



The International Criticality Safety Benchmark Evaluation Project (ICSBEP)

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ABSTRACT

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. Representatives from the United States, United Kingdom, France, Japan, the Russian Federation, Hungary, Republic of Korea, Slovenia, Yugoslavia, Kazakhstan, Israel, Spain, and Brazil are now participating. 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. The work of the ICSBEP is published as an OECD handbook entitled “International Handbook of Evaluated Criticality Safety Benchmark Experiments.” The 2003 Edition of the Handbook contains benchmark model specifications for 3070 critical or subcritical configurations that are intended for validating computer codes that calculate effective neutron multiplication and for testing basic nuclear data.

1 INTRODUCTION

Criticality safety has been a concern since the beginning of the nuclear industry. Initially, most nonprocedural criticality safety issues were addressed through experimentation. Later, computers made it possible to make predictions of criticality through analytic calculations. Through the use of Monte Carlo techniques, criticality safety practitioners were able to accurately model and evaluate complex three-dimensional systems. Closely tied to code development was the need for basic nuclear data that describe neutron interactions with various materials. Efforts were undertaken to evaluate and describe neutron interactions with matter. Both the authors of computer code systems and nuclear data evaluators recognized, from the start, the importance of comparing calculational results with integral experimental data. As the importance of validating calculational techniques and data became more widely recognized, criticality safety organizations and regulators, worldwide, began to require comparison of calculational techniques with experimental data. Validation of nuclear data and analytical methods is now an integral part of criticality safety analysis.

Since the beginning of the nuclear industry, thousands of critical experiments have been performed. Many of these critical experiments can be used as benchmarks for validation of calculational techniques. However, many were performed without a high degree of quality assurance and were not well documented.

For years, common validation practice included the tedious process of researching critical-experiment data scattered throughout journals, transactions, reports, internal memos, and logbooks. This process was repeated over and over, with varying degrees of rigor, at non-reactor nuclear facilities throughout the world in order to ensure that calculated criticality

safety margins were accurate. The need for systematic evaluation and documentation of existing and newly generated experimental data was a common topic at criticality safety conferences and workshops for many years.

2 THE INTERNATIONAL CRITICALITY SAFETY BENCHMARK EVALUATION PROJECT

The Criticality Safety Benchmark Evaluation Project (CSBEP) was initiated in October of 1992 by the US Department of Energy. The project was managed through the Idaho National Engineering and Environmental Laboratory (INEEL), but involved nationally known criticality safety experts from Los Alamos National Laboratory, Lawrence Livermore National Laboratory, Savannah River Technology Center, Oak Ridge National Laboratory, Y-12 Plant, Hanford, Argonne National Laboratory, and the Rocky Flats Plant.

An International Criticality Safety Data Exchange component was added to the project in 1994 and the project became what is currently known as the International Criticality Safety Benchmark Evaluation Project (ICSBEP). Representatives from the United States, United Kingdom, France, Japan, the Russian Federation, Hungary, Republic of Korea, Slovenia, Yugoslavia, Kazakhstan, Israel, Spain, and Brazil are now participating. Participation by South Africa and China is anticipated in the near future. The ICSBEP became an official activity of the Organisation for Economic Cooperation and Development - Nuclear Energy Agency's (OECD-NEA) Nuclear Science Committee in 1995. The United States currently remains the lead country, providing most of the administrative support.

The initial purpose of the ICSBEP was to (1) identify and evaluate a comprehensive set of critical-experiment benchmark data; (2) verify the data, to the extent possible, by reviewing original and subsequently revised documentation, and by talking with the experimenters or individuals who are familiar with the experimenters or the experimental facility; (3) compile the data into a standardized format; (4) perform calculations with standard criticality safety codes to assess the uncertainty in each experiment; and (5) formally document the work into a single source of verified, internationally-peer-reviewed benchmark critical data. The work of the ICSBEP is depicted graphically in Figure 1.

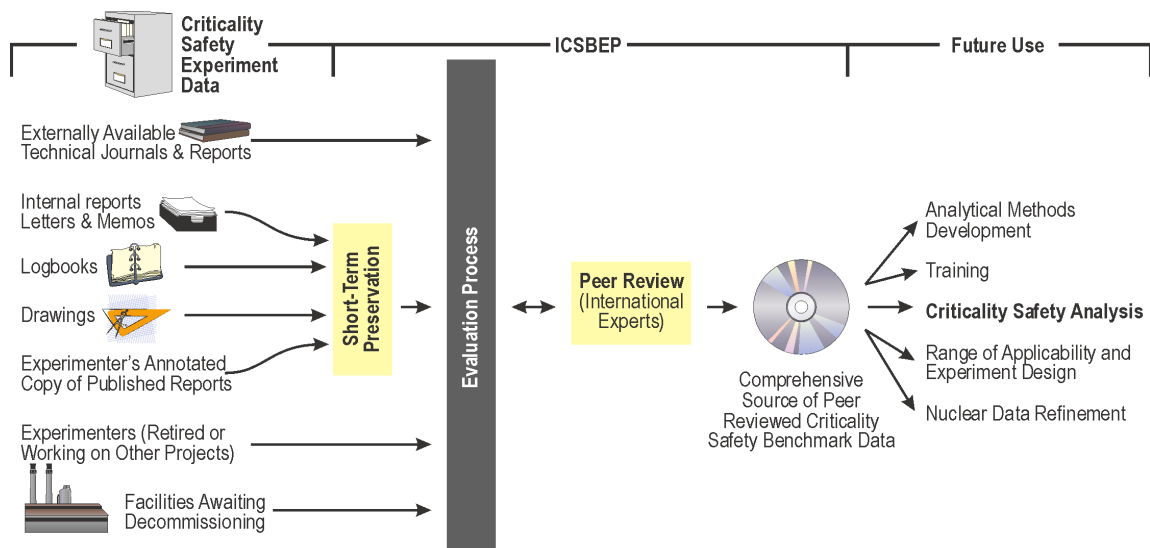


Figure 1: Graphic Representation of the Work of the ICSBEP

3 ICSBEP HANDBOOK

The work performed by the ICSBEP is documented in an OECD NEA Nuclear Science Committee handbook entitled, "International Handbook of Evaluated Criticality Safety Benchmark Experiments" [1]. The Handbook was first published in March of 1995. At that time, it contained 46 evaluations with benchmark specifications for 376 critical or near critical configurations. Additionally, 101 other experimental configurations were reviewed, but were found unacceptable for use as criticality safety benchmark experiments. Unacceptable experiments are evaluated in the Handbook; however, benchmark model specifications are not derived for such experiments.

Additions and revisions to the Handbook were published in August of 1996 and annually in September, thereafter. The 1995 and 1996 Editions of the Handbook were published in both hardcopy and on CD-ROM; however, because of the increasing cost of the hardcopy publication, subsequent editions of the Handbook have been published only on CD-ROM and on the Internet.

3.1 Contributing Nations

Of the 350 evaluations in the Handbook, 162 come from the United States, 114 from the Russian Federation, 19 from France, 19 from Japan, 12 from the United Kingdom, 3 from Yugoslavia, 3 from Spain, 2 from Hungary, 2 from the Republic of Korea, and 1 from Slovenia. There are also 5 joint United States / French evaluations, 5 joint United States / Russian evaluations, 2 joint French / United Kingdom evaluations, and 1 joint Russian Federation / Kazakhstan evaluation included in the Handbook. The contribution by country, in terms of number of configurations, is shown graphically in Figure 2.

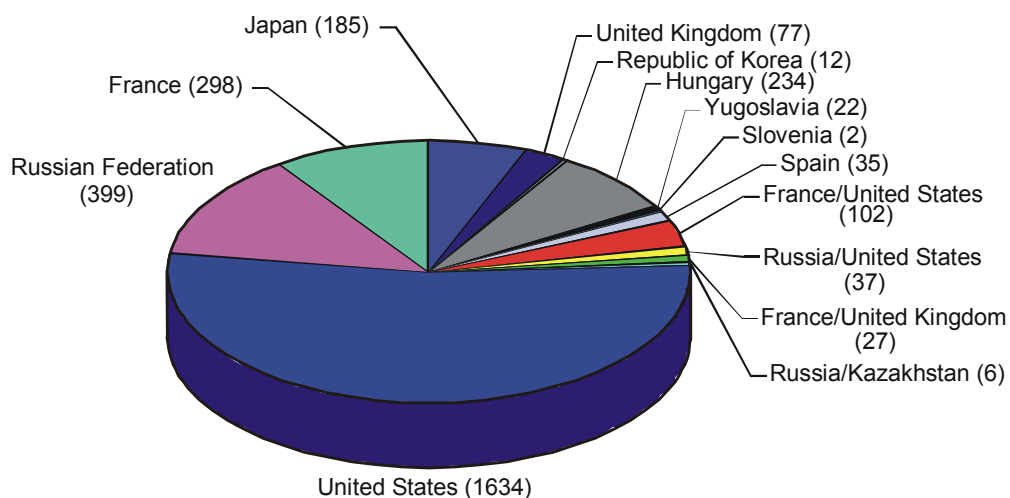


Figure 2: Contribution to the ICSBEP Handbook by Country

3.2 Handbook Organization

The International Handbook of Evaluated Criticality Safety Benchmark Experiments is divided into seven volumes, each representing one of the following seven different types of fissile material:

- Plutonium Systems
- Highly Enriched Uranium Systems (wt.% $^{235}\text{U} \geq 60$)

- Intermediate and Mixed Enrichment Uranium Systems ($10 < \text{wt.}\% \text{}^{235}\text{U} < 60$)
- Low Enriched Uranium Systems ($\text{wt.}\% \text{}^{235}\text{U} \leq 10$)
- Uranium-233 Systems
- Mixed Plutonium - Uranium Systems
- Special Isotope Systems

Each of these seven volumes is divided into four major sections representing the physical form of the fissile material: Metal, Compound, Solution, and Miscellaneous. Each fissile material grouping is further subdivided into FAST (*Energy > 100 keV*), INTERMEDIATE ($0.625 \text{ eV} \leq \text{Energy} \leq 100 \text{ keV}$), THERMAL (*Energy < 0.625 eV*) and MIXED systems, as determined by the energy of the majority of neutrons causing fission.

3.3 Handbook Contents

The 2003 Edition of the Handbook (See Figure 3) spans over 28,000 pages and contains 350 evaluations with benchmark model specifications for 3070 critical, near critical, or subcritical configurations. Approximately 533 additional experimental configurations are evaluated, but are categorized as unacceptable for use as criticality safety benchmark experiments. The distribution of configurations contained in the Handbook, in terms of energy of neutrons causing fission, is given in Table 1.

It is important to note that revisions are sometimes made to ICSBEP evaluations and that a revision history is maintained and published with the Handbook. The actual benchmark models are infrequently affected by these revisions, but occasionally new information is found that impact the models. It is important that users are aware of the possibility that revisions could have been or might be made to the data they are using, especially when using an older edition of the Handbook. Reference to the Handbook should always include the edition number as shown in Reference 1.

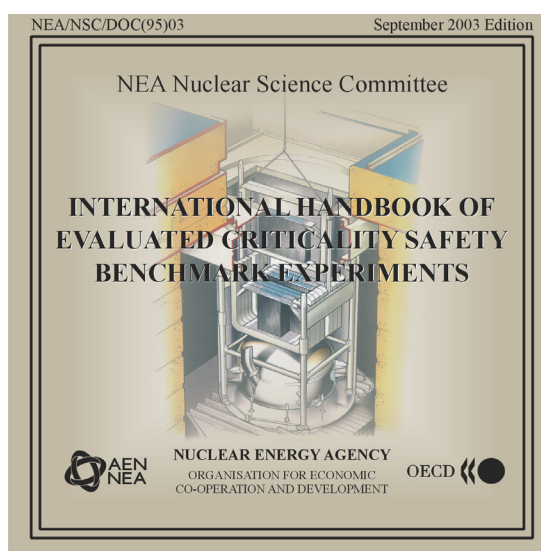


Figure 3: September 2003 Edition of the ICSBEP Handbook

3.4 Access to Handbook

The 2003 Edition of the Handbook was published in September of 2003. The Handbook is available on CD-ROM and 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: <http://icsbep.inel.gov/icsbep>. (Please Note: Some restrictions apply.)

Table 1: Distribution of Configurations in Terms of Energy of Neutrons Causing Fission.

PU(510)	FAST	INTERMEDIATE	THERMAL	MIXED
METAL	87	4	2	1
SOLUTION	NA	0	381	0
COMPOUND	6	1	21	7
HEU (932)	FAST	INTERMEDIATE	THERMAL	MIXED
METAL	191	11	87	29
SOLUTION	NA	3	432	0
COMPOUND	8	14	105	45
COMP/SOL	0	0	2	0
METAL/SOL	0	0	5	0
IEU (61)	FAST	INTERMEDIATE	THERMAL	MIXED
METAL	16	0	0	0
SOLUTION	NA	0	4	0
COMPOUND	1	2	38	0
LEU (1026)	FAST	INTERMEDIATE	THERMAL	MIXED
METAL	0	0	13	0
SOLUTION	NA	0	90	0
COMPOUND	0	0	923	0
U233 (192)	FAST	INTERMEDIATE	THERMAL	MIXED
METAL	10	0	0	0
SOLUTION	NA	29	140	8
COMPOUND	0	0	5	0
MIX (331)	FAST	INTERMEDIATE	THERMAL	MIXED
METAL	42	2	0	1
SOLUTION	NA	0	48	0
COMPOUND	1	0	184	0
COMP/SOL	0	0	53	0
SPEC (18)	FAST	INTERMEDIATE	THERMAL	MIXED
METAL	18	0	0	0
SOLUTION	NA	0	0	0
COMPOUND	0	0	0	0

4 DETERMINATION OF UNCERTAINTIES

As part of the evaluation process, an attempt is made to identify and quantify uncertainties in experimental data. When these uncertainties are not documented by the experimenter, engineering judgment is required in order to develop a reasonable estimate of the

uncertainty. Calculations are then performed to determine the sensitivity of calculated k_{eff} values to the uncertainty in each measured parameter. Efforts are also made to quantify any biases that are introduced as a result of modeling simplifications.

5 QUALITY ASSURANCE

The "International Handbook of Evaluated Criticality Safety Benchmark Experiments" is generally recognized within the international criticality safety community as the most extensively peer reviewed source of Criticality Safety benchmark data available. Each experiment evaluation included in the handbook has undergone a thorough peer review process beginning with an internal review by qualified individuals within the evaluator's organization. The responsibilities of the internal reviewer are to verify (1) the accuracy of the descriptive information given in the evaluation by comparison with original documentation (published and unpublished), (2) that the benchmark specification can be derived from the descriptive information given in the evaluation, (3) the completeness of the benchmark specification, (4) the results and conclusions, and (5) adherence to format.

In addition, each experiment has undergone an independent peer review by another working group member at a different institute or facility. Starting with the evaluator's submittal in the appropriate format, the independent peer reviewer verifies (1) that the benchmark specification can be derived from the descriptive information given in the evaluation, (2) the completeness of the benchmark specification, (3) the results and conclusions, and (4) adherence to format.

A third review by the Working Group verifies that the benchmark specification and the conclusions were adequately supported.

6 RANGE OF APPLICABILITY

In 1999 scientists from the Institute of Physics and Power Engineering (IPPE) in Obninsk, Russia began to recalculate every configuration in the "International Handbook of Evaluated Criticality Safety Benchmark Experiments" and collect the spectral characteristics of each experiment. Included in these data are the energy corresponding to the average neutron lethargy causing fission; the average neutron energy causing fission; the percentage of the flux, fissions, and captures that occur in the fast (Energy >100keV), intermediate ($0.625\text{eV} \leq \text{Energy} \leq 100\text{keV}$), and thermal (Energy <0.625eV) energy ranges; the percentage of fissions and captures by isotope over the core region, and the average fission neutrons produced per neutron absorbed in the fuel, ($\nu\Sigma_f/\Sigma_a$). A plot of the neutron spectrum is also provided for bounding cases in each evaluation. These data enable criticality safety practitioners to more clearly understand the range of applicability for each configuration in the handbook.

7 DATABASE

A searchable database that enables users to more effectively identify experiments that are needed for their specific applications was introduced in the 2001 Edition of the Handbook. The database also makes it easier to characterize the information generated by the ICSBEP and to identify gaps and inconsistencies in the data. The database, designated DICE, is programmed to produce a concise, two-page summary of each configuration.

The CD-ROM version of the ICSBEP Handbook includes a search capability that allows the user to find all occurrences of groups of words. The advanced search capabilities of DICE enable users to more precisely identify experiments of interest. The user is able to search, for example, for all experiments in which a desired minimum percentage of the fissions occur in the intermediate energy range or all experiments in 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 or sensitivity coefficients for major nuclides and nuclear processes in a 30-Energy-Group structure. 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.

8 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. A 5-Year Plan for the ICSBEP is provided on the project Internet Site: <http://icsbep.inel.gov/icsbep>. This plan is updated periodically with changing priorities; however, the criticality safety community can request a specific evaluation by completing the "Request for Evaluation" form that is also located on the project Internet Site. This form includes a justification section, which is used to determine of priorities.

9 CONCLUSIONS

Over 250 scientists from around the world have combined their efforts to produce the "International Handbook of Evaluated Criticality Safety Benchmark Experiments". As a result of these efforts, a large portion of the tedious and redundant research and processing of experimental data has been eliminated. The necessary step in criticality safety analyses of validating computer codes with benchmark critical data has been greatly streamlined, and valuable criticality safety experimental data have been preserved. Criticality safety personnel in 56 different countries are now using the "International Handbook of Evaluated Criticality Safety Benchmark Experiments."

10 ACKNOWLEDGMENTS

The ICSBEP is a collaborative effort that involves numerous scientists, engineers, administrative support personnel and program sponsors from 13 different countries and the OECD NEA. The author would like to acknowledge the efforts of all of these dedicated individuals without whom the ICSBEP would not be possible. Specifically, the author would like to acknowledge the efforts of:

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REFERENCES

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