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Integral benchmark data for nuclear data testing through the ICSBEP and the newly organized IRPHEP

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Abstract. The status of the International Criticality Safety Benchmark Evaluation Project (ICSBEP) was last reported in a nuclear data conference at the International Conference on Nuclear Data for Science and Technology, ND-2004, in Santa Fe, New Mexico. Since that time the number and type of integral benchmarks have increased significantly. Included in the *ICSBEP Handbook* are criticality-alarm / shielding and fundamental physic benchmarks in addition to the traditional critical / subcritical benchmark data. Since ND 2004, a reactor physics counterpart to the ICSBEP, the International Reactor Physics Experiment Evaluation Project (IRPhEP) was initiated. The IRPhEP is patterned after the ICSBEP, but focuses 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-type measurements in addition to the critical configuration. The status of these two projects is discussed and selected benchmarks highlighted in this paper.

1. Introduction

The International Criticality Safety Benchmark Evaluation Project (ICSBEP) first published the *International Handbook of Evaluated Criticality Safety Benchmark Experiments* [1] (*ICSBEP Handbook*) in 1995. Since its publication, the availability of integral benchmarks for nuclear data testing has increased dramatically as evidenced by the level of use of the Handbook for nuclear data testing of the recently released Evaluated Nuclear Data File, ENDF/B-VII.0 [2].

Since the last International Conference on Nuclear Data for Science and Technology, ND-2004, the ICSBEP has continued to expand its efforts and broaden its scope. Criticality-alarm/shielding type benchmarks and fundamental physics measurements relevant to criticality safety applications are not only included in the scope of the project, but benchmark data are also available in the latest version of the *ICSBEP Handbook.* A considerable number of improvements have been made to the searchable database, DICE, and criticality-alarm/shielding and fundamental physics benchmarks are included. Fifteen countries participated in the ICSBEP in 2004. That number has increased to 18 with recent contributions of data and/or resources from India, Canada, and China. South Africa, Germany, Argentina, Australia, and Sweden have been invited to participate.

Since ND-2004, the number of evaluations included in the *ICSBEP Handbook* has increased from 379 (30,000 pages) containing benchmark specifications for 3,331 critical or subcritical configurations to 442 (over 38,000 pages) containing benchmark specifications for 3,955 critical or subcritical configurations, 23 criticality-alarm-placement/shielding configurations with multiple dose points for each, and 20 configurations categorized as fundamental-physics measurements that are relevant to criticality-safety applications in the 2006 Edition of the *ICSBEP Handbook*. Approximately 28 new evaluations and 150 additional configurations are expected to be added to the 2007 Edition of the *ICSBEP Handbook.*

Since ND-2004, a reactor physics counterpart to the ICSBEP, the International Reactor Physics Experiment Evaluation Project (IRPhEP), was initiated. Beginning in 1999, the IRPhEP was conducted as a pilot activity by the Organization of Economic Cooperation and Development (OECD) Nuclear Energy Agency (NEA) Nuclear Science Committee (NSC). The project was endorsed as an official activity of the NSC in June of 2003. The IRPhEP is patterned after the ICSBEP but focuses 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. The two projects are closely coordinated to avoid duplication of effort and to leverage limited resources to achieve a common goal.

The purpose of the IRPhEP is to provide an extensively peer-reviewed set of reactor physics-related integral benchmark 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 these reactors. While coordination and administration of the IRPhEP takes place at an international level, each participating country is responsible for the administration, technical direction, and priorities of the project within their respective countries.

The work of the IRPhEP is documented in an OECD NEA

handbook entitled, *International Handbook of Evaluated Reactor Physics Benchmark Experiments (IRPhEP Handbook)* [3]. The second edition of the *IRPhEP Handbook*, the March 2007 Edition, spans over 15,000 pages and contains data from 21 experimental series performed at 13 reactor facilities. This handbook includes evaluated data from five liquid metal fast reactors (JOYO, BFS-1, BFS-2, ZPPR, and ZEBRA), one gas-cooled reactor (HTR-10), one heavy-water reactor (DCA), three light-water reactors (DIMPLE, CROCUS, and IPEN MB-01), one pressurized water reactor (VENUS), and two VVER reactors (ZR6 and PFACILITY). Four fundamental physics evaluations of non-fast-reactor measurements performed on BFS-1 and BFS-2 are also included.

Seventeen of the 21 evaluations are approved benchmarks; however, three were not finalized in time for publication. The remaining four evaluations are published as draft documents only. Completion of the draft evaluations is planned for the 2008 Edition, in addition to several new evaluations that are currently in progress.

2. The 2006 ICSBEP and 2007 IRPhEP Handbooks

2.1 ICSBEP Handbook

The 2006 Edition of the *ICSBEP Handbook* [1] was published in September of 2006 "fig. 1" and 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 ICSBEP Internet site at <http://icsbep.inl.gov>.

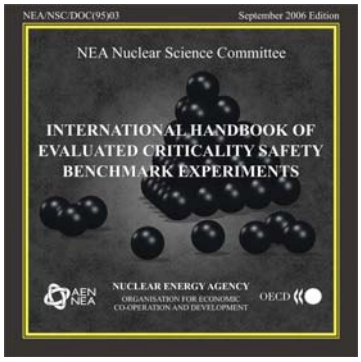

Fig. 1. September 2006 edition of the *ICSBEP Handbook*.

The 2006 Edition of the *ICSBEP Handbook* includes benchmark specifications for the following:

- 658 Pu experiments, of which 94 are metal (87 fast, 4 intermediate, 2 thermal, and 1 mixed), 529 solution (thermal), and 35 compound (6 fast, 1 intermediate, 21 thermal, and 7 mixed);
- 1,233 highly-enriched U experiments, of which 477 are metal (304 fast, 14 intermediate, 127 thermal, and 32 mixed), 466 solution (3 intermediate and 463 thermal), 283 compound (8 fast, 14 intermediate, 216 thermal, and 45 mixed), 5 mixed metal/solution (thermal), and 2 compound/solution (thermal);
- 85 intermediate- and mixed-enrichment U experiments, of which 20 are metal (fast), 5 solution (thermal), and 60 compound (2 fast, 14 intermediate, 41 thermal, and 3 mixed);
- 1,246 low-enrichment U experiments, of which 65 are metal (thermal), 104 solution (thermal), 1,066 compound (thermal), and 11 mixed compound/solution (thermal);
- 245 ^{233}U experiments, of which 11 are metal (10 fast, 1 thermal), 229 solution (192 thermal, 29 intermediate, and 8 mixed), and 5 compound (thermal);
- 468 mixed Pu-U experiments, of which 48 are metal (45 fast, 2 intermediate, and 1 mixed), 72 solution (thermal), and 276 compound (1 fast, 3 intermediate, 255 thermal, and 17 mixed), 56 mixed compound/solution systems (thermal), and 16 mixed metal/compound (8 fast and 8 mixed);
- 20 special isotope experiments, all of which are metal (fast) (^{244}Cm, ^{238}Pu, ^{237}Np, and ^{242}Pu);
- Three criticality-alarm/shielding benchmarks containing 21 configurations with numerous dose points;
- One fundamental physics benchmark, which includes 20 fission-rate measurements.

2.2 IRPhEP Handbook

The 2007 Edition of the *IRPhEP Handbook* [3] was published in March of 2007 "fig. 2" and is currently available only on DVD. The DVD version can be requested from the IRPhEP Internet site at <http://nuclear.inel.gov/irphep/>.

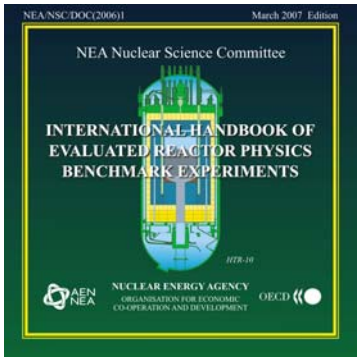

Fig. 2. March 2007 edition of the *IRPhEP Handbook.*

The *IRPhEP Handbook* contains data and, in most cases, benchmark specifications for the following:

- Two VVER reactors: PFacility-VVER-EXP-001 contains benchmark specifications for criticality, but the data provided for the reaction rates have not yet been evaluated. ZPR6-VVER-EXP-001 contains benchmark specifications for criticality, buckling measurements, spectral characteristics, reactivity effects, reactivity coefficients, and reaction-rate distributions.
- Three liquid metal fast reactors: BFS1-LMFR-EXP-001 contains benchmark specifications for criticality,

spectral characteristics, reactivity coefficients, kinetics measurements, and reaction-rate distributions. BFS2-LMFR-EXP-001 contains benchmark specifications for criticality, spectral characteristics, reactivity effects, and reaction-rate distributions. JOYO-LMFR-RESR-001 contains benchmark specifications for criticality, reactivity effects, and reactivity coefficients. Three ZEBRA benchmarks were also approved for publication; however, they were not finalized in time for publication. These three evaluations will be made available on the Internet as soon as they are finalized and will appear in the 2008 Edition of the Handbook.

- One gas-cooled reactor: HTR10-GCR-RESR-001 contains benchmark specifications for criticality, but the data provided for reactivity effects have not been evaluated.
- Four light-water reactors: DIMPLE-LWR-EXP-001 contains benchmark specifications for criticality, buckling, spectral characteristics, and reaction-rate distributions, but data provided for reactivity effects measurements were evaluated and determined to be unacceptable for use as benchmark data. Data provided for reactivity coefficients were evaluated and determined to be of benchmark quality but have not been developed into benchmark specifications. DIMPLE-LWR-EXP-002 also contains benchmark specifications for criticality, buckling, spectral characteristics, and reaction-rate distributions, but data provided for reactivity coefficient measurements were evaluated and determined to be unacceptable for use as benchmark data. CROCUS-LWR-RESR-001 contains benchmark specifications for criticality and kinetics measurements. IPEN(MB01)-LWR-RESR-001 contains benchmark specifications for criticality and reactivity coefficient measurements.
- One heavy-water moderated reactor: DCA-HWR-EXP-001 contains benchmark specifications for criticality, spectral characteristics, and reaction-rate distributions.
- Three fundamental physics assemblies: BFS1-FUND-EXP-001 contains benchmark specifications for criticality, spectral characteristics, and reaction-rate distribution measurements, but reactivity effects and kinetics measurements were not fully evaluated and currently are unacceptable for use as benchmark data. BFS1-FUND-EXP-002 contains benchmark specifications for spectral characteristics measurements and reaction-rate distributions, but measurements for criticality and reactivity effects were determined to be unacceptable for use as benchmark data. BFS2-FUND-EXP-001 contains benchmark specifications for $k\infty$ and spectral characteristics measurements, but measurements for criticality and reactivity effects were determined to be unacceptable for use as benchmark data.

Draft data are available for two pressurized water reactors (VENUS 1 and 2), four liquid metal fast reactors (one ZEBRA Cadenza evaluation, two ZEBRA Mozart evaluations, and ZPPR-10A), and one fundamental physics assembly (BFS-1).

3. New types of benchmarks available in the ICSBEP and IRPhEP handbooks

The first criticality alarm and shielding benchmarks were published in 2005, and fundamental physics measurements were introduced in 2006. Shielding type benchmarks that are particularly useful for nuclear data testing include six configurations in which a Cf source is surrounded by various thicknesses of Fe. Three similar configurations are available using various thicknesses of Pb shielding. An unshielded reference configuration is also available. Most fundamental physics measurements are very useful for nuclear data testing. The first of these types of benchmarks include 20 configurations in which a ^{252}Cf source is positioned inside a spherical region that is either void (dry) or filled with water (wet). Fission rates for ^{235}U, ^{238}U, ^{239}Pu, and ^{237}Np are measured just outside the spherical region. Measurements were made on three different-sized spherical regions (3-, 4-, and 5-inch diameter). The 2007 Edition of the *ICSBEP Handbook* will include benchmark data for additional fission-rate measurements with cadmium on the outside of the water-filled spheres, Baikal-1 Skyshine measurements, and neutron transmission measurements through ^{235}U, ^{238}U, ^{239}Pu, Fe, Cr, and Ni.

IRPhEP-evaluated measurement data that are useful for nuclear data testing generally include other integral measurements, such as buckling, spectral characteristics, reactivity effects, reactivity coefficients, kinetics measurements, reaction-rate and power distributions, nuclide compositions, and other miscellaneous-type measurements in addition to the critical configuration. These data are classified by reactor type or as fundamental physics assemblies with several possible types of measurements. One such benchmark published in the 2007 Edition of the *IRPhEP Handbook* includes spectral characteristics measurements for BFS-1 experimental reactor assemblies configured with several configurations of heterogeneous Pu, depleted-uranium dioxide, and polyethylene that were assembled in order to represent damp MOX powders. The following spectral ratios were measured:

$\sigma_f^{U\text{-}238}/\sigma_f^{U\text{-}235}$ $\quad$ $\sigma_f^{Am\text{-}241}/\sigma_f^{Pu\text{-}239}$

$\sigma_f^{Pu\text{-}239}/\sigma_f^{U\text{-}235}$ $\quad$ $\sigma_f^{Am\text{-}243}/\sigma_f^{Pu\text{-}239}$

$\sigma_f^{Np\text{-}237}/\sigma_f^{Pu\text{-}239}$ $\quad$ $\sigma_f^{Cm\text{-}244}/\sigma_f^{Pu\text{-}239}$

$\sigma_f^{Pu\text{-}240}/\sigma_f^{Pu\text{-}239}$ $\quad$ $\sigma_f^{Cm\text{-}245}/\sigma_f^{Pu\text{-}239}$

4. Conclusions

The ICSBEP continues to provide high-quality criticality safety-related benchmark data from around the world, and the project continues to grow. Eighteen countries have contributed in the past or are currently contributing to the project, and five additional countries have been invited to contribute. Approximately 500 copies of the *ICSBEP Handbook* are distributed annually. The project has expanded to include criticality alarm/shielding benchmarks and fundamental physics measurements.

Although the IRPhEP is a relatively new project, over 300 copies of the first edition of the *IRPhEP Handbook* have been distributed, and the second edition is now available. Eleven countries have directly contributed to this project. While benchmarks produced by the IRPhEP are of primary interest to the reactor physics community, many can be of significant value to the criticality safety and nuclear data communities. Benchmarks that support the Next-Generation Nuclear Plant, for example, also support fuel manufacture, handling, transportation, and storage activities and could challenge current analytical methods.

Criticality alarm/shielding benchmarks and fundamental physics measurements provided by the ICSBEP and benchmarks produced by the IRPhEP significantly expand the collection of available integral benchmarks for nuclear data testing.

The ICSBEP and IRPhEP are collaborative efforts that involve numerous scientists, engineers, administrative support personnel, and program sponsors from 20 different countries. The authors would like to acknowledge the efforts of all of these dedicated individuals without whom the ICSBEP and IRPhEP would not be possible. The authors would especially like to acknowledge the evaluators and reviewers of the benchmark data that were recently published in the 2006 Edition of the *ICSBEP Handbook* and the 2007 Edition of the *IRPhEP Handbook*, which are highlighted in this paper. The special contribution by the government of Japan in support of the IRPhEP evaluation and review activity is acknowledged.

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References

1. *International Handbook of Evaluated Criticality Safety Benchmark Experiments,* NEA/NSC/DOC(95)03/I-IX, Organization for Economic Co-operation and Development - Nuclear Energy Agency (OECD-NEA), September 2006 Edition.
2. *Special Issue on Evaluated Nuclear Data File ENDF/B-VII.0,* Nuclear Data Sheets, Volume 107, Number 12, December 2006.
3. *International Handbook of Evaluated Reactor Physics Benchmark Experiments*, NEA/NSC/DOC(2006)1, Organization for Economic Co-operation and Development - Nuclear Energy Agency (OECD-NEA), March 2007 Edition.