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RECENT ADDITIONS OF CRITICALITY SAFETY RELATED INTEGRAL BENCHMARK DATA TO THE ICSBEP AND IRPHEP HANDBOOKS

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High-quality integral benchmark experiments have always been a priority for criticality safety. However, interest in integral benchmark data is increasing as efforts to quantify and reduce calculational uncertainties accelerate to meet the demands of future criticality safety needs to support next generation reactor and advanced fuel cycle concepts. The importance of drawing upon existing benchmark data is becoming more apparent because of dwindling availability of critical facilities worldwide and the high cost of performing new experiments. Integral benchmark data from the International Handbook of Evaluated Criticality Safety Benchmark Experiments and the International Handbook of Reactor Physics Benchmark Experiments are widely used. Benchmark data have been added to these two handbooks since the last Nuclear Criticality Safety Division Topical Meeting in Knoxville, Tennessee (September 2005). This paper highlights these additions.

I. INTRODUCTION

Since the last Nuclear Criticality Safety Division (NCSD) topical meeting in Knoxville, Tennessee (September 2005), the International Criticality Safety Benchmark Evaluation Project (ICSBEP) and the International Reactor Physics Evaluation Project (IRPhEP) have continued to expand and provide quality integral benchmark data to the international criticality safety, nuclear data, and reactor physics communities. Integral benchmark data from the *International Handbook of Evaluated Criticality Safety Benchmark Experiments (ICSBEP) Handbook*[1] and the *International Handbook of Reactor Physics Benchmark Experiments (IRPhEP) Handbook*[2] are widely used. These two handbooks are published annually in September and March, respectively. Information concerning these handbooks and the associated projects that produce them is well known and has been the topic of numerous technical papers.

Since the last NCSD topical meeting, four new editions of each handbook have been published, each of which contains numerous new types of benchmark data. The contents of the ICSBEP handbook have increased from 416 evaluations (over 32,000 pages) containing benchmark specifications for 3,642 critical or subcritical configurations and 13 criticality alarm placement/shielding configurations to over 500 evaluations (over 50,000 pages) containing benchmark specifications for nearly 4300 critical or subcritical configurations, 24 criticality-alarm-placement/shielding configurations, and 200 configurations categorized as fundamental-physics measurements that are relevant to criticality-safety applications (including estimated contents of the September 2009 edition of the ICSBEP handbook).

The IRPhEP focus is on other integral measurements, such as buckling, spectral characteristics, reactivity

effects, reactivity coefficients, kinetics measurements, reaction-rate and power distributions, nuclide compositions, and other miscellaneous types of measurements in addition to the critical configuration. When the IRPhEP was first introduced at the last NCSD Topical Meeting, the first publication of the IRPhEP handbook had not been released. The 2009 edition of the IRPhEP handbook will contains data from 36 experimental series performed at 21 different reactor facilities. Thirty-three of the 36 evaluations are approved benchmarks. The remaining three evaluations are published as draft documents only. Completion of the draft evaluations is planned for the 2010 edition, in addition to several new evaluations that are in progress.

II. BENCHMARKS ADDED TO ICSBEP AND IRPhEP HANDBOOKS SINCE 2005

Hundreds of new benchmarks have been added to the ICSBEP and IRPhEP handbooks since 2005. These benchmarks are summarized below by the categorization assigned in the respective handbook in which they appear.

II.A ICSBEP Benchmarks

Since the last NCSD Topical Meeting, 669 critical or subcritical benchmark configurations from 86 experimental programs have been added to the ICSBEP handbook. Included are 82 plutonium benchmarks, 263 high-enriched uranium benchmarks, 43 intermediate-enriched uranium benchmarks, 250 low-enriched or natural uranium benchmarks, 5 uranium-233 benchmarks, and 26 mixed uranium/plutonium benchmarks. In addition, 11 criticality/shielding benchmarks and five fundamental physics benchmarks containing 155 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.

II.A.1 Plutonium Benchmarks

Benchmarks for plutonium systems that have been added to the ICSBEP handbook since publication of the 2005 edition include experiments from Los Alamos National Laboratory (LANL) including one from the new Critical Experiments Facility (CEF) in Nevada, 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; and the Valduc and Saclay Nuclear Centers in France. Newly added plutonium benchmarks are given in Table I.

TABLE I. Plutonium Benchmarks Added to the ICSBEP Handbook Since Publication of the 2005 Edition

ICSBEP Identifier	Facility	Benchmark Descriptive Title
PU-MET-FAST-038	LANL	Plutonium Sphere Reflected by Beryllium
PU-MET-FAST-044	LANL	Plutonium (5.1 wt.% ^{240}Pu) Metal Sphere with Beryllium, Graphite, Aluminum, Iron, and Molybdenum Tampers with Polyethylene Reflectors
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-018	PNL	Water-Reflected 24-Inch Diameter Cylinder of Plutonium (42.9% ^{240}Pu) Nitrate Solution
PU-MET-FAST-042	Rocky Flats	Plutonium Hemispheres Reflected by Steel and Oil
PU-MET-FAST-046	IPPE	Fast Reactor with Plutonium Metal Fuel and Mercury Coolant
PU-SOL-THERM-030	Valduc	Water-Reflected Annular Cylinders (50/20 cm Diam.) Containing Plutonium (1.5% ^{240}Pu) Nitrate Solutions
PU-SOL-THERM-019	Saclay	Plutonium Sulfate Solutions Reflected by Beryllium Oxide and Graphite – Proserpine Reactor
PU-SOL-THERM-036	Saclay	Plutonium Nitrate Solutions Water-Reflected or Unreflected – ALECTO-1

II.A.2 High Enriched Uranium Benchmarks

Benchmarks for high enriched uranium systems that have been added to the ICSBEP handbook since publication of the 2005 edition include experiments from LANL, Oak Ridge National Laboratory (ORNL), Lawrence Livermore National Laboratory (LLNL), Argonne National Laboratory (ANL), Missouri University Research Reactor, and the RFP in the United States; the Russian Federal Nuclear Center Institute of Technical Physics (VNIITF) in the Russian Federation; the Valduc and Saclay Nuclear Centers in France; and the Institute of Atomic Energy in Poland. 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 2005 Edition

ICSBEP Identifier	Facility	Benchmark Descriptive Title
HEU-MET-FAST-047	LANL	Niobium - 1wt.% Zirconium Moderated by Polyethylene and Fueled with Highly Enriched Uranium
HEU-MET-FAST-078	LANL	HEU Metal Cylinders, Partially Reflected by Water, Polyethylene, Lucite, and Paraffin
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-086	LANL	GODIVA-IV Delayed-Critical and Static Prompt Supercritical Experiments
HEU-MET-THERM-031	LANL	2 × 2 Array of Highly Enriched Uranium, Moderated and Reflected by Polyethylene
SUB-HEU-SOL-THERM-002	LANL	Subcritical Noise Measurements for Two Coaxial Cylindrical Tanks Containing 93.1% Enriched Uranyl Nitrate Solution
HEU-MET-FAST-076	ORNL	Uranium (93.14 ^{235}U) Metal Annuli and Cylinders with Thick Polyethylene Reflectors and/or Internal Polyethylene Moderator
HEU-MET-MIXED-014	ORNL	Uranium (93.14 ^{235}U) Metal Annuli and Cylinders with Thick Polyethylene Reflectors and/or Internal Polyethylene Moderator
HEU-MET-FAST-053	ORNL	Polyethylene-Reflected Arrays of HEU Metal Units Separated By Plywood, Celotex, Foamglas, or Borated Plastic Foam
HEU-MET-FAST-077	LLNL	Unmoderated Spherical Shells of Highly Enriched Uranium Metal Reflected by Beryllium
HEU-MET-THERM-035	LLNL	Highly Enriched Uranium Metal Foils Moderated by Graphite: 'Snoopy 134'
HEU-MET-MIXED-012	ANL	ZPPR-20 Phase D: A Cylindrical Assembly Of Polyethylene-Moderated U Metal Reflected By Beryllium Oxide And Polyethylene
HEU-COMP-THERM-021	B&W	Water-reflected and Moderated Uniform Lattice Cores of Aluminum Clad Uranium Oxide and Thorium Oxide with and without Boron Poison
SUB-HEU-MET-THERM-001	MURR	Water Moderated U (93.15 wt.%) Aluminum Research Reactor Fuel Element Subcritical Noise Measurements
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
HEU-SOL-THERM-026	Rocky Flats	Highly Enriched Uranyl Nitrate in Annular Tanks with Concrete Reflection: 1 × 3 Line Arrays of Nested Pairs of Tanks
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-MIXED-016	VNIITF	Two Heterogeneous Cylinders of Highly Enriched Uranium, Polyethylene, and Vanadium with Polyethylene Reflector

HEU-MET-FAST-079	VNIITF	Five Titanium-Reflected HEU Cylinders
HEU-MET-MIXED-015	VNIITF	Heterogeneous Cylinder of Highly Enriched Uranium, Polyethylene, and Titanium With Polyethylene Reflector
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 Beryllium-Tungsten Moderated HEU Cylinders
HEU-MET-MIXED-017	VNIITF	Heterogeneous Polyethylene-Tungsten Moderated HEU Cylinders
HEU-MET-FAST-082	VNIITF	Three HEU Assemblies with Polyethylene Top Reflector
HEU-MET-FAST-080	Valduc	Bare, Highly Enriched Uranium Fast Burst Reactor, Caliban
HEU-SOL-THERM-046	Saclay	Highly Enriched Uranium (89.84 wt.% ^{235}U) Sulfate Solutions Reflected by Beryllium Oxide and Graphite – Proserpine Reactor
HEU-MET-THERM-026	IAE	Beryllium-Moderated, Graphite-Reflected Critical Experiments of Highly Enriched Uranium Tubular Fuel

II.A.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 2005 edition include experiments from ORNL, the Idaho National Laboratory (INL) in the United States; Russian Research Institute "Kurchatov Institute" (RRC KI) in the Russian Federation; the Institute of Nuclear and New Energy Technology (INET) at Tsinghua University in the Peoples Republic of China; Aldermaston Atomic Weapons Establishment in the United Kingdom; 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 2005 Edition

ICSBEP Identifier	Facility	Benchmark Descriptive Title
IEU-COMP-INTER-003	ORNL	Unreflected UF_4-CF_2 Blocks with 37.5% ^{235}U
IEU-COMP-INTER-004	ORNL	Unreflected UF_4-CF_2 Blocks with 30, 25, 18.8, and 12.5% ^{235}U
IEU-COMP-MIXED-002	ORNL	Unreflected UF_4-CF_2 Blocks with 30, 25, 18.8, and 12.5% ^{235}U
IEU-COMP-MIXED-003	ORNL	Unreflected UF_4-CF_2 Blocks with 37.5% ^{235}U
IEU-COMP-THERM-011	ORNL	Unreflected UF_4-CF_2 Blocks with 37.5% ^{235}U
IEU-COMP-THERM-009	INL	Power Burst Facility: U(18)O_2-CaO-ZrO_2 Fuel Rods in Water
IEU-COMP-THERM-008	RRC KI	Graphite Annular Core Assemblies With Spherical Fuel Elements Containing Coated UO_2 Fuel Particles
IEU-COMP-THERM-010	INET	Evaluation of the Initial Critical Configuration of the HTR-10 Pebble-Bed Reactor
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: U(nat)-reflected "cylindrical" U(20 % ^{235}U) Metal

II.A.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 2005 edition include experiments from ORNL and PNL in the United States; RRC KI in the Russian Federation; the Institute de Pesquisas Energeticas e Nuclearesthe (IPEN) in Brazil; the Valduc Nuclear Center in France; the Japan Atomic Energy Agency (JAEA) and the Power Reactor Nuclear Development Corporation (PNC) in Japan; the Nuclear Research Institute (NRI) in the Czech Republic; the Atomic Energy of Canada Limited (AECL) Chalk River Laboratories in Canada; and the Institute of Nuclear Sciences "Vinča" in Serbia. 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 2005 Edition

ICSBEP Identifier	Facility	Benchmark Descriptive Title
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-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-094	RRC KI	VVER Physics Experiments: Regular Hexagonal (1.10-cm Pitch) Two-Region Lattices of Low-Enriched U(6.5 and 4.4 wt.% ^{235}U)O_2 Fuel Rods in Light Water at Different Core Critical Dimensions
LEU-COMP-THERM-030	RRC KI	VVER Physics Experiments: Regular Hexagonal (1.27-cm pitch) Lattices of Low - Enriched U(3.5 wt. % U-235)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-089	IPEN	Critical Loading Configurations of the IPEN/MB-01 Reactor with UO_2 and Borated Stainless Steel Plates
LEU-COMP-THERM-090	IPEN	Critical Loading Configurations of the IPEN/MB-01 Reactor with UO_2 And Stainless Steel Rods
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-COMP-THERM-054	IPEN	Critical Loading Configurations of the IPEN/MB-01 Reactor with Gd_2O_3-UO_2 Fuel Rods
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	Low-Enriched (4.738 wt.% ^{235}U), Low Moderated UO_2 Rods Arrays (1.05 or 1.075-cm Square Pitch), Separated by a Variable Thickness of Water in a Tight Lattice Pitch Interaction Configuration
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-SOL-THERM-011	JAEA	STACY: 80-cm-Diameter Cylindrical Tank of 6%-Enriched Uranyl Nitrate Solutions
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
LEU-COMP-THERM-093	PNC	Deuterium Critical Assembly with 1.2% Enriched Uranium Varying Coolant Void Fraction and Lattice Pitch
LEU-COMP-THERM-086	NRI	VVER Physics Experiments: Hexagonal Lattices (1.275-cm Pitch) of Low Enriched U(3.6, 4.4 wt.% 235U)O_2 Fuel Assemblies in Light Water with H_3BO_3
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-081	ANEX	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-MET-THERM-015	Vinča	RB Reactor: Fuel Assemblies Substitution Criticality Experiments in Lattices of 2%-Enriched Uranium in Heavy Water

II.A.5 Uranium-233 Benchmarks

Benchmarks for uranium-233 systems that have been added to the ICSBEP handbook since publication of the 2005 edition include experiments from the Indira Gandhi Centre for Atomic Research (IGCAR) and the Bhaba Atomic Research Centre (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 2005 Edition

ICSBEP Identifier	Facility	Benchmark Descriptive Title
U233-MET-THERM-001	IGCAR	Kalpakkam Mini (KAMINI) Reactor: Beryllium-Oxide-Reflected Water-Moderated ^{233}U-Fueled Reactor
U233-SOL-THERM-007	BARC	PURNIMA-II: ^{233}U Uranyl Nitrate Solution Reactor with Beryllium Oxide Reflector

II.A.6 Mixed Plutonium/Uranium Benchmarks

Benchmarks for mixed plutonium/uranium systems that have been added to the ICSBEP handbook since publication of the 2005 edition include experiments from ANL and PNL 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 2005 Edition

ICSBEP Identifier	Facility	Benchmark Descriptive Title
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-MISC-FAST-004	ANL	ZPR-3 Assembly 56B: A Clean, Cylindrical Plutonium Oxide Benchmark Assembly Reflected by Nickel
MIX-COMP-FAST-003	ANL	ZPR-3 Assemblies 48 and 48B: A Clean Cylindrical Pu /U/C/Na Cores, Reflected by Depleted Uranium
MIX-SOL-THERM-010	PNL	Water-Reflected Plutonium-Uranyl Nitrate Solution Containing Boron And Gadolinium
MIX-MISC-FAST-002	IPPE	BFS-49 Assemblies: Critical Experiments with Heterogeneous Compositions of Plutonium, Depleted-Uranium Dioxide, and Polyethylene
MIX-MISC-FAST-003	IPPE	BFS-97, -99, -101 Assemblies: Critical Experiments with Heterogeneous Compositions of Plutonium, Depleted-Uranium Dioxide, and Polyethylene
MIX-MISC-MIXED-001	IPPE	BFS-97, -99, -101 Assemblies: Critical Experiments With Heterogeneous Compositions of Plutonium, Depleted-Uranium Dioxide, and Polyethylene

II.A.7 Special Isotope Benchmarks

There have been no benchmarks for special isotope systems added to the ICSBEP handbook since publication of the 2005 edition.

II.A.8 Criticality Alarm/Shielding Benchmarks

Criticality alarm/shielding type benchmarks that have been added to the ICSBEP Handbook since publication of the 2005 edition include experiments from IPPE and the 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 2005 Edition

ICSBEP Identifier	Facility	Benchmark Descriptive Title
ALARM-CF-PB-SHIELD-001	IPPE	Neutron and Photon Leakage Spectra from ^{252}Cf Source at Centers of Lead Spheres of Various Diameters
ALARM-REAC-AIR-SKY-001	Semipalatinsk Nuclear Test Site	BAIKAL-1 Skyshine Benchmark Experiment

II.A.9 Fundamental Physics Measurements

Fundamental physics benchmarks that have been added to the ICSBEP handbook since publication of the 2005 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 2005 Edition

ICSBEP Identifier	Facility	Benchmark Descriptive Title
FUND-NIST-CF-MULT-FISS-001	NIST	NIST Sphere Experiments for ^{235}U, ^{239}Pu, ^{238}U, and ^{237}Np Fission Rates
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

II.B New IRPhEP Benchmarks

The IRPhEP was introduced as a new project at the last NCSD Topical Meeting. The IRPhEP handbook has been published four times since that meeting, the latest being March of 2009. This handbook includes evaluated data from seven liquid metal fast reactors (JOYO, BFS-1, BFS-2, ZPPR, ZEBRA, ZPR, and SNEAK), three gas-cooled reactors (HTR-10, ASTRA, and HTTR), two heavy-water reactors (DCA and HFR), four light-water reactors (DIMPLE, CROCUS, IPEN MB-01, and TCA), two simulated pressurized water reactors (VENUS and CREOLE), two VVER reactors (ZR6 and PFACILITY) and one fundamental physics test reactor (ATR). 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. These measurements are summarized in the following subsections.

II.B.1 PWR Reactor Benchmarks

Benchmark specifications for experiments performed at the EOLE facility at CEA Cadarache in France are presently the only simulated PWR experiments included in the IRPhEP handbook. A short summary of these benchmark specifications is given in Table IX. Evaluation of several other simulated PWR experiments that were performed at the VENUS facility located in Belgium are in progress; however, only three appear in the handbook and they remain in DRAFT status.

TABLE IX. Simulated PWR Reactor Benchmarks Included in the IRPhEP Handbook

IRPhEP Identifier	Facility	Benchmark Descriptive Title
CREOLE-PWR-EXP-001	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

II.B.2 VVER Reactors Benchmarks

Benchmark specifications for experiments performed at two simulated VVER facilities are included in the IRPhEP handbook. These experiments were performed at the RRC KI PFACILITY in the Russian Federation and the KFKI Atomic Energy Research Institute's ZR6 facility in Hungary. A short summary of these benchmark specifications are given in Table X.

TABLE X. Simulated VVER Reactor Benchmarks Included in the IRPhEP Handbook

IRPhEP Identifier	Facility	Benchmark Descriptive Title
PFACILITY-VVER-EXP-001	RRC KI	VVER Physics Experiments: Hexagonal (1.27-cm Pitch) Lattices of U(4.4 wt.% ^{235}U)O_2 Fuel Rods in Light Water, Perturbed by Boron, Hafnium, or Dysprosium Absorber Rods, or by a Water Gap with/without Aluminum Tubes – contains benchmark specifications for criticality and reaction-rate distributions
ZR6-VVER-EXP-001	KFKI	VVER Experiments: Regular and Perturbed Hexagonal Lattices of Low-Enriched UO_2 Fuel Rods in Light Water – contains benchmark specifications for criticality, buckling measurements, spectral characteristics, reactivity effects, reactivity coefficients, and reaction-rate distributions

II.B.3 Liquid Metal Fast Reactor Benchmarks

There are benchmark specification from seven fast reactor facilities in the IRPhEP handbook, IPPE's BFS1 and BFS2 facilities in the Russian Federation, JAEA's JOYO facility in Japan, ANL's ZPR and ZPPR at facilities in the United States, Atomic Energy Establishment Winfrith's (AEEW's) ZEBRA facility in the United Kingdom, and SNEAK in Germany. Approved benchmarks are summarized in Table XI.

TABLE XI. Simulated Fast Reactor Benchmarks Included in the IRPhEP Handbook

IRPhEP Identifier	Facility	Benchmark Descriptive Title
BFS1-LMFR-EXP-001	IPPE	BFS-73-1 Assembly: Experimental Model of Sodium-Cooled Fast Reactor with Core of Metal Uranium Fuel of 18.5% Enrichment and Depleted Uranium Dioxide Blanket – contains benchmark specifications for criticality, spectral characteristics, reactivity coefficients, kinetics measurements, and reaction-rate distributions
BFS2-LMFR-EXP-001	IPPE	BFS-62-3A Assembly: Fast Reactor Core with U and U-Pu Fuel of 17% Enrichment and Partial Stainless Steel Reflector – contains benchmark specifications for criticality, spectral characteristics, reactivity coefficients, and reaction-rate distributions
JOYO-LMFR-RESR-001	JAEA	Japan's Experimental Fast Reactor JOYO MK-I Core: Sodium-Cooled Uranium-Plutonium Mixed Oxide Fueled Fast Core Surrounded by UO_2 Blanket – contains

		benchmark specifications for criticality, reactivity effects, and reactivity coefficients
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
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 criticality, spectral characteristics, reactivity effects, and reaction-rate distributions
ZEBRA-LMFR-EXP-001	AEEW	Fast Critical Experiments in Plate and Pin Geometry Form (ZEBRA Cadenza Cores, Assemblies 22, 23, 24 and 25) – contains benchmark specifications for criticality, spectral characteristics, reactivity effects, 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
SNEAK-LFMR-EXP-001	Karlsruhe	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

II.B.4 Gas-Cooled Reactor Benchmarks

Benchmark specifications for experiments performed at three GCR facilities are included in the IRPhEP handbook. These experiments were performed at INET's HTR-10 Facility in the People's Republic of China, the RRC KI ASTRA Facility in the Russian Federation, and JAEA's High Temperature Engineering Test Reactor (HTTR) in Japan. A short summary of these benchmark specifications is given in Table XII.

TABLE XII. Simulated GCR Reactor Benchmarks Included in the IRPhEP Handbook

IRPhEP Identifier	Facility	Benchmark Descriptive Title
HTR10-GCR-RESR-001	INET	Initial Critical Configuration of the HTR-10 Pebble-Bed Reactor – contains benchmark specifications for criticality (unevaluated reactivity effects data are also available)
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 only; however, data are available for subcritical configurations, reactivity effects measurements, reactivity coefficients, kinetics measurements, and reaction-rate distributions

II.B.5 Light-Water Reactor Benchmarks

Benchmark specifications for experiments performed at four LWR facilities are included in the IRPhEP Handbook. These experiments were performed at the CROCUS critical facility operated by the Swiss Federal Institute of Technology (SFIT), Switzerland; DIMPLE facility at AEEW in the United Kingdom; the IPEN MB01 Reactor in Brazil; and the KRITZ reactor operated at the Studsvik facilities in Sweden. A short summary of these benchmark specifications is given in Table XIII.

TABLE XIII. Simulated LWR Reactor Benchmarks Included in the IRPhEP Handbook

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
DIMPLE-LWR-EXP-001	AEEW	Light Water Moderated and Reflected Low Enriched Uranium (3 wt.% ^{235}U) Dioxide Rod Lattices (DIMPLE S01) – contains benchmark specifications for criticality, buckling measurements, spectral characteristics, and reaction-rate distributions (Reactivity coefficient data have been evaluated and determined to be of benchmark quality, but benchmark specifications have not been developed.)
DIMPLE-LWR-EXP-002	AEEW	Light Water Moderated and Reflected Low Enriched Uranium (3 wt.% ^{235}U) Dioxide Rod Lattices (DIMPLE S06 simulation of the core baffle, barrel, neutron shield pad and pressure vessel) – contains benchmark specifications for criticality, buckling measurements, spectral characteristics, and reaction-rate distributions
IPEN(MB01)-LWR-RESR-001	IPEN	Reactor Physics Experiments in the IPEN/MB-01 Research Reactor Facility – contains benchmark specifications for criticality, reactivity coefficients, kinetics measurements, and reaction-rate 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

II.B.6 Heavy-Water Moderated Reactor Benchmarks

Benchmark specifications for experiments performed at two heavy-water reactor facilities are included in the IRPhEP handbook. These experiments were performed in the Deuterium Critical Assembly (DCA) at the O-arai Engineering Center of the Power Reactor and Nuclear Fuel Development Corporation (PNC) in Japan and on the High Flux Reactor at the Institute Laue-Langevin (ILL) in France. A short summary of these benchmark specifications is given in Table XIV.

TABLE XIV. Heavy-Water Reactor Benchmarks Included in the IRPhEP Handbook

IRPhEP Identifier	Facility	Benchmark Descriptive Title
DCA-HWR-EXP-001	PNC	Deuterium Critical Assembly with 1.2% Enriched Uranium Varying Coolant Void Fraction and Lattice Pitch – contains benchmark specifications for criticality, spectral characteristics, and reaction-rate distributions
HFR-HWR-RESR-001	ILL	Measurements Performed on the French High Flux Reactor (HFR) – contains benchmark specifications for criticality configurations

II.B.7 Fundamental Physics Assembly Benchmarks

Benchmark specifications for four series of fundamental physics experiments performed at three research reactor facilities are included in the IRPhEP Handbook. These experiments were performed on the BFS1 and BFS2 facilities at IPPE in the Russian Federation and at the Idaho National Laboratory (INL) Advance Test Reactor (ATR) in the United States. A short summary of these benchmark specifications is given in Table XV.

TABLE XV. Fundamental Physics Benchmarks Included in the IRPhEP Handbook

IRPhEP Identifier	Facility	Benchmark Descriptive Title
BFS1-FUND-EXP-001	IPPE	BFS-97, -99, -101 Assemblies: Experimental Program on Critical Assemblies with Heterogeneous Compositions of Plutonium, Depleted-Uranium Dioxide, and Polyethylene – contains benchmark specifications for criticality, spectral characteristics, and reaction-rate distribution measurements
BFS1-FUND-EXP-002	IPPE	BFS-42 Assembly - K-Infinity Experiments for ^{238}U in a Fast Neutron Spectra: Measurements with Plutonium Mixed with Depleted Uranium Dioxide and Polyethylene – contains benchmark specifications for spectral characteristics and reaction-rate distribution measurements
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
BFS2-FUND-EXP-001	IPPE	BFS-31 Assemblies – K-Infinity Experiments for ^{238}U in a Fast Neutron Spectra: Measurements with Plutonium Mixed with Depleted Uranium Dioxide – contains benchmark specifications for spectral characteristics measurements
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

II.B.8 BWR, GCFR, MSR, and RBMK Reactor Benchmarks

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

III. 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.

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