivation for the measurements was to study neutron scattering in aluminum due to its wide usage in the nuclear industry as an important structural component.

FUND-LLNL-DT-H2O-PNDA: This fundamental physics evaluation benchmarked the second series PNDA experiments completed at LLNL, with the goal of providing a validation for thermal neutron scattering laws [11]. Four light water targets were evaluated.

FUND-SNL-U-HE3-MULT-001: This fundamental physics benchmark evaluated neutron multiplicity measurements conducted at SCXF on high multiplication, yet subcritical water-moderated and -reflected LEU oxide fuel lattices. The configurations measured were based on a previous critical benchmark configuration from LEU-COMP-THERM-078, and the goal was to produce time series neutron count data exceeding a subcritical multiplication of 20. This threshold represents the upper limit of existing fundamental physical benchmarks for neutron multiplicity currently included in ICSBEP [16].

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 interested in benchmarking new integral experiments and the ICSBEP content has shifted from evaluations of historical experiments to contemporaneous benchmarking of recently completed experiments. Additionally, many of the new experiments included in the handbook have been specifically designed to target long-standing validation gaps applicable to the nuclear criticality safety and nuclear data communities.

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