NUCLEAR KNOWLEDGE MANAGEMENT EXPERIENCE OF THE INTERNATIONAL CRITICALITY SAFETY BENCHMARK EVALUATION PROJECT

J. B. Briggs
Idaho National Engineering and Environmental Laboratory, U.S.A

A. Nouri
OECD Nuclear Energy Agency, Paris, France

V. A. F. Dean
Under subcontract to the Idaho National Engineerging and Environmental Laboratory
Elgin, Arizona
United States of America

Email address of main author: bbb@inel.gov

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 Organization 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, Serbia and Montenegro (formerly Yugoslavia), Kazakhstan, Spain, Israel, Brazil, Poland, and the Czech Republic are now participating. South Africa, India, China, and Germany are considering participation. 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 2004 Edition of the Handbook contains benchmark specifications for 3331 critical or subcritical configurations that are intended for use in validation efforts and for testing basic nuclear data. The Handbook is being used extensively for validation of criticality safety methodologies and nuclear data testing and is expected to be a valuable resource for code and data validation and improvement efforts for decades to come.

1. Introduction

Since the beginning of the nuclear industry, thousands of experiments related to criticality safety have been performed. Many of these experiments can be used as benchmarks for validation of calculational techniques. However, many were performed in direct support of fissile processing operations and thus were not performed with 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, and, occasionally, logbooks. This process was repeated over and over at non-reactor nuclear facilities throughout the world in order to ensure that calculated criticality safety margins were accurate.

The Criticality Safety Benchmark Evaluation Project (CSBEP) [1] was initiated in October of 1992 by the United States Department of Energy Defense Programs, now NNSA. The U.S. effort to support and provide leadership for the CSBEP has been funded by DOE-NNSA since that time. The project is managed through the Idaho National Engineering and Environmental Laboratory (INEEL), but involves nationally known criticality safety experts from Los

Alamos National Laboratory, Lawrence Livermore National Laboratory, Savannah River Technology Center, Oak Ridge National Laboratory and the Y-12 Plant, Hanford, Argonne National Laboratory, and the Rocky Flat Plant.

The purpose of the CSBEP was to identify, evaluate, verify, and formally document a comprehensive and internationally peer-reviewed set of criticality safety benchmark data that could be used in the validation of neutronics codes and nuclear cross section data. Early in the project, the importance of identification and estimation of experimental uncertainties became apparent and was included in the project objectives. It was recognized at the beginning that this project would significantly reduce the time, money, and resources expended at the numerous non-reactor nuclear facilities; however, the magnitude of the reduction has far exceeded early expectations.

The CSBEP became an official activity of the Organisation for Economic Cooperation and Development (OECD) – Nuclear Energy Agency (NEA) – Nuclear Science Committee (NSC) in 1995 and the name was changed to the International Criticality Safety Benchmark Evaluation Project (ICSBEP). Representatives from the United Kingdom, France, Japan, the Russian Federation, Hungary, Republic of Korea, Slovenia, Serbia and Montenegro (formerly Yugoslavia), Kazakhstan, Spain, Israel, Brazil, Poland, and the Czech Republic are now participating on the project and China, South Africa, and India are considering plans to contribute to the project.

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. Future focus of the ICSBEP includes the evaluation of all four types of experiments.

The data provided by the ICSBEP are intended primarily for criticality safety practitioners to validate their safety analysis tools; however, the data are also of great value for training, range of applicability determinations, experiment design, nuclear data refinement, and validation and verification by analytical methods development groups.

2. The International Handbook of Evaluated Criticality Safety Benchmark Experiments

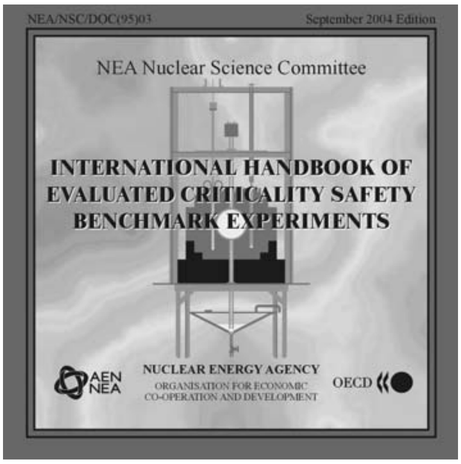
The work of the ICSBEP is documented as an International Handbook of Evaluated Criticality Safety Benchmark Experiments [2]. The Handbook was first published in March of 1995. At that time, it contained 46 evaluations with benchmark specifications for 376 critical or near critical configurations. Additions 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. The 2004 Edition of the Handbook was published on DVD because of storage contraints of CD ROM.

Over 250 scientists from around the world have combined their efforts to produce this handbook, which currently spans over 30,000 pages and contains benchmark specifications for 3331 critical and subcritical configurations. Approximately 554 additional experimental configurations are evaluated, but are categorized as unacceptable for use as criticality safety benchmark experiments. The handbook is intended for use by criticality safety analysts to perform necessary validations of their calculational techniques and is expected to be a valuable tool for decades to come. The handbook has currently been distributed to scientists and students in 58 different countries [Fig. 1].

Fig. 1. The 58 Countries to which the "International Handbook of Evaluated Criticality Safety Benchmark Experiments" has been distributed.

Of the 3331 configurations in the Handbook, 1790 come from the United States, 418 from the Russian Federation, 360 from France, 234 from Hungary, 197 from Japan, 84 from the United Kingdom, 35 from Spain, 22 from Serbia and Montenegro (formerly Yugoslavia), 12 from the Republic of Korea, 5 from Brazil, and 2 from Slovenia. There are also 102 joint United States / French configurations, 37 joint United States / Russian configurations, 27 joint French / United Kingdom configurations, and 6 joint Russian Federation / Kazakhstan configurations included in the Handbook.

The 2004 Edition of the Handbook was published in September of 2004 [Fig. 2]. The handbook is available on DVD or on the Internet. Both the DVD 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.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NEA Nuclear Science Committee

INTERNATIONAL HANDBOOK OF
EVALUATED CRITICALITY SAFETY
BENCHMARK EXPERIMENTS

AEN NEA
NUCLEAR ENERGY AGENCY
ORGANISATION FOR ECONOMIC
CO-OPERATION AND DEVELOPMENT
OECD

Fig. 2. 2004 Edition of the International Handbook of Evaluated Criticality Safety Benchmark Experiments

Revisions are sometimes made to ICSBEP evaluations and a revision history is maintained and published with each edition of the Handbook.

3. Organization of the Handbook

The International Handbook of Evaluated Criticality Safety Benchmark Experiments is divided into eight volumes. Each of the first seven volumes contain critical or subcritical benchmark data for one of the following seven different types of fissile material systems:

1. PLUTONIUM (Pu)
2. Highly Enriched Uranium (HEU)
3. Intermediate & Mixed Enrichment Uranium (IEU)
4. Low Enriched Uranium Systems (LEU)
5. URANIUM-233 SYSTEMS (U233)
6. MIXED PLUTONIUM - URANIUM SYSTEMS (Mix)
7. SPECIAL ISOTOPE SYSTEMS (Spec)

Each of these seven volumes is divided into four major sections representing the physical form of the fissile material: Metal (MET), Compound (COMP), Solution (SOL), and Miscellaneous (MISC). Each fissile material grouping is further subdivided into fast (FAST), intermediate (INTER), thermal (THERM) and MIXED systems, as determined by the energy at which fission occurs.

Each ICSBEP evaluation report is assigned a unique identifier and is presented in a standard format, the details of which are given in the introductory material provided at the beginning of each volume of the Handbook. Identifiers take the following form:

(Fissile Material)-(Physical Form)-(Spectrum)-(Three-Digit Numerical Identifier)

Radiation-transport measurements that can be used to validate criticality-safety-related shielding or alarm-placement methodologies are provided in the 8th volume. Data of this type were first evaluated and published, in DRAFT form, by the ICSBEP in 2004. These data are characterized by the type of radiation source (critical assembly, ^{252}Cf, accelerator, etc.), shielding material (lead, concrete, air, etc.), and experiment type (shielding, streaming, labyrinth, etc.). The identifiers for this type of benchmark take the following form:

ALARM-(Source)-(Shield Material)-(Experiment Type)-(Three-Digit Numerical Identifier)

4. Evaluation Process [3]

Each of the ICSBEP documents, or evaluations, in the Handbook are divided into four main parts:

Section 1. experiment description,
Section 2. experiment evaluation,
Section 3. specification of a benchmark model, and
Section 4. sample calculations.

The value of each section depends on the needs of the user.

In the following paragraphs, the process of creating each of the four main sections of an ICSBEP evaluation is described. The discussion includes goals of the evaluation process, as well as common attributes of the documents. In the discussion, the parameter of interest is k_{eff}. But the discussion also applies to any other calculable neutronic parameter measured by the experiment and reported for the benchmark model.

4.1. Description of Experiments

After or while gathering the experimental data, the evaluator organizes and writes the experiment description, indicating the sources of various data [Fig. 3]. All information is carefully referenced. Published references with specific information about the experiments being evaluated are listed at the end of the evaluation. Unpublished references (such as logbooks, internal memos, archive documents, and personal communications from experimenters) and general references (such as material handbooks and standards, and code manuals) are included as footnotes.

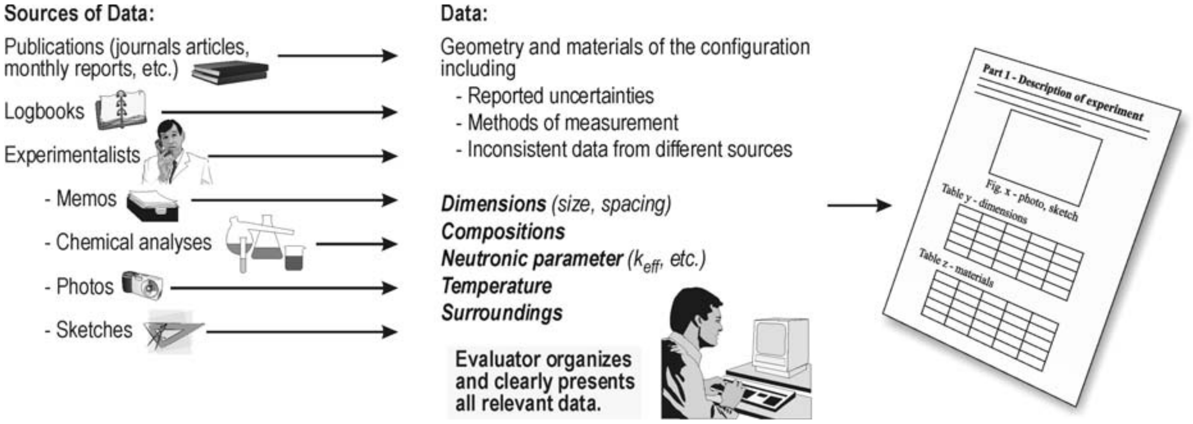


Fig. 3. Section 1 of the ICSBEP evaluation describes the experiment.

Section 1 begins with an overview of salient characteristics of the experiment. This includes a short description of the basic configuration, where and when the experiment was performed, and its original purpose. Other ICSBEP evaluations of similar experiments of the same series or program are identified.

Following the overview is a detailed description of experiment geometry and surroundings, measurement methods, and associated uncertainties. Values with their uncertainties are simply copied from the source document, with the same precision and units of measure as given in the source document. This enables easy verification of the data by comparison to the original documentation. Inconsistent data and their sources are noted.

When available, methods of measurement of the geometry data are described, as well as the method used to determine criticality, including any repeated measurements. Such details of the measurements give credibility to the data, provide useful information for determining uncertainties, and help the reader better understand the conclusions of the evaluation.

When the experimentalist provides relevant information, it is included and footnoted as a personal communication. Even if the evaluator does not recognize the direct relevance of what he has learned from the experimenter, he may choose to include it anyway. This is encouraged in order to preserve everything learned about the experiment, in case the information becomes useful later.

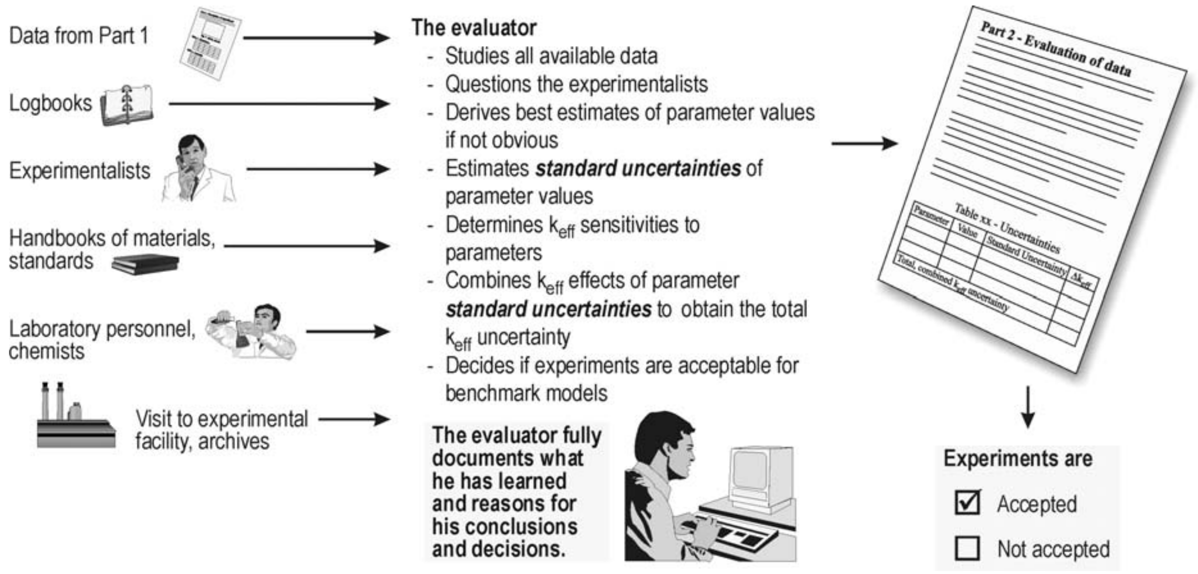
Numerical data, clearly labeled, are organized in tables, with explanations in footnotes or in the text. Photographs are especially valuable to include with the experiment description. Photos can be studied to obtain information about the surroundings that are not completely described in experiment documentation. Figures found in reports or logbooks are also valuable for similar reasons. Sometimes details of an original sketch that at first seem insignificant may later provide a clue about a measurement procedure or about the exact meaning of a particular phrase or description in a reference. The evaluator notes any modifications that he makes to reproduced figures.

After describing the geometry and measurement methods, the evaluator provides whatever is known about the materials of the assembly. If anything important about the experiment is not found in the references, such as temperature or isotopic composition of a fissile element, this lack of data is mentioned. This is so users know that the evaluator did not inadvertently omit it, but made an effort to obtain the information and was not able to find it.

The evaluator concludes with “supplemental data,” which refers to any additional measurements performed during the experiments that are not relevant to the benchmark model or uncertainties. If the data are available in a published or easily obtainable document, reference to the document is given. If the supplemental data have not been published, the data may be included either here or in an appendix.

4.2. Evaluation of Experimental Data

The second section is the evaluation, or assessment, of the experimental data. If some data are inconsistent or inconclusive, reasons for choices of parameter values for the model are given. Reported uncertainties in the data are restated and unreported uncertainties are estimated. Standard uncertainties (best estimates of the standard deviation) of the parameters that define the model are determined, and their effects on k_{eff} are presented. This part concludes with an estimate of the total, combined k_{eff} uncertainty and an assessment of the fitness of the experiments for use as benchmarks. This step is depicted in Fig. [4].



The evaluator
- Studies all available data
- Questions the experimentalists
- Derives best estimates of parameter values if not obvious
- Estimates ***standard uncertainties*** of parameter values
- Determines k_{eff} sensitivities to parameters
- Combines k_{eff} effects of parameter ***standard uncertainties*** to obtain the total k_{eff} uncertainty
- Decides if experiments are acceptable for benchmark models

The evaluator fully documents what he has learned and reasons for his conclusions and decisions.

Fig. 4. The evaluation of the data is described in Section 2.

4.3. Benchmark Model Specifications

The third section contains the final product of the benchmark evaluation process, the benchmark model of the experiment [Fig. 5]. This is the complete description of the geometry and materials that the evaluator determines to best represent the experiment for the purpose of validating calculation methods. All geometry and material information used for developing the benchmark models comes from Sections 1 and 2, so that the evaluation is entirely self-contained.

The description of the benchmark model includes model simplifications and their effects on k_{eff}. The expected value of k_{eff} and its uncertainty, obtained from experimental uncertainties of the parameters that define the model, are given. The geometry is concisely described in text, tables, and figures. Atom densities for all elements of all materials of the model are given.

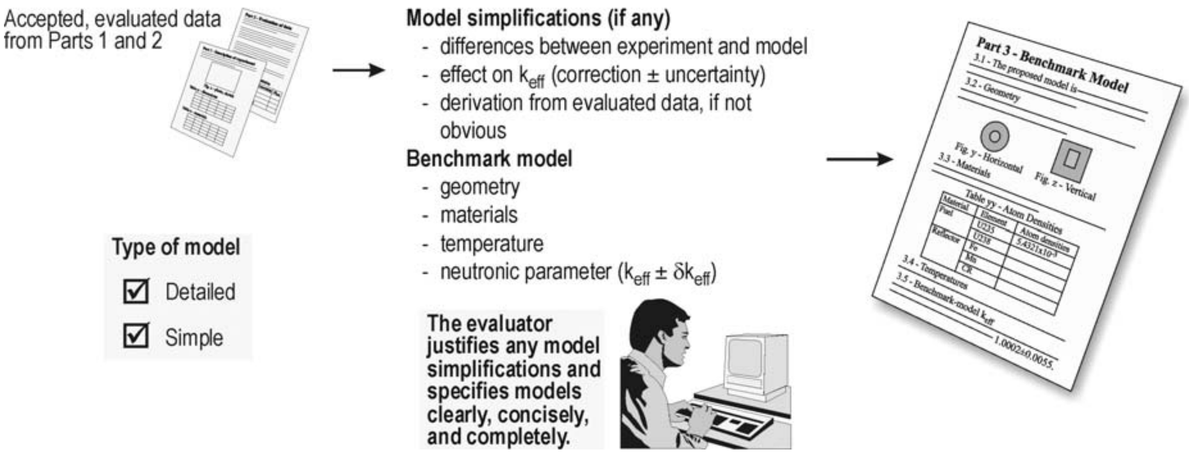


Fig. 5. Section 3 specifies the benchmark model.

4.4. Results of Sample Calculations

After completing the benchmark model described in Section 3, the evaluator calculates k_{eff} using code inputs derived from the model. Results are calculated using common, standard neutron-transport codes and cross-section data. The evaluator presents his results of the sample calculations in a table [Fig. 6] and mentions any unexpectedly high or low results. Appendix A provides examples of the input listings for the sample calculations.

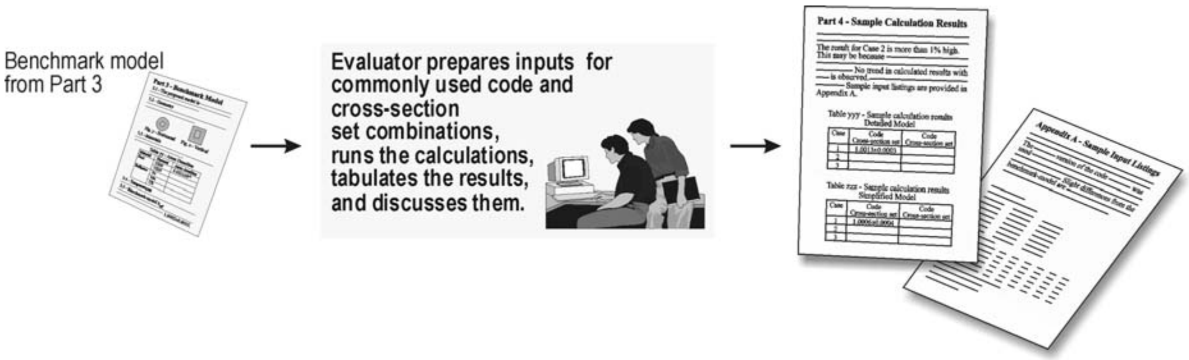


Fig. 6. Sample calculation results are presented in Section 4.

5. Extensive Peer Review Process

Each experiment evaluation undergoes a thorough internal review by someone within the evaluator's organization. The internal reviewer verifies:

1. The accuracy and completeness 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.
5. Adherence to format.

In addition, each evaluation undergoes an independent peer review by another working group participant at a different 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.
4. Adherence to format.

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

6. Database for the ICSBEP (DICE)

Introduced with the 2001 publication of the Handbook was a searchable database, DICE [4] that enables users to more effectively identify the experiments that are needed for their specific applications. The database also makes it easier to characterize the information generated by the ICSBEP and to identify gaps and inconsistencies in the data.

The CD-ROM version of the "International Handbook of Evaluated Criticality Safety Benchmark Experiments" 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. Plotting capabilities have been implemented into DICE that allow users to view graphical representations of neutron flux and certain reaction rates or sensitivity coefficients for major nuclides and nuclear processes. 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.

7. The Future of the ICSBEP

The ICSBEP will continue to identify, evaluate, verify, and formally document critical and subcritical benchmark data. The work of the ICSBEP will continue at approximately the same level of effort for several more years; however, the level of effort will eventually decline to an appropriate on-going base level at a time when only newly generated data are being added to the Handbook. The current five-year plan for the ICSBEP is provided on the ICSBEP Internet Site (http://icsbep.inel.gov/icsbep).

REFERENCES

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