The 2018 Edition of the ICSBEP Handbook

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INTRODUCTION

Over the past several decades, numerous experiments have been performed worldwide to support criticality safety. These experiments represent a significant investment in infrastructure, expertise, and cost, and are valuable resources of data for present and future research. These valuable assets provide the basis for recording, development, and validation of methods and nuclear data [1]. If the experimental data are lost, the high cost to repeat many of these measurements may be prohibitive.

The International Criticality Safety Benchmark Evaluation Project (ICSBEP) was established to:

1. Identify a comprehensive set of critical benchmark data and, to the extent possible, verify the data;
2. Evaluate the data and quantify overall uncertainties through various types of sensitivity analyses;
3. Compile the data into a standardized format;
4. Perform calculations of each experiment with standard criticality safety codes; and
5. Formally document the work into a single source of verified benchmark critical data.

Annually, contributors from around the world continue to collaborate in the evaluation and review of select benchmark experiments for inclusion in the *International Handbook of Evaluated Criticality Safety Benchmark Experiments* (ICSBEP Handbook) [2]. Further information regarding the ICSBEP, including highlighted criticality safety benchmark evaluations, can be found in the September and October 2003 editions of *Nuclear Science and Engineering* [3].

New and recently revised evaluations have been prepared for inclusion in the 2018 edition of the ICSBEP Handbook.

DESCRIPTION OF THE ACTUAL WORK

Recent Additions to the Handbook

A total of 26 benchmark evaluations were revised (22) or newly prepared (4) for inclusion in the ICSBEP Handbook (Table I) since the prior release of the handbook. The ICSBEP Handbook now includes data for 574 evaluations containing benchmark specifications for 4,916 critical, subcritical, or near-critical configurations, representing contributions from over 20 countries. There are a total of 7 criticality-alarm-placement/shielding evaluations containing a total of 45 benchmark configurations, and 8 fundamental physics benchmark evaluations containing a total of 215 measurements relevant to criticality safety applications. Full technical details and results can be found for the various benchmark reports in this latest edition of the ICSBEP Handbook.

Planned Evaluations for Future Publication

New benchmark evaluation activities are planned and/or ongoing for inclusion in future editions of the ICSBEP Handbook in the next few years. A few of the upcoming benchmark evaluations include the following:

- Belarus
  - GIACINT
- Brazil
  - IPEN/MB-01 with U-Mo Plates
- France
  - MIRTE, Pu Nitrate Annular Cylinders
- Japan
  - FCA IX-7 Assembly
- Slovenia
  - ASPIS-Fe Shielding Benchmark
- United States
  - 7UpCX Experiments, BeRP with CH_2/Ni Composite Reflector, BUCCX with Titanium Sleeves, FFTF Pin Criticals in Organic Moderator, GODIVA-IV Revision, ISSA Subcritical Multiplicity, KRUSTY, Lucite-Moderated and -Reflected HEU Foils, Np Subcritical Measurements, SCRαP, TEX Experiments, TRX Critical Experiments, UF_6 Cylinders, University of New Mexico AGN Reactor

RESULTS

Revised Benchmark Evaluations

Twenty-two revisions (19 minor and 3 significant) were prepared for inclusion in the 2018 edition of the ICSBEP Handbook. Minor revisions typically includes corrections to figures, tables, and/or text to clarify the benchmark. More significant revisions impact the overall results or incur changes to the benchmark model description.

Summary of Minor Revisions

- PU-SOL-THERM-039
  - Corrected the exponent for O of Case 5 in Table 3-6 from “E02” to E-02”.
- HEU-MET-FAST-073
  - Swapped fast and intermediate fission distribution values in Table 36.
- HEU-MET-FAST-083
  - Removed the verbiage “(Case 1)” from the headings of Tables 29 and 30.
- IEU-COMP-FAST-001
  - Headers of Table 27 for the second and third columns renamed as “Radial Blanket RR1” and “Radial Blanket RR2 & Matrix”, respectively.
- IEU-MET-FAST-013
  - Replaced the atom density for Mg in Table 18 for AR3 material with the value 1.52717E-4 a/b-cm.
- LEU-COMP-THERM-076
  - Corrected Figure 29: position of fuel rods and steel baffle shifted three grid positions to the left.
- LEU-COMP-THERM-080
  - In the paragraph between Tables 38 and 39, the coordinates in the text have been swapped: “x=25.43 cm, y=7.2 cm” is now “x=-7.2 cm, y=25.43 cm”, and “x=-25.43 cm, y=5.6 cm” is now “x=-5.6 cm, y=*25.43 cm”.
- LEU-COMP-THERM-096
  - Corrected Figure 33: fixed fuel rod lattice arrangement.
  - Corrected Figure 36: fixed alignment for line for “(top of model)”.
  - Corrected Figure 56: fixed fuel rod lattice arrangement
  - In the paragraph after Table 40, the coordinates in the text have been swapped: “x=32.385 cm, y=6.4 cm” is now “x=6.4 cm, y=-32.385 cm”, and “x=-32.385 cm, y=-6.4 cm” is now “x=-6.4 cm, y=32.385 cm”.
  - Updated sample calculations in Section 4 and input decks
- LEU-COMP-THERM-097
  - Corrected Figure 42: aluminum rod outer diameter (OD) is 0.638736 cm.
  - Corrected Figure 52: placement of one fuel rod updated.
  - Corrected Figure 62: added three fuel rods for a total of 1097.
- LEU-MET-THERM-003
  - Corrected Figure 3-5: the dump line radius is 22.066 cm.
- LEU-MET-THERM-005
  - Corrected Figures 1-20, 1-21, 3-5, and 3-6 and Table 1-7: Core 0 has 36 unit cells, not 31.
  - Corrected Figure 3.3 and Table 3-14: now includes control rod positions for Core 0.
- LEU-MET-THERM-006
  - Included MCNP6 sample calculations in Section 4 (Table 13.c) and input decks in Appendix A.3. These were provided by Bor Kos from Jožef Stefan Institute, Slovenia.
- LEU-MISC-THERM-001, -002, -003, and -005
  - Replaced Figure 8.a with Figure 9.a found in LEU-MISC-THERM-006 and -007.
- MIX-COMP-THERM-011
  - Corrected Figure 10: Distance from top of Fuel pin to top of Tie-rod is 34.2 cm, not 34.8 cm.
  - Corrected KENO input decks and updated Section 4 sample calculations.
- MIX-MISC-THERM-002
  - Corrected exponent of water densities in Table 19 to be “E-02” instead of “E-01”.
  - Corrected Figure 15: distance between Outer tank and Support plate should be 27.34 cm, not 27.14 cm.
  - Corrected Table 15.a: pitch is 2.5 cm, not 2 cm; the solution and stainless steel volume fractions are 18.41 % and 81.59 %, respectively, for Bottom grid outside fuel assembly.
- MIX-MISC-THERM-003
  - Various clarifications in the text.
  - Corrected Figures 8, 9, and 10: added grid diameter of 28.5 cm. Corrected critical height position.

Summary of Significant Revisions

- HEU-SOL-THERM-048
  - Reevaluated uncertainty in tygon tubing (Section 2.5.2), which effectively doubled the Δk uncertainty in all cases.
  - Number of acceptable benchmark experiment cases reduced from 20 to 11.
- LEU-COMP-THERM-072
  - Improved quality of Figures 4 and 12.
  - Provided additional data for polyethylene blocks (Section 1.3.10).
  - Updated uncertainty analysis (minor effect).
  - Updated Section 4 sample calculations.
- LEU-COMP-THERM-079
  - Minor update to array pitch.
  - Reevaluated uncertainties in fuel element ODs, array pitch, and temperature corrections.

New Benchmark Evaluations

A series of critical experiments were performed at the Westinghouse Reactor Evaluation Center (WREC) in 1965 as part of the Saxton Plutonium Program (SPP) to verify nuclear design of the Saxton partial plutonium core [4]. Seven critical loadings with UO_2 fuel (5.74 wt.% ^{235}U) were evaluated and documented in LEU-COMP-THERM-098. Fuel arrangement, number of fuel rods, rod pitch, and critical water height varied between experiments. Three configurations included either an aluminum plate, water slot, or Ag-In-Cd control rods.

The PolyTetraFluoroEthylene (PTFE) Program was designed at Institut de Radioprotection et de Sûreté Nucléaire (IRSN) in France to improve experimental validation of fluorine [5]. Two critical configurations with a single PTFE block were conducted in 2001 with UO_2 fuel (4.738 wt.% ^{235}U) in water. Benchmark k_{eff}'s of 1.0000 with uncertainties of 0.080 %Δk and 0.077 %Δk, for Cases 1 and 2, respectively, were evaluated. APOLLO2-MORET5 calculations using JEFF-3.1.1 and ENDF/B-VII.1 nuclear data libraries, and MCNP6.2 calculations using ENDF/B-VII.1, were within 1σ to 3σ of the benchmark values, and are documented in LEU-COMP-THERM-100.

A critical and supercritical loading from the Transient Experiment Critical Facility (TRACY) of the Japan Atomic Energy Agency (JAEA) using 10 % enriched uranyl nitrate solution and performed in 2001 [6] were evaluated and documented in LEU-SOL-THERM-012. Benchmark k_{eff}'s for the two experiments are 1.0046 ± 0.0002 and 1.0282 ± 0.0002, respectively.

The Fast Critical Assembly (FCA) facility from the Japan Atomic Energy Agency (JAES) in Tokai-mura has provided significant contributions to the development of fast reactors [7]. The FCA IX-7 assembly represents the fundamental configuration from which other similar cores were developed and various fission rate ratios of minor actinides were measured. The critical configuration of this assembly was evaluated with a benchmark k_{eff} of 1.0068 ± 0.0014; eigenvalue calculations using MCNP6.1.1b with JENDL-4.0 and ENDF/B-VII.1 nuclear data libraries are within 3σ of the benchmark value. This evaluation was accepted for publication in the *International Handbook of Evaluated Reactor Physics Experiments* (IRPhEP Handbook) [8] with the identifier FCA-FUND-EXP-002; because of its importance to criticality safety practitioners, the evaluation has also been adopted into the ICSBEP Handbook with the identifier IEU-MET-FAST-024.

Summary

The final revision of each evaluation and subsequent preparation of this latest edition of the ICSBEP Handbook was held between November 2017 and April 2018 following the Annual ICSBEP Technical Review Meeting in October 2017. This summary provides an overview of latest available information for criticality safety analysts. More comprehensive technical details for each evaluation is too exhaustive to include in this summary and may be found in their respective benchmark evaluations as identified in Table I.

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Table I. New and Revised Benchmark Evaluation Data in the 2018 Edition of the ICSBEP Handbook.

Evaluation ID	Evaluation Title	Status
PU-SOL-THERM-039	Plutonium Temperature Effect Program - Low Concentrated (20, 15, or 14.3 g/L) Plutonium Nitrate Solutions at Temperatures Varying from 28ºC to 40ºC	Minor Revision
HEU-MET-FAST-073	The Unmoderated ZEUS Experiment: A Cylindrical HEU Core Surrounded by a Copper Reflector	Minor Revision
HEU-MET-FAST-083	Complex Geometry Bare Oralloy (93.15 235U) Metal Annuli Experiments	Minor Revision
IEU-COMP-FAST-001	ZPR-6 Assembly 6A: A Cylindrical Assembly with Uranium Oxide Fuel and Sodium with a Thick Depleted-Uranium Blanket	Minor Revision
IEU-MET-FAST-013	ZPR-9 Assembly 1: A Cylindrical Assembly of U Metal (93% 235U) and Depleted Uranium with Aluminum Reflectors	Minor Revision
LEU-COMP-THERM-076	Light Water Moderated and Reflected Low Enriched Uranium (3 wt.% 235U) Dioxoide Rod Lattices with Ex-Core Detector Feature	Minor Revision
LEU-COMP-THERM-080	Water-Moderated Square-Pitched U(6.90)O2 Fuel Rod Lattices with 0.67 Fuel to Water Volume Ratio	Minor Revision
LEU-COMP-THERM-096	Partially-Reflected Water-Moderated Square-Pitched U(6.90)O2 Fuel Rod Lattices with 0.67 Fuel to Water Volume Ratio (0.800 cm Pitch)	Minor Revision
LEU-COMP-THERM-097	Titanium and/or Aluminum Rod-Replacement Experiments in Fully-Reflected Water-Moderated Square-Pitched U(6.90)O2 Fuel Rod Lattices with 0.67 Fuel to Water Volume Ratio (0.800 cm Pitch)	Minor Revision
LEU-MET-THERM-003	ZED-2 Reactor: Natural-Uranium Metal Fuel Assemblies in Heavy-Water	Minor Revision
LEU-MET-THERM-005	Evaluation of Kyoto University Critical Assembly Erbium Oxide Experiments	Minor Revision
LEU-MET-THERM-006	Low-Enriched Uranium (1.6% 235U) Metal Tube Arrays Water-Moderated and Water-Reflected BUGEY Program	Minor Revision
LEU-MISC-THERM-001	STACY Heterogeneous Cores: A 60-cm-Diameter Tank Containing 5%-Enriched UO2 Fuel Rods in 6%-Enriched Uranyl Nitrate Solutions, Water-Reflected	Minor Revision
LEU-MISC-THERM-002	STACY: A 60-cm-Diameter Tank Containing 5%-Enriched UO2 Fuel Rods (2.1-cm Square Lattice Pitch) in 6%-Enriched Uranyl Nitrate Solutions, Uneflected	Minor Revision
LEU-MISC-THERM-003	STACY: A 60-cm-Diameter Tank Containing 5%-Enriched UO2 Fuel Rods (1.5-cm Square Lattice Pitch) in 6%-Enriched Uranyl Nitrate Solutions	Minor Revision
LEU-MISC-THERM-004	STACY: A 60-cm-Diameter Tank Containing 5%-Enriched UO2 Fuel Rods (1.5-cm Square Lattice Pitch) in 6%-Enriched Uranyl Nitrate Solutions Poisoned with Pseudo-Fission-Product Elements	Minor Revision
LEU-MISC-THERM-005	Mixed Oxide RAPSODIE Fuel-Pin Arrays Moderated and Reflected by Water	Minor Revision
MIX-MISC-THERM-002	Mixed Oxide RAPSODIE Fuel Pin Arrays Moderated by Dilute Plutonium Nitrate Solution (9.89, 10.07, or 19.6 g Pu/L) and Reflected by Water	Minor Revision
MIX-MISC-THERM-003	Mixed-Oxide RAPSODIE Fuel-Pin Arrays Moderated by Concentrated Plutonium Nitrate Soluion (19.7 to 194 g Pu/l) and Reflected by Water	Minor Revision
HEU-SOL-THERM-048	Critical Parameters of Enriched 235U Solutions in Reflected, Interacting Arrays of Aluminum Cylinders	Revision
LEU-COMP-THERM-072	Under-Moderated 4.738-wt.%-Enriched Uranium Dioxide Fuel Rod Arrays Reflected by Water or Polyethylene	Revision
LEU-COMP-THERM-079	Water-Moderated U(4.31)O2 Fuel Rod Lattices Containing Rhodium Foils	Revision
LEU-COMP-THERM-098	Moderator-Controlled Critical Experiments with UO2-5.74 wt.% U-235 Fuel Rods	New
LEU-COMP-THERM-100	Lattice of U(4.738 wt%)O2 Rods with Polytetrafluoroethylene Block	New
LEU-SOL-THERM-012	TRACY: 3$ Super Critical State of Unreflected 10% Enriched Uranyl Nitrate Solution in a 50 cm Diameter Annular Tank	New
IEU-MET-FAST-024	FCA IX-7 Assembly Experiments: 20% Enriched Uranium Metal Core Surrounded by Depleted Uranium Metal Blanket	New