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Growth of the International Criticality Safety and Reactor Physics Experiment Evaluation Projects

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GROWTH OF THE INTERNATIONAL CRITICALITY SAFETY AND REACTOR PHYSICS EXPERIMENT EVALUATION PROJECTS

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ABSTRACT

Since the International Conference on Nuclear Criticality Safety (ICNC) 2007, the International Criticality Safety Benchmark Evaluation Project (ICSBEP) and the International Reactor Physics Experiment Evaluation Project (IRPhEP) have continued to expand their efforts and broaden their scope. Eighteen countries participated on the ICSBEP in 2007. Now, there are 20, with recent contributions from Sweden and Argentina. The IRPhEP has also expanded from eight contributing countries in 2007 to 16 in 2011. Since ICNC 2007, the contents of the "International Handbook of Evaluated Criticality Safety Benchmark Experiments[1]" have increased from 442 evaluations (38000 pages), containing benchmark specifications for 3955 critical or subcritical configurations to 533 evaluations (approximately 58000 pages), containing benchmark specifications for 4552 critical or subcritical configurations in the 2011 Edition of the *ICSBEP Handbook*. The number of criticality-alarm-placement/shielding benchmark configurations has also increased from 21 to 24 and the number of fundamental physics measurements relevant to criticality safety applications from 20 to 200. Since ICNC 2007, the contents of the "International Handbook of Evaluated Reactor Physics Benchmark Experiments[2]" have increased from 16 different experimental series that were performed at 12 different reactor facilities to 53 experimental series that were performed at 31 different reactor facilities in the 2011 edition of the *Handbook*. The status of the ICSBEP and the IRPhEP is discussed and benchmarks that have been added to the ICSBEP and IRPhEP Handbooks are highlighted.

Key Words: benchmark, experiment, ICSBEP, IRPhEP

1 INTRODUCTION

Since the International Conference on Nuclear Criticality Safety (ICNC) 2007, the International Criticality Safety Benchmark Evaluation Project (ICSBEP) and the International Reactor Physics Experiment Evaluation Project (IRPhEP) have continued to expand their efforts and broaden their scope. Eighteen countries participated on the ICSBEP in 2007. Now, there are 20, with recent contributions from Sweden and Argentina. The IRPhEP has also expanded from eight contributing countries in 2007 to 16 in 2011.

Since ICNC 2007, the contents of the "International Handbook of Evaluated Criticality Safety Benchmark Experiments[1]" have increased from 442 evaluations (38000 pages), containing benchmark specifications for 3955 critical or subcritical configurations to 533 evaluations (approximately 58000 pages), containing benchmark specifications for 4551 critical or subcritical configurations in the 2011 Edition of the *ICSBEP Handbook*. The number of criticality-alarm-placement/shielding benchmark configurations has also increased from 21 to 24 and the number of fundamental physics measurements relevant to criticality safety applications from 20 to 200.

Since ICNC 2007, the contents of the "International Handbook of Evaluated Reactor Physics Benchmark Experiments[2]" have increased from 16 different experimental series that were performed at 12 different reactor facilities to 53 experimental series that were performed at 31 different reactor facilities in the 2011 edition of the *Handbook*.

2 THE 2011 ICSBEP AND IRPhEP HANDBOOKS

Hundreds of new benchmarks have been added to the ICSBEP and IRPhEP Handbooks since ICNC 2007. These benchmarks are summarized below by the categorization assigned in the respective handbook in which they appear.

2.1 ICSBEP Handbook

The 2011 Edition of the *International Handbook of Evaluated Criticality Safety Benchmark Experiments* (ICSBEP Handbook) [1] will be published in September or October of 2011 (Fig. 1). The ICSBEP Handbook is available on DVD or on the Internet. Both the DVD version and a password to access the online version can be requested from the NEA Internet site at <http://irphep.inl.gov>.

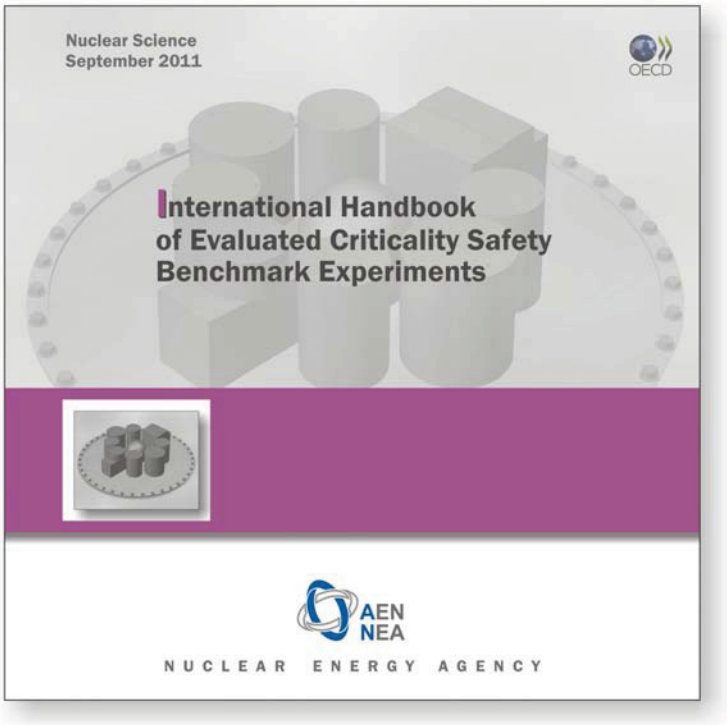

Figure 1. September 2011 Edition of the ICSBEP Handbook.

2.1.1 Recently Added ICSBEP Benchmarks

Since ICNC 2007, 596 critical or subcritical benchmark configurations from 91 experimental programs have been added to the ICSBEP Handbook. Included are 59 plutonium benchmarks, 143 high-enriched uranium benchmarks, 99 intermediate-enriched uranium benchmarks, 274 low-enriched or natural uranium benchmarks, 7 uranium-233 benchmarks, and 14 mixed uranium/plutonium benchmarks. In addition, 3 criticality/shielding benchmarks and 5 fundamental physics benchmarks containing 135 fission rate and transmission measurements and reaction rate ratios for 45 different materials have been added. Newly added benchmarks are summarized in the following subsections. (Note: The 2007 Edition of the ICSBEP Handbook was published after ICNC-2007.)

2.1.1.1 Plutonium Benchmarks

Benchmarks for plutonium systems that have been added to the ICSBEP Handbook since publication of the 2006 edition include experiments from Los Alamos National Laboratory (LANL), Pacific Northwest Laboratory (PNL), and the Rocky Flats Plant (RFP) in the United States; the Institute of Physics and Power Engineering (IPPE) in the Russian Federation; the Valduc Nuclear Center in France and the Bhaba Atomic Research Centre (BARC) in India. Newly added plutonium benchmarks are given in Table I.

TABLE I. Plutonium Benchmarks Added to the ICSBEP Handbook since Publication of the 2006 Edition

ICSBEP Identifier	Facility	Benchmark Descriptive Title
PU-MET-FAST-038	LANL	Plutonium Sphere Reflected by Beryllium
PU-MET-FAST-042	RFP	Plutonium Hemispheres Reflected by Steel and Oil
PU-MET-FAST-044	LANL	Plutonium (5.1 wt.% ^{240}Pu) Metal Sphere with Beryllium, Graphite, Aluminum, Iron, and Molybdenum Tampers and Polyethylene Reflectors
PU-MET-FAST-046	IPPE	Fast Reactor with Plutonium Metal Fuel and Mercury Coolant
PU-SOL-THERM-034	PNL	Plutonium (8.3 wt.% ^{240}Pu) Nitrate Solution with Gadolinium in Water-Reflected 24-Inch Diameter Cylinder
PU-SOL-THERM-031	VALDUC	Plutonium (19% ^{240}Pu) Nitrate Solution in a Water-Reflected Parallelepiped Tank (50x50 cm Side) Poisoned by an Array of Hafnium Plates
PU-COMP-FAST-004	BARC	PURNIMA-I: A Plutonium Oxide Fast Reactor with Axial Molybdenum and Radial Copper and Steel Reflectors

2.1.1.2 Highly Enriched Uranium Benchmarks

Benchmarks for high-enriched uranium systems that have been added to the ICSBEP Handbook since publication of the 2006 edition include experiments from LANL, Oak Ridge National Laboratory (ORNL), Bettis Atomic Power Laboratory (BAPL), Missouri University Research Reactor (MURR), and the RFP in the United States; the Russian Federal Nuclear Center Institute of Technical Physics (VNIITF) in the Russian Federation; and VALDUC and SACLAY in France. Newly added high enriched uranium benchmarks are given in Table II.

TABLE II. High-Enriched Uranium Benchmarks Added to the ICSBEP Handbook since Publication of the 2006 Edition

ICSBEP Identifier	Facility	Benchmark Descriptive Title
HEU-MET-FAST-025	VNIITF	Five Vanadium-Reflected HEU Cylinders
HEU-MET-FAST-040	VNIITF	Heterogeneous Vanadium Diluted HEU Cylinder
HEU-MET-FAST-042	VNIITF	Two Heterogeneous Vanadium Diluted and Beryllium or Beryllium Oxide Moderated HEU Cylinders
HEU-MET-FAST-043	VNIITF	HEU Cylinders Axially Reflected by Steel
HEU-MET-FAST-044	VNIITF	HEU Cylinders Axially Reflected by Aluminum
HEU-MET-FAST-049	VNIITF	Three Tungsten-Reflected HEU Cylinders
HEU-MET-FAST-050	VNIITF	Heterogeneous Tungsten-Diluted HEU Cylinder
HEU-MET-FAST-052	VNIITF	Heterogeneous Tungsten-Diluted and Beryllium- or Beryllium-Oxide-Moderated HEU Cylinder

ICSBEP Identifier	Facility	Benchmark Descriptive Title
HEU-MET-FAST-053	ORNL	Polyethylene-Reflected Arrays of HEU Metal Units Separated by Plywood, Celotex, Foamglas, or Borated Plastic Foam
HEU-MET-FAST-056	ORNL	Polyethylene-Reflected Arrays of U(93.2) Metal Separated by Vermiculite
HEU-MET-FAST-059	ORNL	Oralloy (93.15 ^{235}U) Metal Annuli with Beryllium Core
HEU-MET-FAST-069	ORNL	Oralloy (93.2 ^{235}U) Metal Cylinder with Beryllium Top Reflector
HEU-MET-FAST-080	VALDUC	Bare, Highly Enriched Uranium Fast Burst Reactor CALIBAN
HEU-MET-FAST-081	ORNL	GROTESQUE: Complex Geometric Arrangement of Unreflected HEU (93.15) Metal Pieces
HEU-MET-FAST-082	VNIITF	Three HEU Assemblies with Polyethylene Top Reflector
HEU-MET-FAST-084	LANL	HEU Metal Cylinders With Magnesium, Titanium, Aluminum, Graphite, Mild Steel, Nickel, Copper, Cobalt, Molybdenum, Natural Uranium, Tungsten, Beryllium, Aluminum Oxide, Molybdenum Carbide, and Polyethylene Reflectors
HEU-MET-FAST-085	LANL	Highly Enriched Uranium Metal Spheres Surrounded By Copper, Cast Iron, Nickel, Nickel-Copper-Zinc Alloy, Thorium, Tungsten Alloy, or Zinc Reflectors
HEU-MET-FAST-087	VNIITF	Heterogeneous Iron-Diluted HEU Cylinder
HEU-MET-FAST-088	VNIITF	Two Heterogeneous Cylinders of Highly Enriched Uranium, Polyethylene, and Steel with Polyethylene Reflector
HEU-MET-FAST-089	VNIITF	Heterogeneous Aluminum-Diluted HEU Cylinder
HEU-MET-FAST-090	VNIITF	Two Heterogeneous Cylinders of Highly Enriched Uranium, Polyethylene, and Aluminum with Polyethylene Reflector
HEU-MET-FAST-091	VNIITF	Highly Enriched Uranium Cylinder Reflected by Polyethylene
HEU-MET-THERM-032	LANL	One Dimensional Array of Highly Enriched Uranium, Moderated and Reflected by Polyethylene
HEU-MET-THERM-033	LANL	2 x 2 Polyethylene Reflected and Moderated Highly Enriched Uranium System with Rhenium
HEU-MET-THERM-034	LANL	2 x 2 x 13 Array of Highly Enriched Uranium with Ni-Cr-Mo-Gd Alloy, Moderated and Reflected by Polyethylene
HEU-MET-MIXED-015	VNIITF	Heterogeneous Cylinder of Highly Enriched Uranium, Polyethylene, and Titanium with Polyethylene Reflector
HEU-MET-MIXED-016	VNIITF	Two Heterogeneous Cylinders of Highly Enriched Uranium, Polyethylene, and Vanadium with Polyethylene Reflector
HEU-MET-MIXED-017	VNIITF	Heterogeneous Cylinder of Highly Enriched Uranium, Polyethylene, and Tungsten with Polyethylene Reflector
HEU-SOL-THERM-026	RFP	Highly Enriched Uranyl Nitrate in Annular Tanks with Concrete Reflection: 1 × 3 Line Array of Nested Pairs of Tanks
HEU-SOL-THERM-034	ORNL	Water-Moderated and -Reflected Slabs of Uranium Oxyfluoride

ICSBEP Identifier	Facility	Benchmark Descriptive Title
HEU-SOL-THERM-046	SACLAY	Highly Enriched Uranium (89.84 Wt.% ^{235}U) Sulfate Solutions Reflected by Beryllium Oxide and Graphite Proserpine Reactor - SACLAY
HEU-SOL-THERM-047	ORNL	Interaction of Unreflected Aluminum Cylinders in a Hexagonal Array Containing Uranyl Fluoride Solution
HEU-COMP-THERM-018	BAPL	D_2O Moderated Lattice of UO_2-ThO_2
SUB-HEU-MET-THERM-002	MURR	Water Moderated U (93.15 Wt.%) Aluminum Research Reactor Fuel Element Subcritical Noise Measurements with Strong Neutron Absorbing Materials
SUB-HEU-SOL-THERM-002	LANL	Subcritical Noise Measurements for Two Coaxial Cylindrical Tanks Containing 93.1% Uranyl Nitrate Solution

2.1.1.3 Intermediate and Mixed Enrichment Uranium Benchmarks

Benchmarks for intermediate and mixed enrichment uranium systems that have been added to the ICSBEP Handbook since publication of the 2006 edition include experiments from ORNL, Argonne National Laboratory-West (ANL-W), and Idaho National Laboratory (INL) in the United States; Russian Research Institute "Kurchatov Institute" (RRC KI) in the Russian Federation; Aldermaston Atomic Weapons Establishment (AWE) and Dounreay Facilities in the United Kingdom; Centro Atómico Bariloche in Argentina, and Studsvik Facilities in Sweden. Newly added intermediate and mixed enrichment uranium benchmarks are given in Table III.

TABLE III. Intermediate and Mixed Enrichment Uranium Benchmarks Added to the ICSBEP Handbook since Publication of the 2006 Edition

ICSBEP Identifier	Facility	Benchmark Descriptive Title
IEU-MET-FAST-015	ANL-W	ZPR-3 Assembly 6F: A Spherical Assembly of Highly Enriched Uranium, Depleted Uranium, Aluminum and Steel with an Average U-235 Enrichment of 47 Atom %
IEU-MET-FAST-016	ANL-W	ZPR-3 Assembly 11: A Cylindrical Assembly of Highly Enriched Uranium and Depleted Uranium with an Average U-235 Enrichment of 12 Atom % and a Depleted Uranium Reflector
IEU-MET-FAST-019	AWE	45.5% ^{235}U Pseudo-Cylindrical Metal Slabs: Bare Assemblies
IEU-MET-FAST-020	Studsvik	The FR0 Series 1: Copper-Reflected "Cylindrical" Uranium (20 % ^{235}U) Metal
IEU-MET-FAST-021	Studsvik	The FR0 Series 4: Uranium(Nat)-Reflected "Cylindrical" Uranium (20 % ^{235}U) Metal
IEU-MET-FAST-022	Studsvik	The FR0 Experiments with Diluted 20%-Enriched "Cylindrical" Uranium Metal Reflected by Copper
IEU-SOL-THERM-002	Dounreay	Bare and Water-Reflected Spheres and Hemispheres of Aqueous Uranyl Fluoride Solutions (30.45% ^{235}U)
IEU-SOL-THERM-002	Dounreay	Bare and Water-Reflected Cylinders of Aqueous Uranyl Fluoride Solutions (30.3% ^{235}U)
IEU-COMP-FAST-004	ANL-W	ZPR-3 Assembly 12: A Cylindrical Assembly of Highly Enriched Uranium, Depleted Uranium and Graphite with

ICSBEP Identifier	Facility	Benchmark Descriptive Title
		an Average U-235 Enrichment of 21 Atom %
IEU-COMP-INTER-004	ORNL	Unreflected UF_4-CF_2 Blocks with 30, 25, 18.8, and 12.5% ^{235}U
IEU-COMP-THERM-008	RRC KI	Graphite Annular Core Assemblies with Spherical Fuel Elements Containing Coated UO_2 Fuel Particles
IEU-COMP-THERM-009	INL	Power Burst Facility: U(18)O_2-CAO-ZrO_2 Fuel Rods in Water
IEU-COMP-THERM-013	INL	Fresh-Core Reload of the Neutron Radiography (NRAD) Reactor with Uranium(20)-Zirconium-Hydride Fuel
IEU-COMP-THERM-014	Centro Atómico Bariloche	RA-6 Reactor: Water Reflected, Water Moderated U(19.77)$_3Si_2$-Al Fuel Plates
IEU-COMP-MIXED-002	ORNL	Unreflected UF_4-Cf_2 Blocks with 30, 25, 18.8, and 12.5% ^{235}U

2.1.1.4 Low Enriched or Natural Uranium Benchmarks

Benchmarks for low-enriched or natural uranium systems that have been added to the ICSBEP Handbook since publication of the 2006 edition include experiments from ORNL and PNL in the United States, RRC KI in the Russian Federation, Institute de Pesquisas Energeticas e Nuclearesthe (IPEN) in Brazil, VALDUC in France, Japan Atomic Energy Agency (JAEA) in Japan, Gesellschaft für Kernenergieverwertung in Schiffbau und Schiffahrt (GKSS) in Germany, and the Nuclear Research Institute (NRI) in the Czech Republic. Newly added low-enriched or natural uranium benchmarks are given in Table IV.

TABLE IV. Low-Enriched or Natural Uranium Benchmarks Added to the ICSBEP Handbook since Publication of the 2006 Edition

ICSBEP Identifier	Facility	Benchmark Descriptive Title
LEU-MET-THERM-004	ORNL	Triangular Lattices of 2.49-cm-Diameter LEU (4.948) Rods in Water
LEU-MET-THERM-007	ORNL	Water-Moderated and Water-Reflected 0.30-in. Diameter U(4.95) Metal Rods in Square-Pitched Arrays
LEU-SOL-THERM-011	JAEA	STACY: 80-cm-Diameter Cylindrical Tank of 6%-Enriched Uranyl Nitrate Solutions
LEU-COMP-THERM-028	PNL	Water-Moderated U(4.31)O_2 Fuel Rods in Triangular Lattices with Boron, Cadmium and Gadolinium as Soluble Poisons
LEU-COMP-THERM-030	RRC KI	VVER Physics Experiments: Regular Hexagonal (1.27-cm Pitch) Lattices of Low-Enriched U(3.5 Wt.% ^{235}U)O_2 Fuel Rods in Light Water at Different Core Critical Dimensions
LEU-COMP-THERM-043	IPEN	Critical Loading Configurations of the IPEN/MB-01 Reactor with a Heavy SS-304 Reflector
LEU-COMP-THERM-044	IPEN	Critical Loading Configurations of the IPEN/MB-01 Reactor with UO_2, Stainless Steel and Copper Rods
LEU-COMP-THERM-046	IPEN	Critical Loading Configurations of the IPEN/MB-01 Reactor Considering Temperature Variations from 14°C to 85°C

ICSBEP Identifier	Facility	Benchmark Descriptive Title
LEU-COMP-THERM-053	RRC KI	VVER Physics Experiments: Regular Hexagonal (1.27 cm Pitch) Lattices of Low-Enriched U(4.4 Wt.% $^{235}U)O_2$ Fuel Rods in Light Water at Different Core Critical Dimensions
LEU-COMP-THERM-054	IPEN	Critical Loading Configurations of the IPEN/MB-01 Reactor with UO_2, and UO_2-Gd_2O_3 Rods
LEU-COMP-THERM-057	VALDUC	4.738-Wt.%-Enriched Uranium Dioxide Fuel Rod Arrays Reflected by Water in a Dry Storage Configuration
LEU-COMP-THERM-058	IPEN	Critical Loading Configurations of the IPEN/MB-01 Reactor with Large Void in the Reflector
LEU-COMP-THERM-064	RRC KI	VVER Physics Experiments: Regular Hexagonal (1.27 cm Pitch) Lattices of Low-Enriched U(2.4 Wt.% $^{235}U)O_2$ Fuel Rods in Light Water at Different Core Critical Dimensions
LEU-COMP-THERM-071	VALDUC	Low Moderated 4.738-Wt.%-Enriched Uranium Dioxide Fuel Rod Arrays
LEU-COMP-THERM-072	VALDUC	Under-Moderated 4.738-Wt.%-Enriched Uranium Dioxide Fuel Rod Arrays Reflected by Water or Polyethylene
LEU-COMP-THERM-073	VALDUC	Under-Moderated 4.738-Wt.%-Enriched Uranium Dioxide Fuel Rod Arrays Reflected by Water with Heterogeneities
LEU-COMP-THERM-081	GKSS	PWR Type UO_2 Fuel Rods with Enrichments of 3.5 and 6.6 Wt.% with Burnable Absorber (“Otto Hahn” Nuclear Ship Program, Second Core)
LEU-COMP-THERM-087	NRI	VVER Physics Experiments: Hexagonal Lattices (1.22-cm Pitch) of Low-Enriched U(3.6, 4.4 Wt.% $^{235}U)O_2$ Fuel Assemblies in Light Water with Variable Fuel-Assembly Pitch
LEU-COMP-THERM-091	IPEN	Critical Loading Configurations of the IPEN/MB-01 Reactor with UO_2, Stainless Steel and Gd_2O_3 Rods
LEU-MISC-THERM-003	JAEA	Stacy: A 60-cm-Diameter Tank Containing 5%-Enriched UO_2 Fuel Rods (1.5-Cm Square Lattice Pitch) In 6%-Enriched Uranyl Nitrate Solutions
LEU-MISC-THERM-005	JAEA	STACY: A 60-cm-Diameter Water Reflected Tank Containing 5%-Enriched UO_2 Fuel Rods (1.5-cm Square Lattice Pitch) in 6%-Enriched Uranyl Nitrate Solutions with Pseudo Fission Product Elements
LEU-MISC-THERM-006	JAEA	STACY: A 60-cm-Diameter Tank Containing 5%-Enriched UO_2 Fuel Rods (1.5-cm Square Lattice Pitch) in 6%-Enriched Uranyl Nitrate Solutions Poisoned with Gadolinium, Unreflected and Water-Reflected
LEU-MISC-THERM-007	JAEA	Stacy: A 60-cm-Diameter Tank Containing 5%-Enriched UO_2 Fuel Rods (2.5-cm Square Lattice Pitch) in 6%-Enriched Uranyl Nitrate Solutions, Unreflected and Water-Reflected

2.1.1.5 Uranium-233 Benchmarks

Benchmarks for uranium-233 systems that have been added to the ICSBEP Handbook since publication of the 2006 edition include experiments BAPL in the United States and BARC in India. Newly added uranium-233 benchmarks are given in Table V.

TABLE V. Uranium-233 Benchmarks Added to the ICSBEP Handbook since Publication of the 2006 Edition

ICSBEP Identifier	Facility	Benchmark Descriptive Title
U233-SOL-THERM-007	BARC	PURNIMA-II: U-233 Uranyl Nitrate Solution Reactor with Beryllium Oxide Reflector
U233-COMP-THERM-004	BAPL	D_2O MODERATED LATTICE of $^{233}UO_2$-$^{232}ThO_2$

2.1.1.6 Mixed Plutonium/Uranium Benchmarks

Benchmarks for mixed plutonium/uranium systems that have been added to the ICSBEP Handbook since publication of the 2006 edition include experiments from ANL and ANL-W in the United States and IPPE in the Russian Federation. Newly added mixed plutonium/uranium benchmarks are given in Table VI.

TABLE VI. Mixed Plutonium/Uranium Benchmarks Added to the ICSBEP Handbook since Publication of the 2006 Edition

ICSBEP Identifier	Facility	Benchmark Descriptive Title
MIX-MET-FAST-006	IPPE	BFS-61 Assemblies: Critical Experiments of Mixed Plutonium, Depleted Uranium, Graphite and Lead with Different Reflectors
MIX-COMP-FAST-002	ANL	ZPR-6 Assembly 7 High ^{240}Pu Core: A Cylindrical Assembly with Mixed (Pu,U)-Oxide Fuel and a Central High ^{240}Pu Zone
MIX-COMP-FAST-003	ANL-W	ZPR-3 Assemblies 48 and 48b: Cylindrical Assemblies of Mixed (Pu,U), Graphite and Sodium with a Depleted Uranium Blanket
MIX-COMP-FAST-004	ANL-W	ZPR-3 Assembly 56b: A Cylindrical Assembly of Mixed (Pu,U), Oxide and Sodium with a Nickel-Sodium Reflector
MIX-MET-FAST-006	IPPE	BFS-61 Assemblies: Critical Experiments of Mixed Plutonium, Depleted Uranium, Graphite and Lead with Different Reflectors
MIX-MET-INTER-003	ANL	ZPR-3 Assembly 54: A Cylindrical Assembly Of Plutonium Metal, Depleted Uranium And Graphite With A Thick Iron Reflector
MIX-MET-INTER-004	ANL	ZPR-3 Assembly 53: A Cylindrical Assembly of Plutonium Metal, Depleted Uranium and Graphite with a Thick Depleted Uranium Reflector
MIX-MISC-FAST-004	IPPE	BFS-97, -99 Assemblies, Part II: Critical Experiments with Heterogeneous Compositions of Plutonium, Depleted-Uranium Dioxide, and Polyethylene

2.1.1.7 Special Isotope Benchmarks

There have been no benchmarks for special isotope systems added to the ICSBEP Handbook since publication of the 2006 edition.

2.1.1.8 Criticality Alarm/Shielding Benchmarks

Criticality alarm/shielding type benchmarks that have been added to the ICSBEP Handbook since publication of the 2006 edition include experiments from Semipalatinsk Nuclear Test Site in the Russian Federation. Newly added criticality alarm/shielding benchmarks are summarized in Table VII.

TABLE VII. Criticality Alarm/Shielding Benchmarks Added to the ICSBEP Handbook since Publication of the 2006 Edition

ICSBEP Identifier	Facility	Benchmark Descriptive Title
ALARM-REAC-AIR-SKY-001	Semipalatinsk Nuclear Test Site	BAIKAL-1 Skyshine Benchmark Experiment

2.1.1.9 Fundamental Physics Measurements

Fundamental physics benchmarks that have been added to the ICSBEP Handbook since publication of the 2006 edition include experiments from the National Institute of Standards (NIST) and LLNL in the United States and IPPE and the Joint Institute of Nuclear Research (JINR) in the Russian Federation. Newly added fundamental physics benchmarks are given in Table VIII.

TABLE VIII. Fundamental Physics Benchmarks Added to the ICSBEP Handbook since Publication of the 2006 Edition

ICSBEP Identifier	Facility	Benchmark Descriptive Title
FUND-NIST-CF-MULT-FISS-002	NIST	NIST Sphere Experiments for ^{235}U, ^{239}Pu, ^{238}U, and ^{237}Np Fission Rates for Cadmium Covered Fission Chambers
FUND-LLNL-1/E-U235-TRANS-001	LLNL	Self-Shielded Fission Rates for ^{235}U
FUND-IPPE-VDG-MULT-TRANS-001	IPPE	Measurement of Fast Neutron Transmission Through Iron, Nickel, and Chromium Samples of Various Thicknesses
FUND-IPPE-FR-MULT-RRR-001	IPPE	Measurements of Reaction-Rate Ratios for Numerous Nuclides in the BR-1 Reactor
FUND-JINR-1/E-MULT-TRANS-001	JINR	Neutron Transmission Through Samples of Depleted Uranium, Highly-Enriched Uranium, and Plutonium for Determination of Resonance Self-Shielding of Total Cross Section and Fission Cross Section of ^{238}U, ^{235}U, and ^{239}Pu

2.2 IRPhEP Handbook

The 2011 Edition of the *International Handbook of Evaluated Reactor Physics Benchmark Experiments* (IRPhEP Handbook) [2] was published in March of 2011 (Fig. 2). The IRPhEP Handbook is currently available only on DVD. The DVD version of the IRPhEP Handbook can be requested from the IRPhEP Internet site at <http://irphep.inl.gov>.

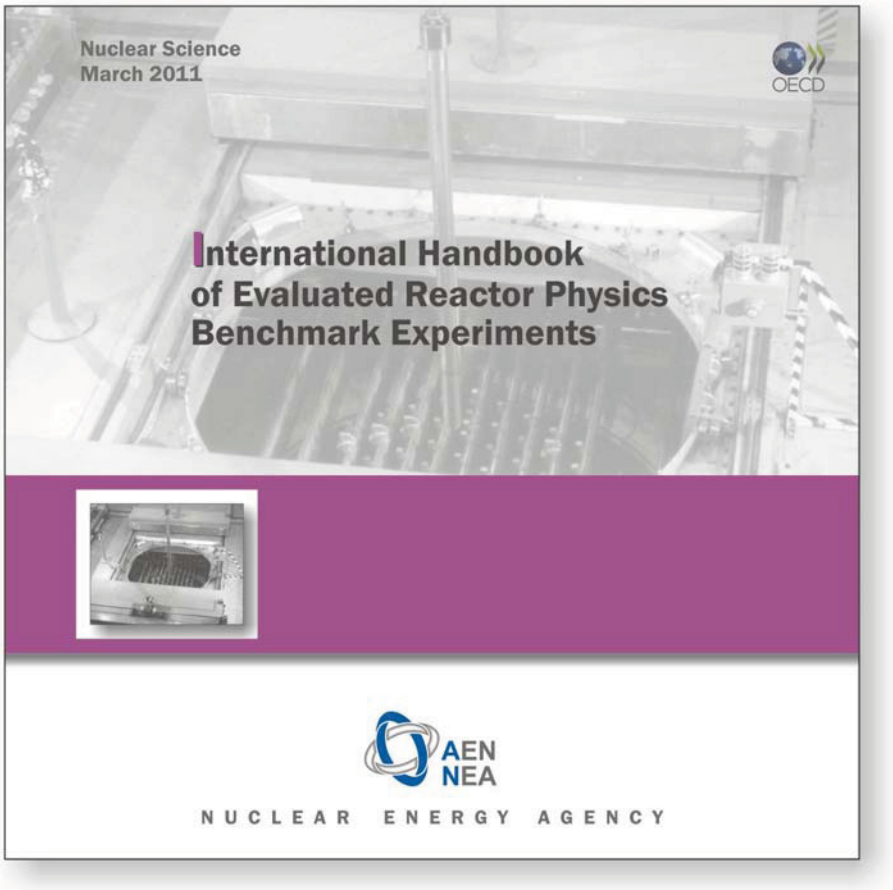

Figure 2. March 2011 Edition of the IRPhEP Handbook.

2.2.1 Recently Added IRPhEP Benchmarks

The IRPhEP was introduced as a relatively new project at ICNC 2007 in St. Petersburg, Russian Federation. The IRPhEP Handbook has been published four times since that conference. The IRPhEP Handbook includes data from three pressurized water reactors (CREOLE, SSCR, and a draft versions of VENUS); three VVER reactors (ZR6, PFACILITY, and a draft version of LR-0); eight liquid metal fast reactors (BFS-1, BFS-2, FFTF, JOYO, SNEAK, ZEBRA, ZPPR, and ZPR); four gas-cooled reactors (HTR-10, ASTRA, HTTR and VHTRC); five light-water reactors (CROCUS, DIMPLE, IPEN/MB-01, KRITZ, and TCA); two heavy-water reactors (DCA and ZED2); one RBMK reactor (RBMKCF); and five fundamental physics test reactors (ATR, NRAD, PBF, RHF, and ZEBRA). Four fundamental physics evaluations of non-fast-reactor measurements performed on BFS-1 and BFS-2 are also included. (Note: Certain experimental assemblies were constructed to simulate specific reactor types. IRPhEP identification convention refers to such experimental assemblies by the reactor types for which the experiments were intended to simulate.)

Most IRPhEP evaluations include a critical configuration; however, the main focus of this project is other reactor physics-type measurements, many of which can be used to test specific nuclear cross section data and enable refinement of those data. Such refinements can be of great importance to the criticality safety community. The IRPhEP handbook contains data and, in most cases, benchmark specifications for several reactor types as noted above. Those measurements are summarized in the following subsections.

2.2.1.1 Pressurized Water Reactor (PWR) Benchmarks

Benchmark specifications for simulated PWRs that have been added to the IRPhEP Handbook since publication of the 2007 edition include data from the Commissariat à l'Énergie Atomique

(CEA) in Cadarache, France, Studiecentrum Voor Kernenergie (SCK) Centre d'etude de L'Energie Nucleaire (CEN) in Belgium, and Babcock & Wilcox facilities in the United States. A short summary of those benchmark specifications is given in Table IX.

TABLE IX. Simulated PWR Benchmarks Added to the IRPhEP Handbook since Publication of the 2007 Edition

IRPhEP Identifier	Facility	Benchmark Descriptive Title
CREOLE-PWR-EXP-001	CEA Cadarache	CREOLE PWR Reactivity Temperature Coefficient Experiment – contains benchmark specifications for criticality, reactivity coefficients, reaction-rate distributions, and some miscellaneous aluminum over-cladding reactivity measurements
VENUS-PWR-EXP-005	SCK/CEN	Experimental Study of the VENUS-PRP Configurations No. 9 and 9/1 – contains benchmark specifications for spectral effects and power distributions
SSCR- PWR-EXP-001	B&W SSCR	B&W Spectral Shift Control Reactor (SSCR) Lattice Experiment: A 484 Uranium Rods Critical Experiment with Infinite Radial Reflector – contains benchmark specifications for criticality only

2.2.1.2 Vodo-Vodyanoi Energetichesky Reactor (VVER) Benchmarks

Benchmark specifications for VVERs or Water-Water Energetic Reactors that have been added to the IRPhEP Handbook since publication of the 2007 edition include data from Nuclear Research Institute (NRI) facilities in the Czech Republic. A short summary of those benchmark specifications is given in Table X.

TABLE X. Simulated VVER Benchmarks Added to the IRPhEP Handbook since Publication of the 2007 Edition

IRPhEP Identifier	Facility	Benchmark Descriptive Title
LR0-VVER-EXP-001 (DRAFT)	NRI LR-0	VVER Physics Experiments: Hexagonal Lattices (1.22-cm Pitch) of Low-Enriched U(2.0 – 3.3 Wt.% $^{235}U)O_2$ Fuel Assemblies in Light Water with Central Control-Assembly Mockup – contains benchmark specifications for criticality only

2.2.1.3 Liquid Metal Fast Reactor (LMFR) Benchmarks

Benchmark specifications for LMFRs that have been added to the IRPhEP Handbook since publication of the 2007 edition include data from IPPE facilities in the Russian Federation, Hanford Engineering Development Laboratory (HEDL in the United States, Forschungszentrum Karlsruhe's (FZK's) facilities in Germany, Atomic Energy Establishment Winfrith's (AEEW's) facilities in the United Kingdom, and ANL / ANL-W facilities in the United States. A short summary of those benchmark specifications is given in Table XI.

TABLE XI. Simulated Fast Reactor Benchmarks Added to the IRPhEP Handbook since Publication of the 2007 Edition

IRPhEP Identifier	Facility	Benchmark Descriptive Title
BFS1-LMFR-EXP-002	IPPE	BFS-61 Assemblies: Experimental Model of Lead-Cooled Fast Reactor with Core of Metal Plutonium-Depleted Uranium Fuel and Different Reflectors – contains benchmark specifications for criticality, spectral characteristics, and reaction-rate distributions
FFTF-LMFR-RESR-001	HEDL	Evaluation of the Initial Isothermal Physics Measurements at the Fast Flux Test Facility, a Prototypic Liquid Metal Fast Breeder Reactor – contains benchmark specifications for criticality, spectral characteristics, reactivity effects, reactivity coefficients, and gamma spectra measurements
SNEAK-LFMR-EXP-001	FZK	SNEAK 7A and 7B Pu-Fueled Fast Critical Assemblies in the Karlsruhe Fast Critical Facility – contains benchmark specifications for criticality, spectral characteristics, reactivity coefficients, kinetics measurements, and reaction-rate distributions
ZEBRA-LMFR-EXP-002	AEEW	The ZEBRA MOZART Program (MZA and MZB ZEBRA Assemblies 11 and 12) – contains benchmark specifications for criticality, spectral characteristics, reactivity effects, and reaction-rate distributions
ZEBRA-LMFR-EXP-003	AEEW	The ZEBRA MOZART Program (MZC and the Control Rod Studies for ZEBRA Assemblies 12/4 and 12/5 – contains benchmark specifications for reactivity effects and reaction-rate distributions
ZPPR-LMFR-EXP-001	ANL-W	ZPPR-10A Experiment: A 650 MWe-Class Sodium-Cooled MOX-Fueled FBR Homogeneous Core Mock-Up Critical Experiment with Two Enrichment Zones and Nineteen Control Rod Positions – contains benchmark specifications for criticality, spectral characteristics, reactivity effects, and reaction-rate distributions
ZPPR-LMFR-EXP-002	ANL-W	ZPPR-9 Experiment: A 650 MWe-Class Sodium-Cooled MOX-Fueled FBR Core Mock-Up Critical Experiment with Clean Core of Two Homogeneous Zones – contains benchmark specifications for criticality, spectral characteristics, reactivity effects, and reaction-rate distributions
ZPPR-LMFR-EXP-003	ANL-W	ZPPR-18A Experiment: A 1,000 MWe-Class Sodium-Cooled MOX-Fueled FBR Core Mock-Up Critical Experiment with Two-Homogeneous Zones and Control-Rod Withdrawal, where Enriched Uranium is Used with the Shape of a Sector in the Outer Core – contains benchmark specifications for criticality, spectral characteristics, reactivity effects, and reaction-rate distributions
ZPPR-LMFR-EXP-004	ANL-W	ZPPR-19B Experiment: A 1,000 MWe-Class Sodium-Cooled MOX-Fueled FBR Core Mock-Up Critical Experiment with Two-Homogeneous Zones and Control-Rod Withdrawal, where Plutonium and Enriched Uranium Are Used in the Outer Core – contains benchmark specifications for

IRPhEP Identifier	Facility	Benchmark Descriptive Title
		criticality, spectral characteristics, reactivity effects, and reaction-rate distributions
ZPPR-LMFR-EXP-005	ANL-W	ZPPR-10B Experiment: A 650 MWe-Class Sodium-Cooled MOX-Fueled FBR Homogeneous Core Mock-Up Critical Experiment with Two Enrichment Zones, Seven Control Rods and Twelve Control Rod Positions – contains benchmark specifications for criticality, spectral characteristics, reactivity effects, and reaction-rate distributions
ZPPR-LMFR-EXP-006	ANL-W	ZPPR-10C EXPERIMENT: A 800 MWe-Class Sodium-Cooled MOX-Fueled FBR Homogeneous Core Mock-Up Critical Experiment with Two Enrichment Zones and Nineteen Control Rod Positions – contains benchmark specifications for criticality, spectral characteristics, reactivity effects, and reaction-rate distributions
ZPPR-LMFR-EXP-007	ANL-W	ZPPR-13A Experiment: A 650 MWe-Class Sodium-Cooled MOX-Fueled FBR Radial Heterogeneous Core Mock-Up Critical Experiment with Central Blanket Zone and Two Internal Blanket Rings – contains benchmark specifications for criticality, spectral characteristics, reactivity effects, and reaction-rate distributions
ZPPR-LMFR-EXP-008	ANL-W	ZPPR-18C Experiment: A 1,000 MWe-Class Sodium-Cooled MOX-Fueled FBR Homogeneous Core Mock-Up Critical Experiment in the State of Removal of One of Eighteen Half-Inserted Control Rods, Where Enriched Uranium is Used with the Shape of a Sector in the Outer Core – contains benchmark specifications for criticality, spectral characteristics, reactivity effects, and reaction-rate distributions
ZPR-LMFR-EXP-001	ANL	ZPR-6 Assembly 7 Experiments: A Fast Reactor Core with Mixed (Pu,U)-Oxide Fuel and Sodium with a Thick Depleted Uranium Reflector – contains benchmark specifications for criticality, spectral characteristics, reactivity effects, and reaction-rate distributions
ZPR-LMFR-EXP-002	ANL	ZPR-6 Assembly 7 High ^{240}Pu Core Experiments: A Fast Reactor Core with Mixed (Pu,U)-Oxide Fuel and a Central High ^{240}Pu Zone – contains benchmark specifications for criticality, reactivity effects, and reaction-rate distributions

2.2.1.4 Gas-Cooled Reactor (GCR) Benchmarks

Benchmark specifications for GCRs that have been added to the IRPhEP Handbook since publication of the 2007 edition include data from the RRC KI facilities in the Russian Federation and JAEA facilities in Japan. A short summary of those benchmark specifications is given in Table XII.

TABLE XII. Simulated GCR Reactor Benchmarks Added to the IRPhEP Handbook since Publication of the 2007 Edition

IRPhEP Identifier	Facility	Benchmark Descriptive Title
ASTRA-GCR-EXP-001	RRC KI	Graphite Annular Core Assemblies with Spherical Fuel Elements Containing Coated UO_2 Fuel Particles – contains benchmark specifications for criticality
HTTR-GCR-RESR-001	JAEA	Evaluation of the Start-Up Core Physics Tests at Japan's High Temperature Engineering Test Reactor (Fully-Loaded Core) – contains benchmark specifications for criticality and sub-criticality, reactivity effects, and reaction-rate distributions
HTTR-GCR-RESR-002	JAEA	Evaluation of the Start-Up Core Physics Tests at Japan's High Temperature Engineering Test Reactor (Annular Core Loadings) – contains benchmark specifications for criticality, reactivity effects, and reaction-rate distributions
HTTR-GCR-RESR-003	JAEA	Evaluation of Zero-Power, Elevated-Temperature Measurements at Japan's High Temperature Engineering Test Reactor – contains benchmark specifications for criticality and reactivity coefficients
VHTRC-GCR-EXP-001 (DRAFT)	JAEA	Temperature Effect on Reactivity in VHTRC-1 Core – contains benchmark specifications for criticality and reactivity coefficients

2.2.1.5 Light-Water Moderated Reactor (LWR) Benchmarks

Benchmark specifications for LWRs that have been added to the IRPhEP Handbook since publication of the 2007 edition include data from the Swiss Federal Institute of Technology (SFIT) facilities in Switzerland, IPEN facilities in Brazil, Studsvik facilities in Sweden, and JAEA facilities in Japan. A short summary of those benchmark specifications is given in Table XIII.

TABLE XIII. Simulated LWR Reactor Benchmarks Added to the IRPhEP Handbook since Publication of the 2007 Edition

IRPhEP Identifier	Facility	Benchmark Descriptive Title
CROCUS-LWR-RESR-001	SFIT	CROCUS Reactor: Simple Two-Zone Uranium-Fueled Water-Moderated Critical Facility – contains benchmark specifications for criticality and kinetics measurements
IPEN(MB01)-LWR-RESR-001	IPEN	Reactor Physics Experiments in the IPEN/MB-01 Research Reactor Facility – contains benchmark specifications for criticality, spectral characteristics, reactivity coefficients, kinetics measurements, reaction-rate distributions, and power distributions
KRITZ-LWR-RESR-001	Studsvik	KRITZ-2:19 Experiment on Regular H_2O/Fuel Pin Lattices with Mixed Oxide Fuel at Temperatures of 21.1 and 235.9°C – contains benchmark specifications for criticality and reaction-rate distributions
KRITZ-LWR-RESR-002	Studsvik	KRITZ-2:1 Experiment on Regular H_2O/Fuel Pin Lattices with Low Enriched Uranium Fuel at a Temperature of 248.5°C – contains benchmark

		specifications for criticality and reaction-rate distributions
KRITZ-LWR-RESR-003	Studsvik	Kritz-2:13 Experiment on Regular H_2O/Fuel Pin Lattices with Low Enriched Uranium Fuel at a Temperature of 243°C – contains benchmark specifications for criticality and reaction-rate distributions
TCA-LWR-EXP-001	JAEA	Temperature Effects on Reactivity in Light Water Moderated UO_2 Core with Soluble Poisons at TCA – contains benchmark specifications for reactivity coefficients

2.2.1.6 Heavy-Water Moderated Reactor (HWR) Benchmarks

Benchmark specifications for HWRs that have been added to the IRPhEP Handbook since publication of the 2007 edition include data from Atomic Energy of Canada Limited (AECL) facilities in Canada. A short summary of those benchmark specifications is given in Table XIV.

TABLE XIV. Heavy-Water Reactor Benchmarks Added to the IRPhEP Handbook since Publication of the 2007 Edition

IRPhEP Identifier	Facility	Benchmark Descriptive Title
ZED2-HWR-RESR-001	AECL	28-Element Natural UO2 Fuel Assemblies in ZED-2 – contains benchmark specifications for criticality only

2.2.1.7 Reaktor Bolshoy Moshchnosti Kanalniy (RBMK) Reactor Benchmarks

Benchmark specifications for RBMK or High Power Channel-type Reactors that have been added to the IRPhEP Handbook since publication of the 2007 edition include data from RRC KI facilities in the Russian Federation. A short summary of those benchmark specifications is given in Table XV.

TABLE XV. RBMK Benchmarks Added to the IRPhEP Handbook since Publication of the 2007 Edition

IRPhEP Identifier	Facility	Benchmark Descriptive Title
RBMKCF-RBMK-EXP-001	RRC KI	RBMK Graphite Reactor: Uniform Configurations of U(1.8, 2.0, Or 2.4% $^{235}U)O_2$ Fuel Assemblies, and Configurations of U(2.0% $^{235}U)O_2$ Assemblies with Empty Channels, Water Columns, and Boron or Thorium Absorbers, with or without Water in Channels – contains benchmark specifications for criticality only

2.2.1.8 Fundamental Physics Assembly Benchmarks

Benchmark specifications for Fundamental Physics Assemblies or Reactors that have been added to the IRPhEP Handbook since publication of the 2007 edition include data from the INL facilities in the United States, IPPE facilities in the Russian Federation, Institute Laue-Langevin (ILL) facilities in France, and AEEW facilities in the United Kingdom. A short summary of those benchmark specifications is given in Table XVI.

TABLE XVI. Fundamental Physics Benchmarks Added to the IRPhEP Handbook since Publication of the 2007 Edition

IRPhEP Identifier	Facility	Benchmark Descriptive Title
ATR-FUND-RESR-001	INL	Advanced Test Reactor: Serpentine Arrangement of Highly Enriched Water-Moderated Uranium-Aluminide Fuel Plates Reflected by Beryllium – contains benchmark specifications for criticality only
BFS1-FUND-EXP-003	IPPE	BFS-57 and BFS -59 Assemblies: Heterogeneous Compositions of Enriched-Uranium Dioxide or Plutonium, Depleted-Uranium Dioxide, and Polyethylene – contains benchmark specifications for spectral characteristics measurements
NRAD-FUND-RESR-001	INL	Fresh-Core Reload of the Neutron Radiography (NRAD) Reactor with Uranium(20)-Erbium-Zirconium-Hydride Fuel – contains benchmark specifications for criticality only
PBF-FUND-RESR-001	INL	Power Burst Facility: U(18)O_2-CaO-ZrO_2 Fuel Rods in Water – contains benchmark specifications for criticality only
RHF-FUND-RESR-001	ILL	Evaluation of Measurements Performed on the French High Flux Reactor (RHF) – contains benchmark specifications for criticality and reactivity effects
ZEBRA-FUND-RESR-001	AEEW	K-Infinity Measurements in ZEBRA Core 8 – contains benchmark specifications for criticality and spectral characteristics measurements

2.2.1.9 BWR, GCFR, MSR, Benchmarks

There are no BWR, GCFR, or MSR benchmarks available in the IRPhEP handbook.

3 CONCLUSIONS

Over 400 scientists from 24 different countries have combined their efforts to produce the ICSBEP and IRPhEP handbooks. These two handbooks continue to grow and provide high-quality integral benchmark data that will be of use to the criticality safety, nuclear data, and reactor physics communities for future decades.

4 ACKNOWLEDGEMENTS

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5 REFERENCES

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