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New Reactor Physics Benchmark Data in the March 2012 Edition of the IRPhEP Handbook

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John D. Bess
J. Blair Briggs
Jim Gulliford

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John D. Bess and J. Blair Briggs

Idaho National Laboratory, P.O. Box 1625, Idaho Falls, ID 83415
John.Bess@inl.gov, J.Briggs@inl.gov

Jim Gulliford

Organisation for Economic Co-operation and Development (OECD) Nuclear Energy Agency (NEA)
Jim.Gulliford@oecd.org

INTRODUCTION

The International Reactor Physics Experiment Evaluation Project (IRPhEP) was established to preserve integral reactor physics experimental data, including separate or special effects data for nuclear energy and technology applications. Numerous experiments that have been performed worldwide, represent a large investment of 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. If the experimental data are lost, the high cost to repeat many of these measurements may be prohibitive.

The purpose of the IRPhEP is to provide an extensively peer-reviewed set of reactor physics-related integral data that can be used by reactor designers and safety analysts to validate the analytical tools used to design next-generation reactors and establish the safety basis for operation of those reactors. Contributors from around the world collaborate in the evaluation and review of selected benchmark experiments for inclusion in the *International Handbook of Evaluated Reactor Physics Benchmark Experiments* (IRPhEP Handbook) [1]. Several new evaluations have been prepared for inclusion in the March 2012 edition of the IRPhEP Handbook.

DESCRIPTION OF THE ACTUAL WORK

Recent Additions to the Handbook

A total of 11 benchmark evaluations were revised or newly prepared for inclusion in the IRPhEP Handbook (Table I). The IRPhEP Handbook now includes data from 56 experimental series (representing 32 reactor facilities) and represents contributions from 16 countries. Of the 56 benchmarks, four are draft contributions to the handbook.

Six of the benchmark evaluations contain new information to be included in the handbook. Draft evaluations represent new information that has not been completely evaluated in time for handbook publication; however, there is a desire to preserve the experimental data and current evaluation information, making it available for public use. Benchmark revisions typically include reactor physics measurements in addition to those previously evaluated, or further clarification of prior evaluation efforts.

Planned Evaluations for Future Publication

Benchmark evaluation activities are ongoing for inclusion in future editions of the IRPhEP Handbook. The remaining HTR-PROTEUS critical core configurations (4 through 10) with possible inclusion of reactor physics measurements will encompass three additional benchmark reports (PROTEUS-GCR-EXP-002, -003, and -004). Two additional benchmark evaluations include graphite- and beryllium-reflected configurations (SCCA-FUND-EXP-002 and -003) of small space power reactor mock-up assemblies performed at the Oak Ridge Critical Experiments Facility (ORCEF). A revision to the Neutron Radiography (NRAD) Reactor benchmark report includes control rod and graphite reflector worth measurements as well as the evaluated critical configuration of the initial core critical (NRAD-FUND-RESR-001). The B&W Spectral Shift Reactor Lattice Experiments is currently being revised (SSCR-PWR-EXP-001) to include additional reactor physics measurements. The AGN-201M reactor at Idaho State University (AGN-FUND-RESR-001) is also being evaluated. One or two additional ZPR (Zero Power Reactor) or ZPPR (Zero Power Physics Reactor) benchmarks should also be included in the IRPhEP Handbook in the next publication.

RESULTS

Drafts and Revisions

Of the 11 benchmarks evaluations included in the March 2012 edition of the handbook, the two draft configurations include VVER (Vodo-Vodyanoi Energetichesky Reactor) physics experiments (criticality and reaction rate measurements) performed in the zero-power reactor LR-0 in Řež, Czech Republic and VHTRC (Very High Temperature Reactor Critical) Assembly

measurements (criticality and temperature coefficients) performed in Japan to support the neutronic design of the HTTR (High Temperature Engineering Test Reactor).

Minor revisions were made to the FFTF (Fast Flux Test Facility), RHF (French: High Flux Reactor), and ZPPR-13A benchmark reports. The FFTF revision included a correction in the benchmark model fuel densities. The RHF and ZPPR-13A revisions included updates to the benchmark model and inclusion of detailed MCNP [2] input decks, respectively.

The BFS-1 (Russian: Big Physical Facility) benchmark was revised to include fission rate ratios: $\sigma_f^{U\text{-}238}/\sigma_f^{U\text{-}235}$, $\sigma_f^{Pu\text{-}239}/\sigma_f^{U\text{-}235}$, $\sigma_f^{Np\text{-}237}/\sigma_f^{Pu\text{-}239}$, $\sigma_f^{Pu\text{-}240}/\sigma_f^{Pu\text{-}239}$, $\sigma_f^{Am\text{-}241}/\sigma_f^{Pu\text{-}239}$, $\sigma_f^{Am\text{-}243}/\sigma_f^{Pu\text{-}239}$, $\sigma_f^{Cm\text{-}244}/\sigma_f^{Pu\text{-}239}$, and $\sigma_f^{Cm\text{-}245}/\sigma_f^{Pu\text{-}239}$ for various assemblies. Most calculated values are less than 10% from the benchmark values. The exception is the Cm^{244} ratios, which calculate between 10 and 50% higher than the benchmark values. Experiments in the BFS facility (Fig. 1) in Obninsk, Russia are used to obtain neutron physics information for the design of fast reactors.

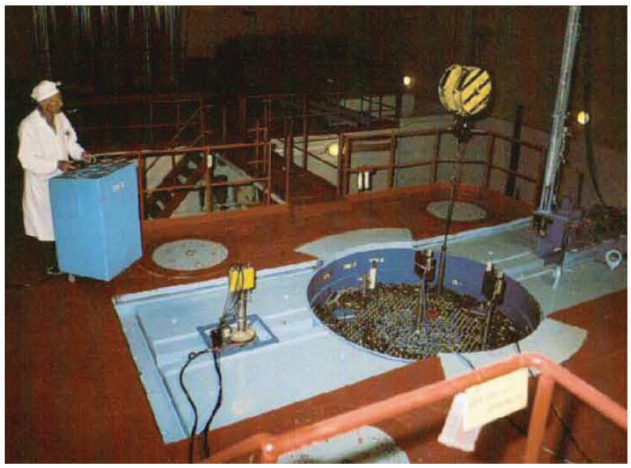

Fig. 1. Photograph of BFS-1 Facility.

The benchmark report of the IPEN/MB01 reactor (zero power critical facility in São Paulo, Brazil used to simulate light water reactor conditions; see Fig. 2) was revised to include reactivity effects measurements: control rod bank calibration, soluble boron content in the moderator, heavy reflector experiments (SS-304 and carbon steel plates), and heavy water tank reflector. Calculations of the benchmark parameters were within 10% of the benchmark values except for heavy reflector experiments using 15 or more SS-304 plates and 18 or more carbon steel plates. The ~0.3-mm-thick plates were placed in layers, flat against one vertical side of the reactor core. Worth calculations using MCNP5 and ENDF/B-VII.0 neutron cross section data were high by up to ~1500% for the SS-304 case of 21 plates (0.63 cm) and ~500% for the carbon steel case of 32 plates (0.96 cm).

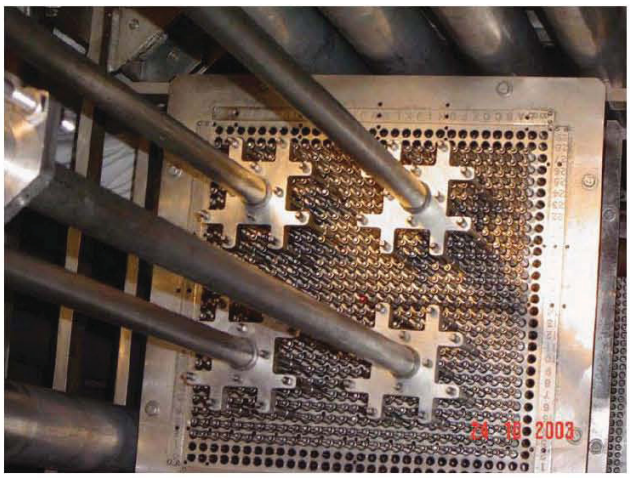

Fig. 2. Photograph of IPEN/MB-01 Core.

New Benchmark Evaluations

Four benchmark reports were added to the handbook, of which three represent facilities not previously evaluated: PROTEUS, VENUS, and SCCA (Small Compact Critical Assembly at ORCEF).

PROTEUS was a zero-power research reactor based on a cylindrical graphite annulus with central cylindrical cavity, which was located Paul Scherrer Institut in Villigen, Switzerland. The HTR-PROTEUS experimental program was conducted to provide benchmark data for assessing reactor physics computer codes for high temperature reactors. Moderator and fuel pebbles (containing 16.7 wt.% U^{235} in TRISO particles) were packed with varying arrangements within the core cavity in various moderator-to-fuel ratios. A comprehensive amount of data was measured during the course of the four-year program. Critical configurations of Cores 1, 1A, 2, and 3 (see Fig. 3), representing the hexagonal close-packed pebble arrangements with a moderator-to-fuel ratio of 1:2, were evaluated. Results from eigenvalue calculations performed using MCNP5 and ENDF/B-VII.0 are approximately 0.6 to 0.9% higher than the benchmark values. The total uncertainty in the benchmark configurations is ~0.4 $\%\Delta k_{eff}$ (1σ) with dominant contributions from uncertainties in the fuel enrichment and impurities in the moderator pebbles.

VENUS (Vulcain Experimental Nuclear Study) – PRP (Plutonium Recycle Programme) Configurations 9 and 9/1 were designed to study the boundary effects between fuel zones with different plutonium content and to investigate the influence of perturbations at the boundary. It was operated at CEN/SCK in Mol, Belgium. Currently only power distribution measurements have been evaluated, with very good agreement between CASMO-4 (JEF-2.2 neutron cross section data) and the experimental measurements.

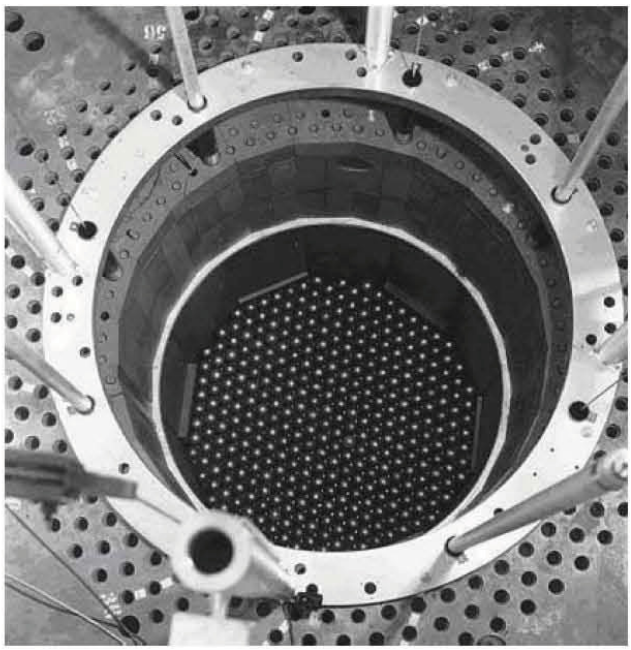

Fig. 3. Photograph of an HTR-PROTEUS Core.

The first SCCA experimental series consisted of graphite-reflected close-packed arrays of UO_2 (93.15 wt.% U^{235}) critical assemblies in support of the Medium-Power Reactor Experiments (MPRE) for the validation of reactor physics methods and calculations to design a potassium-cooled 140-kWe space power reactor (see Fig. 4). Experimental data includes two critical configurations, some worth measurements, and axial/radial fission rate measurements. Cadmium measurements were also performed but have not yet been evaluated. Monte Carlo calculations using KENO-IV [3] and MCNP5 with ENDF/B-VII.0 are approximately 0.5% high compared to the benchmark eigenvalues. There is good agreement between calculated and benchmark values for the axial fission rates; the radial fission rate calculations are approximately 10 to 20% lower than the benchmark values.

ZPPR-17A was performed as part of the JUPITER program at the former Argonne National Laboratory-West facility in Idaho. It simulated a mixed Pu/U oxide core with sodium cooling. Evaluated data include a reference critical configuration; numerous $\sigma_f^{U\text{-}235}/\sigma_f^{Pu\text{-}239}$, $\sigma_f^{U\text{-}238}/\sigma_f^{Pu\text{-}239}$, and $\sigma_c^{U\text{-}238}/\sigma_f^{Pu\text{-}239}$ reaction rate ratios; control rod worth measurements; sodium void reactivity measurements; and reaction rate distributions along the x- and y-axis. A comprehensive discussion of the calculations and comparisons with the benchmark values can be found in the benchmark report [1].

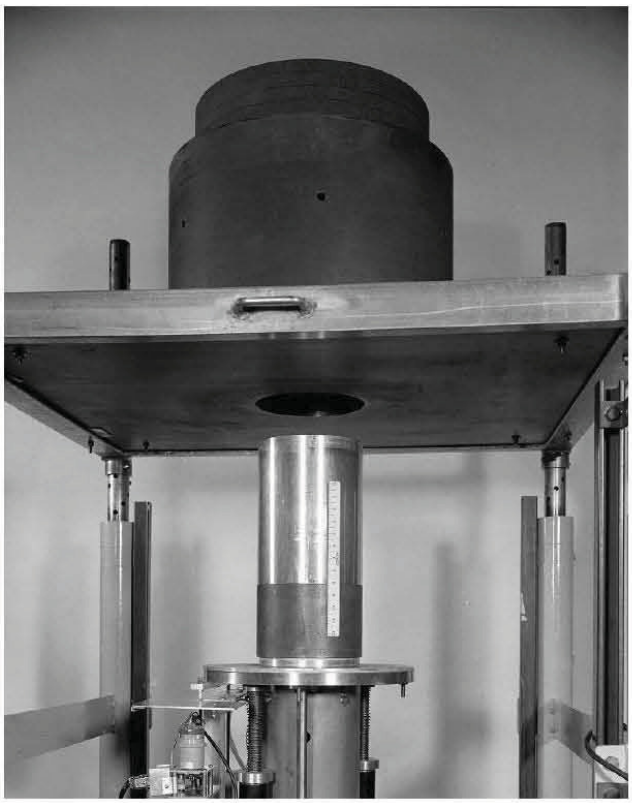

Fig. 4. Photograph of the SCCA-1 experiment assembly.

ACKNOWLEDGMENTS

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3. D. F. Hollenbach, L. M. Petrie, S. Goluoglu, N. F. Landers, M. E. Dunn, "KENO-VI: A General Quadratic Version of the KENO Program," ORNL/TM-2005/39 Version 6 Vol. II, Sect. F17, Oak Ridge National Laboratory (2009).

Table I. March 2012 Additions to the IRPhEP Handbook

Evaluation ID	Evaluation Title	Report Type
BFS1-FUND-EXP-001	BFS-97, -99, -101 Assemblies: Experimental Program on Critical Assemblies with Heterogeneous Compositions of Plutonium, Depleted-Uranium Dioxide, and Polyethylene	Revision with New Data
FFTF-LMFR-RESR-001	Evaluation of the Initial Isothermal Physics Measurements at the Fast Flux Test Facility, A Prototypic Liquid Metal Fast Breeder Reactor	Revision
IPEN/MB01-LWR-RESR-001	Reactor Physics Experiments in the IPEN/MB-01 Research Reactor Facility	Revision with New Data
LR(0)-VVER-RESR-001	VVER Physics Experiments: Hexagonal Lattices (1.22-cm Pitch) of Low-Enriched U(2.0, 3.0, 3.3 wt.% U^{235})O_2 Fuel Assemblies in Light Water with Control Rod Model	Draft
PROTEUS-GCR-EXP-001	HTR-PROTEUS Pebble Bed Experimental Program Cores 1, 1A, 2, & 3: Hexagonal Close Packing with a 1:2 Moderator-to-Fuel Pebble Ratio	New
RHF-FUND-RESR-001	Evaluation of Measurements Performed on the French High Flux Reactor (RHF)	Revision
SCCA-FUND-EXP-001	Critical Configuration and Physics Measurements for Graphite Reflected Assemblies of U(93.15)O_2 Fuel Rods (1.27-cm Pitch)	New
VENUS-PWR-EXP-005	Experimental Study of the VENUS Configuration No. 9	New
VHTRC-GCR-EXP-001	Temperature Effect on Reactivity in VHTRC-1 Core	Draft Revision
ZPPR-LMFR-EXP-007	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	Revision
ZPPR-LMFR-EXP-009	ZPPR-17A Experiment: A 650 MWe-Class Sodium-Cooled MOX-Fueled FBR Axial Heterogeneous Core Mock-Up Critical Experiment with Central Internal Blanket Zone	New