Status of the International Criticality Safety Benchmark Evaluation Project (ICSBEP)

J. Blair BRIGGS[1*], Ali NOURI[2], and Lori SCOTT[3]
[1] *Idaho National Engineering & Environmental Laboratory, Idaho Falls, ID 83415-3860, U.S.A.*
[2] *Organisation for Economic Cooperation and Development Nuclear Energy Agency, Paris, France*
[3] *Under Subcontract to the Idaho National Engineering & Environmental Laboratory, Pittsburgh, PA, U.S.A.*

Since ICNC'99, four new editions of the International Handbook of Evaluated Criticality Safety Benchmark Experiments have been published. The number of benchmark specifications in the Handbook has grown from 2157 in 1999 to 3073 in 2003, an increase of nearly 1000 specifications. These benchmarks are used to validate neutronics codes and nuclear cross-section data. Twenty evaluations representing 192 benchmark specifications were added to the Handbook in 2003. The status of the International Criticality Safety Benchmark Evaluation Project (ICSBEP) is provided in this paper along with a summary of the newly added benchmark specifications that appear in the 2003 Edition of the Handbook.

KEYWORDS: criticality safety data, experimental data, ICSBEP, integral benchmark data, international project, NEA, nuclear data, OECD, OECD NEA project subcritical measurements

1.0 Introduction – Change Since ICNC'99

The International Criticality Safety Benchmark Evaluation Project (ICSBEP) was initiated in 1992 by the United States Department of Energy. The ICSBEP became an official activity of the Organisation for Economic Cooperation and Development (OECD) – Nuclear Energy Agency (NEA) in 1995. The purpose of the ICSBEP is to identify, evaluate, verify, and formally document a comprehensive and internationally peer-reviewed set of criticality safety benchmark data that may be used to validate neutronics codes and nuclear cross-section data.

The work of the ICSBEP is documented in the "International Handbook of Evaluated Criticality Safety Benchmark Experiments" (Ref. 1). Since ICNC'99, four new editions of the Handbook have been published. The number of benchmark specifications in the Handbook has grown from 2157 in 1999 to 3073 in 2003, an increase of nearly 1000 specifications (Ref. 2).

In addition to new benchmark specifications, a searchable database that enables users to more effectively identify the experiments that are needed for their specific application was added to the Handbook in 2001 along with a Java-based user interface. The database has been expanded and the capabilities of the user interface improved with each publication since 2001.

The database designated DICE, also makes it easier to characterize the information generated by the ICSBEP and identify gaps and inconsistencies in the data. While the CD-ROM version of the Handbook includes a search capability that allows the user to find all occurrences of groups of words. The advanced search capabilities of the database enable users to more precisely define the experiments of interest. The user is able to search, for example, for all experiments for which a desired minimum percentage of the fissions occur in the intermediate energy range or all experiments for which the fraction of capture in ^{238}U exceeds a user-specified percentage. Plotting capabilities have been implemented into DICE that allow users to view graphical representations of neutron flux and certain reaction rates [fission, capture, (n,2n), and neutron production] in an ABBN 299-Energy-Group structure. Sensitivity coefficients for major nuclides and nuclear processes in a 30-Energy-Group structure can also be viewed graphically. DICE also allows users to download data into a delimited file structure that enables users to generate separate plots of calculated k_{eff} values versus various other parameters in the database. The database is also programmed to produce a concise, two-page summary of each configuration.

The status of the ICSBEP is summarized and a preview of the 2003 Edition of the Handbook is given in this paper.

2.0 International Participation

There were 9 countries participating on the ICSBEP in 1999 (United States, United Kingdom, France, Japan, Russian Federation, Hungary, Republic of Korea, Slovenia, and Yugoslavia). That number increased to 12 shortly thereafter (Kazakhstan, Spain, and Israel).

* Corresponding author, Tel. 1-208-526-7628, Fax. 1-208-526-2930, E-mail: bbb@inel.gov

Recently, Brazil, South Africa, and China have agreed to participate, bringing the total number of participating countries to 15. Representatives from the Instituto de Pesquisas Energéticas e Nucleares (IPEN) in Brazil will begin their efforts by contributing data from the IPEN/MB-01 low enriched light water moderated Research Reactor. Representatives from the Pebble Bed Modular Reactor (PBMR) Ltd Company in South Africa have begun their participation through a collaborative effort with scientists from the Russian Research Center "Kurchatov Institute" to contribute data from the graphite moderated pebble bed research reactor, ASTRA. Finally, representatives from the Institute of Nuclear Energy Technology at Tsinghua University in China have agree to begin their participation by contributing data from their helium-cooled, graphite-moderated pebble bed reactor, HTR-10.

The distribution, in terms of number of benchmark specifications contributed by country to the 2003 Edition of the Handbook is given in Figure 1.

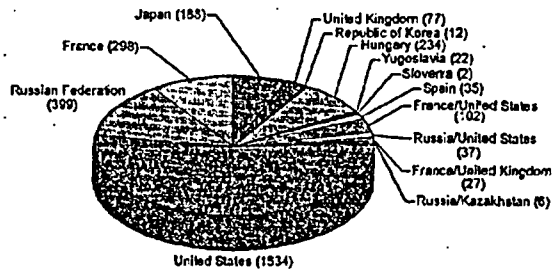

Fig. 1 Contribution of Benchmark Specifications

3.0 The 2003 Edition of the Handbook

The work of the ICSBEP is published as an OECD handbook entitled "International Handbook of Evaluated Criticality Safety Benchmark Experiments" (Ref. 1). The 2003 Edition of the Handbook spans over 28,000 pages and contains benchmark specifications for 3073 critical, near critical, or subcritical configurations from 350 experimental series. These benchmark specifications are intended for use in validation efforts and for basic nuclear data evaluations.

The 2003 Edition of the Handbook was published in September of 2003 (See Fig. 2). The handbook is available on CD-ROM or on the Internet. Both the CD-ROM version of the Handbook or a password to access the Handbook on the Internet can be requested from the ICSBEP Internet Site at: http://icsbep.inel.gov/icsbep

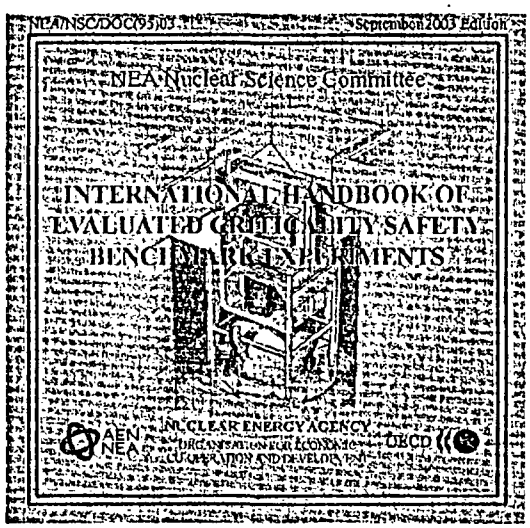

Fig. 2 September 2003 Edition

There are currently benchmark specifications for:

- 510 plutonium experiments of which 94 are Metal (87 Fast, 4 Intermediate, 2 Thermal, 1 Mixed), 381 Solution (Thermal), and 35 Compound (6 Fast, 1 Intermediate, 21 Thermal, 7 Mixed);
- 932 uranium experiments of which 320 are Metal (197 Fast, 13 Intermediate, 85 Thermal, 25 Mixed), 433 Solution (3 Intermediate, 430 Thermal), 172 Compound (24 Intermediate, 131 Thermal, 17 Mixed), 5 mixed Metal / Solution (Thermal) and 2 Compound / Solution (Thermal);
- 61 intermediate and mixed enrichment uranium experiments of which 16 are Metal (Fast), 4 Solution (Thermal), and 41 Compound (1 Fast, 2 Intermediate, 38 Thermal),
- 1029 low enriched uranium experiments of which 13 are Metal (Thermal), 90 Solution (Thermal), and 926 Compound (Thermal);
- 192 ^{233}U experiments of which 10 are Metal (Fast), 177 Solution (140 Thermal, 29 Intermediate, and 8 Mixed) and 5 Compound (Thermal);
- 331 mixed plutonium - uranium experiments of which 45 are Metal (42 Fast, 2 Intermediate, 1 Mixed), 48 Solution (Thermal), and 185 Compound (184 Thermal, 1 Fast), and 53 mixed Compound / Solution systems (Thermal); and
- 18 special isotope experiments, all of which are Metal (Fast) [^{244}Cm, ^{238}Pu, ^{237}Np, and ^{242}Pu].

4.0 Newly Contributed Benchmarks

Twenty evaluations representing 192 new benchmark specifications were added to the Handbook in 2003. A typical sketch and a short summary (included in the figure title) of the benchmarks from each evaluation are given in Figures 3 through 20. The number of cases, the author(s), and the affiliated laboratory or institute is also included in the figure titles.

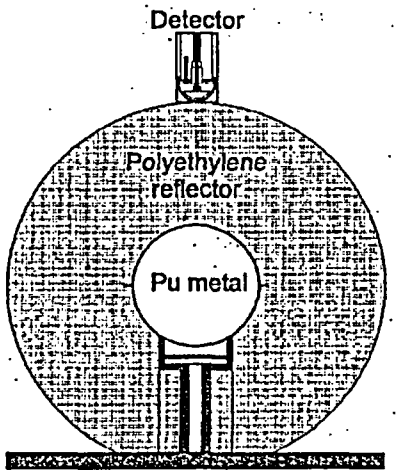

Fig. 3 Volume I: SUB-PU-MET-FAST-001, Polyethylene-Reflected Plutonium Metal Sphere Subcritical Noise Measurements, (5 Cases), *Timothy E. Valentine (Oak Ridge National Laboratory – USA).*

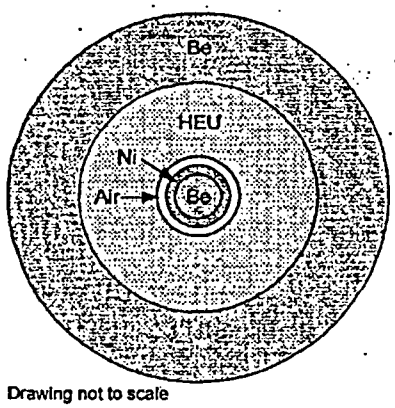

Fig. 4 Volume II: HEU-MET-FAST-058, Highly Enriched Uranium Metal Spheres with Berylium Reflectors, (5 Cases), *Dave Heinrichs (Lawrence Livermore National Laboratory - USA).*

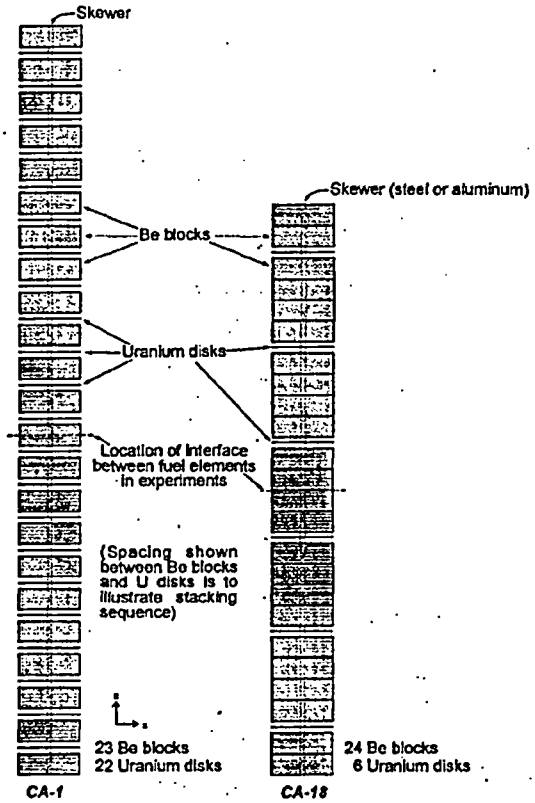

Fig. 5 Volume II: HEU-MET-INTER-015, Beryllium Moderated Critical Assemblies (ORNL CA-I and CA-18), (2 Cases), *Herbert C. Benhard, (Westinghouse Safety Management Solutions - USA).*

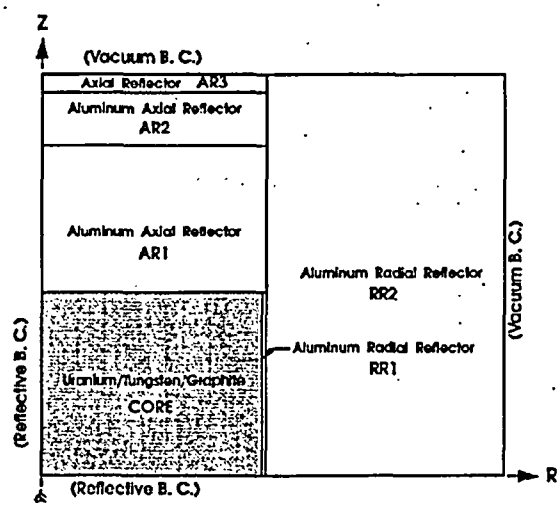

Fig. 6 Volume II: HEU-MET-FAST-067, ZPR-9 Assemblies 5 and 6: HEU (93% ^{235}U) Cylindrical Cores with Tungsten, Graphite, and Aluminum Diluents with a Dense Aluminum Reflector, (2 Cases), *Karl N. Grimm, Richard M. Lell, Micheal A. Smith, and Richard D. McKnight (Argonne National Laboratory - USA).*

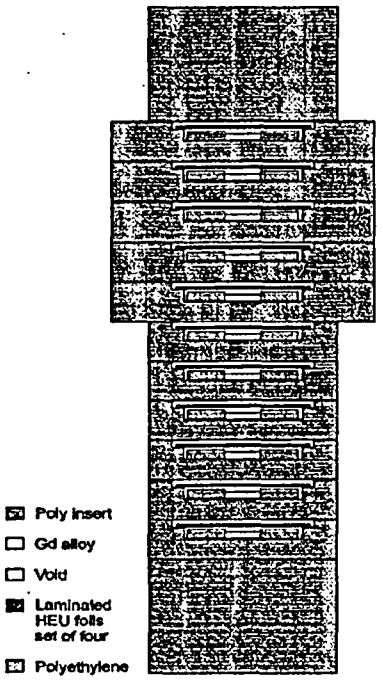

Fig. 7 Volume II: HEU-MET-THERM-016, 2 X 2 Array Experiment of Highly Enriched Uranium Foils Mixed with Ni-Cr-Mo-Gd Alloy and Moderated - Reflected by Polyethylene, (1 Case), (Two very similar evaluations, HEU-MET-THERM-013 with iron plates (2 Cases), and HEU-MET-THERM-014 with silicon dioxide plates (1 Case), are also included in the 2003 publication), *David Loaiza (Los Alamos National Laboratory - USA).*

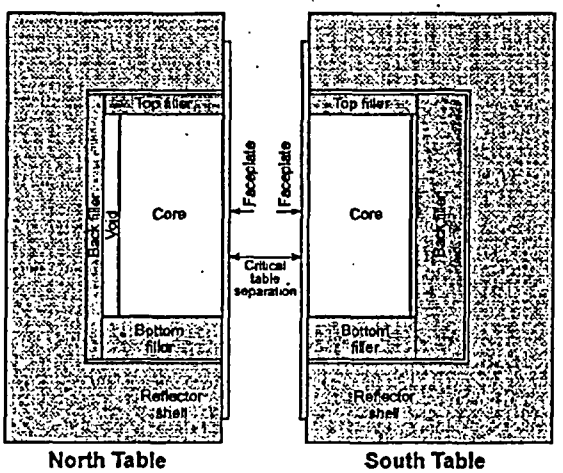

Fig. 8 Volume IV: LEU-COMP-THERM-045, Plexiglas and Concrete-Reflected $U(4.46)_3O_8$ with H/U=0.77 and Interstitial Moderation, (21 Cases), *Karla R. Elam (Oak Ridge National Laboratory - USA).*

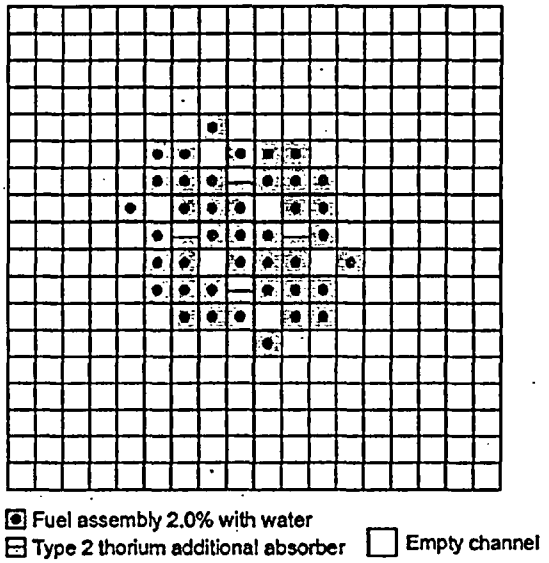

Fig. 9 Volume IV: LEU-COMP-THERM-060, RBMK Graphite Reactor – Uniform Configurations of $U(1.8, 2.0, \text{or } 2.4)O_2$ Fuel Assemblies, and Configurations of $U(2.0)O_2$ Assemblies with Empty Channels, Water Columns, and Boron or Thorium Absorbers, with and without Water in Channels, (28 Cases), *V. M. Kachanov, A. N. Kuzmin, V. E. Jitarev (RRC "Kurchatov Institute"- Russian Federation) and V. F. Dean (under subcontract to the Idaho National Engineering and Environmental Laboratory - USA).*

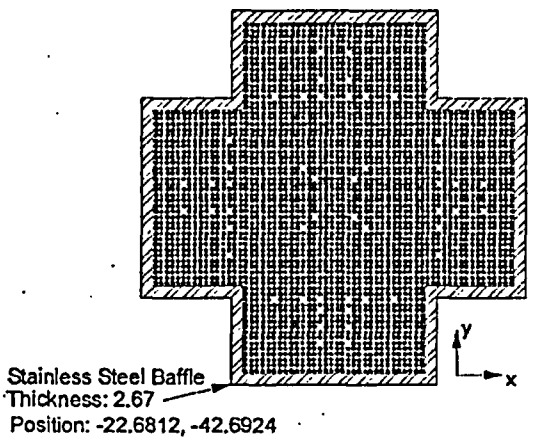

Fig. 10 Volume IV: LEU-COMP-THERM-063, Light Water Moderated and Reflected Low Enriched Uranium (3 wt.% ^{235}U) Dioxide Rod Lattices with Discrete Poison Rod Arrays, (12 Cases), *David Hanlon (Serco Assurance – United Kingdom).*

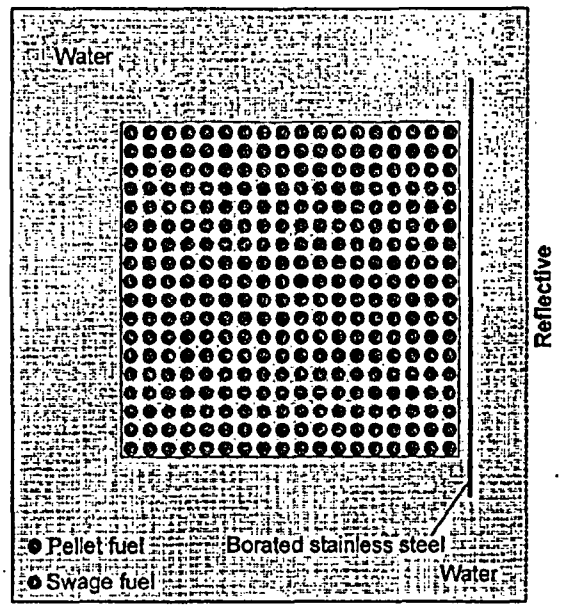

Fig. 11 Volume IV: LEU-COMP-THERM-065, Critical Configurations of 2.6% Enriched UO_2 Rod Arrays in Light Water Moderator with Borated Stainless Steel Plate: Coupled Array, (20 Cases), *Toshihiro Yamamoto and Yoshinori Miyoshi (Japan Atomic Energy Research Institute – Japan).*

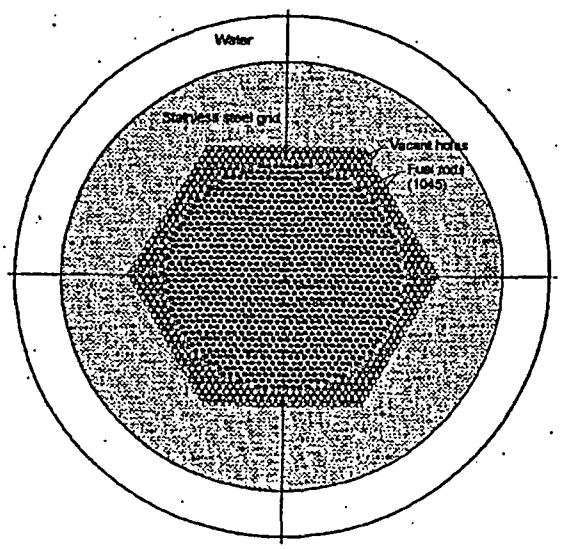

Fig. 12 Volume IV: LEU-COMP-THERM-070, VVER Physics Experiments: Regular Hexagonal (1.10 cm pitch) Lattices of Low-Enriched U(6.5 wt.% $^{235}U)O_2$ Fuel Rods in Light Water at Different Core Critical Dimensions, (12 Cases), *Nicholai Alexeyev, Yuri Krainov, Yuri Kravchenko, and Victor Tcvetkov (RRC "Kurchatov Institute"- Russian Federation).*

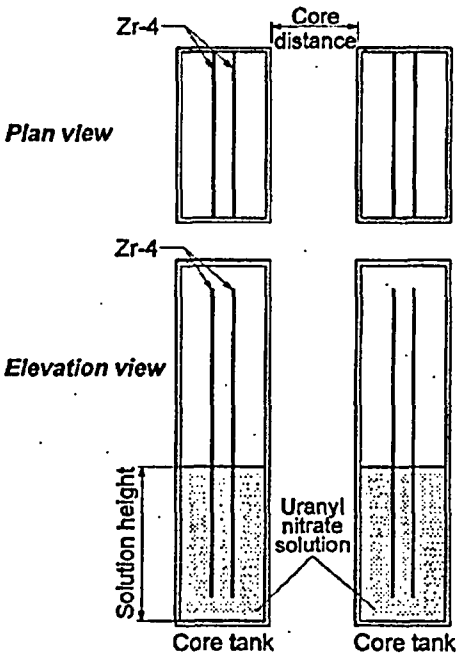

Fig. 13 Volume IV: LEU-SOL-THERM-023, STACY: Two Interacting Slab Cores of 10%-Enriched Uranyl Nitrate Solution without Neutron Isolator, (9 Cases), *Kotaro Tonoike (Japan Atomic Energy Research Institute – Japan).*

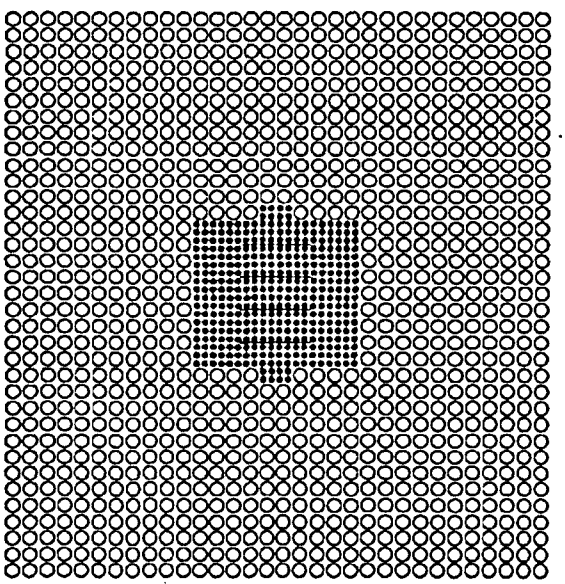

Fig. 14 Volume V: U233-COMP-THERM-001, LWBR SB Core Experiments, (5 Cases with ^{233}U, 3 Cases with ^{235}U), *Valerie L. Putman, (Idaho National Engineering and Environmental Laboratory – USA).*

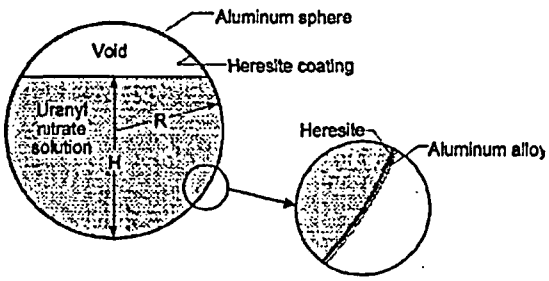

Fig. 15 Volume V: U233-SOL-THERM-013, Spherical Vessels Partially Filled or Filled With $^{233}UO_2(NO_3)_2$ Solution, (21 Cases), *Paul J. Foster (Brigham Young University – USA) and J. Blair Briggs (Idaho National Engineering and Environmental Laboratory – USA).*

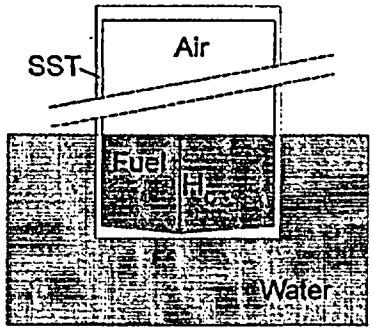

Fig. 17 Volume VI: MIX-SOL-THERM-006, Mixed Uranium (70%) Plutonium (30%) Nitrate Solution Poisoned with Gadolinium, (6 Cases), *Gilles Poullot [Institut de Radioprotection et de Sûreté Nucléaire (IRSN) – France].*

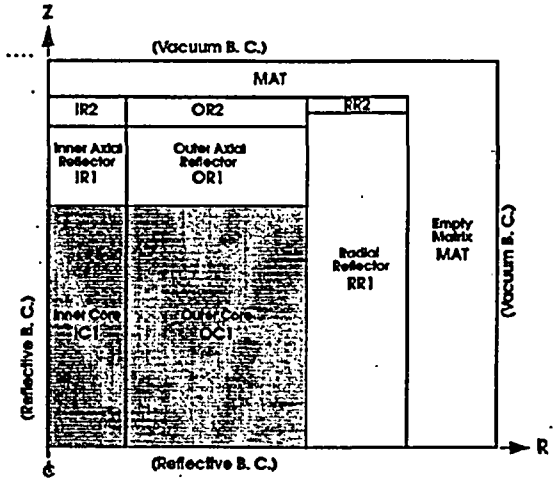

Fig. 16 Volume VI: MIX-COMP-FAST-001, ZPR-6/7 Benchmark Assembly – A Cylindrical Assembly with Mixed (Pu,U) – Oxide Fuel and Sodium with a Thick Depleted-Uranium Reflector, (1 Case), *Micheal A. Smith and Richard M. Lell (Argonne National Laboratory – USA) and Pedro Moneo and Paul A. Van den Hende (Institut National des Sciences et Techniques Nucléaire, CEA / Saclay).*

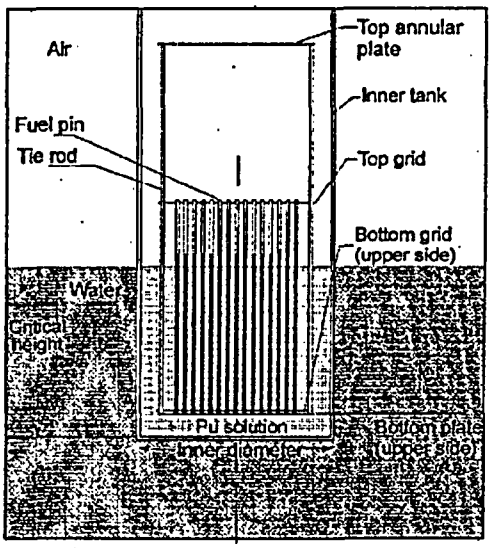

Fig. 18 Volume VI: MIX-MISC-THERM-003, Mixed Oxide Rapsodic Fuel Pin Arrays Moderated by Concentrated Plutonium Nitrate Solution (19.7 to 194 G Pu/L) and Water Reflected, (24 Cases with mixed Pu /U rods in solution, 5 with Pu solution only), *Jean-Marc Bordy [Institut de Radioprotection et de Sûreté Nucléaire (IRSN) – France]*

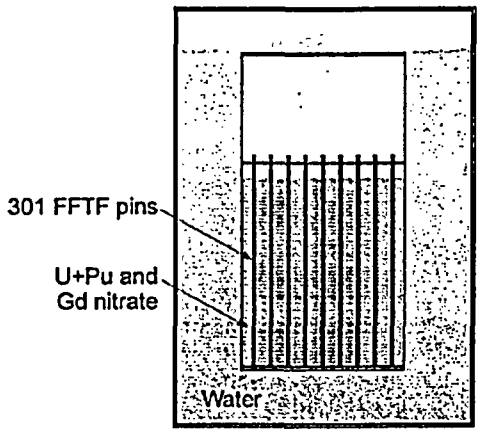

Fig. 19 Volume VI: MIX-MISC-THERM-004, Water-Reflected Triangular-Pitched Lattice of Mixed Oxide Fuel Rods Immersed in Plutonium / Uranyl Nitrate Solution Containing Gadolinium, (6 Cases), *Paul J. Foster (Brigham Young University) and J. Blair Briggs (Idaho National Engineering and Environmental Laboratory – USA)*

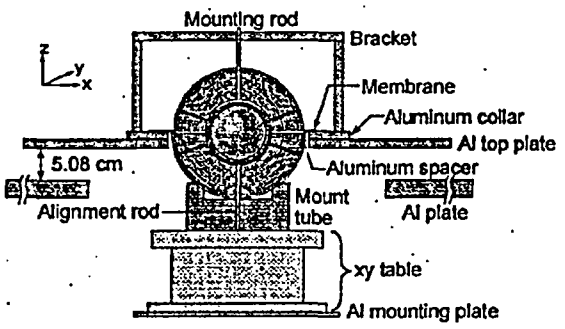

Fig. 20 Volume VII: SPEC-MET-FAST-008, Neptunium-237 Sphere Reflected by Hemisphere Shells of Highly Enriched Uranium Critical Experiment, (1 Case), *David Loaiza (Los Alamos National Laboratory).*

6.0 Future Work

There are four general types of experimental measurements that have relevance to criticality safety: (1) measurement of critical assemblies, (2) measurement of subcritical assemblies, (3) criticality alarm and shielding measurements, and (4) fundamental physics measurements such as integral measurements of neutron leakage, scattering, and absorption (e.g., NIST iron and water sphere or LLNL pulsed sphere measurements). The ICSBEP has focused primarily on critical assemblies of fissile material; however, some effort has been devoted to subcritical measurements. The future focus of the ICSBEP includes the evaluation of all four types of experiments.

7.0 Conclusions

The ICSBEP continues to provide high quality criticality safety related benchmark data from around the world. The project continues to grow. Twelve countries have contributed in the past or are currently contributing to the project and 3 additional counties are making plans to contribute. The ICSBEP Handbook is currently being used in 56 different countries

Acknowledgements

The ICSBEP is a collaborative effort that involves numerous scientists, engineers and administrative support personnel from 15 different countries. The authors would like to acknowledge the efforts of all of these dedicated individuals without whom the ICSBEP would not be possible. The authors would especially like to acknowledge the evaluators and reviewers of the newly provided benchmark data that were recently published in the 2003 Edition of the Handbook and are highlighted in this paper.

This paper was prepared at the Idaho National Engineering and Environmental Laboratory (INEEL) for the United States Department of Energy under Contract Number (DE-AC07-99ID13727).

References

1) International Handbook of Evaluated Criticality Safety Benchmark Experiments, September 2003 Edition, NEA/NSC/ DOC(95)03/I-VII, OECD-NEA, (2003).

2) J. Blair Briggs, Virginia F. Dean, Lori Scott, "Status of the International Criticality Safety Benchmark Evaluation Project (ICSBEP)," Proceedings of the Sixth International Conference on Nuclear Criticality Safety, ICNC'99, Versailles, France, Sep. 20 –24, 1999, I, 140 (1999).