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The International Criticality Safety Benchmark Evaluation Project

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Abstract—*The International Criticality Safety Benchmark Evaluation Project (ICSBEP) was initiated in 1992 by the U.S. Department of Energy. The ICSBEP became an official activity of the Organisation for Economic Co-operation and Development (OECD) Nuclear Energy Agency in 1995. Representatives from the United States, United Kingdom, France, Japan, the Russian Federation, Hungary, Republic of Korea, Slovenia, Yugoslavia, Kazakhstan, Spain, and Israel 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" (ICSBEP Handbook). The 2002 edition of the ICSBEP Handbook contains benchmark model specifications for 2881 critical or subcritical configurations that are intended for validating computer codes that calculate effective neutron multiplication and for testing basic nuclear data.*

I. 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 nonreactor nuclear facilities throughout the world in order to ensure that calculated criticality safety margins were accurate.

The Criticality Safety Benchmark Evaluation Project (CSBEP) was initiated in 1992 by the U.S. Department of Energy (DOE). The purpose of the CSBEP was to identify, evaluate, verify, and formally document a comprehensive and extensively 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 they were 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 nonreactor nuclear facilities; however, the magnitude of the reduction has far exceeded early expectations.

The CSBEP became an official activity of the Organisation for Economic Co-operation and Development (OECD) Nuclear Energy Agency (NEA) Nuclear Science Committee in 1995, and the name was changed to

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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, Spain, and Israel are now participating.

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
4. fundamental physics measurements such as integral measurements of neutron leakage, scattering, and absorption (e.g., National Institute of Standards and Technology iron and water sphere or Lawrence Livermore National Laboratory 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. The work of the ICSBEP is depicted graphically in Fig. 1.

II. ICSBEP HANDBOOK

The work performed by the ICSBEP is documented in an OECD NEA handbook entitled, "International Handbook of Evaluated Criticality Safety Benchmark Experiments"[1] (ICSBEP Handbook), which was first published in March 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 ICSBEP Handbook; however, benchmark model specifications are not derived for such experiments.

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

The 2002 edition of the ICSBEP Handbook spans more than 26000 pages and contains 330 evaluations with benchmark model specifications for 2881 critical or near-critical configurations. Approximately 531 additional experimental configurations are evaluated but are categorized as unacceptable for use as criticality safety benchmark experiments.

Of the 330 evaluations in the ICSBEP Handbook, 149 come from the United States, 113 from the Russian Federation, 17 from France, 17 from Japan, 11 from the

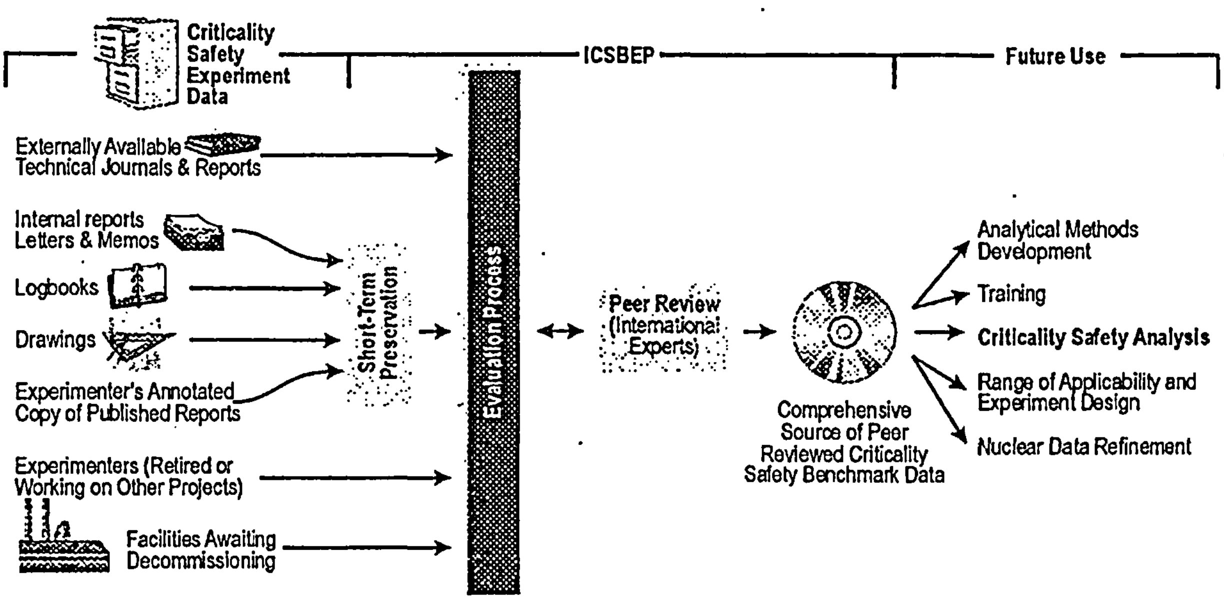

Fig. 1. Graphic representation of the work of the ICSBEP.

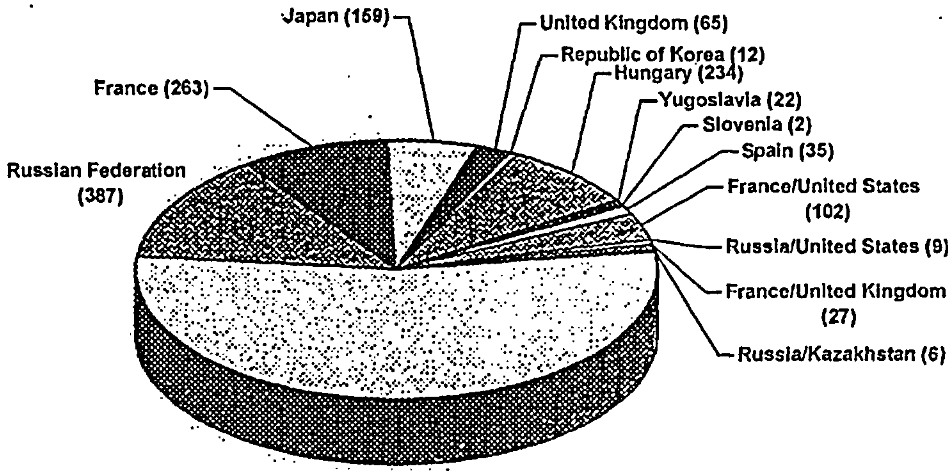

Fig. 2. Contribution by country (2881 configurations).

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 U.S./French evaluations, 4 joint U.S./Russian evaluations, 2 joint French/U.K. evaluations, and 1 joint Russian Federation/Kazakhstan evaluation included in the ICSBEP Handbook. The contribution by country, in terms of number of configurations, is shown graphically in Fig. 2.

The ICSBEP Handbook is divided into seven volumes, each representing one of the following seven different types of fissile material:

1. plutonium systems
2. highly enriched uranium (HEU) systems (wt% $^{235}U \geq 60$)
3. intermediate-enriched uranium (IEU) and mixed-enrichment uranium systems ($10 <$ wt% $^{235}U < 60$)
4. low-enriched uranium (LEU) systems (wt% $^{235}U \leq 10$)
5. Uranium-233 systems
6. mixed plutonium–uranium systems
7. 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 (see Fig. 3). Each fissile material grouping is further subdivided into "Fast" (Energy $>$ 100 keV), "Intermediate" (0.625 eV $\leq$ Energy $\leq$ 100 keV), "Thermal" (Energy $<$ 0.625 eV), and "Mixed" systems (see Table I), as determined by the energy of the majority of neutrons causing fission.

The 2002 edition of the ICSBEP Handbook was published in September 2002 (see Fig. 4). The ICSBEP Handbook is available on CD-ROM and on the Internet. Both the CD-ROM version of the ICSBEP Handbook or a password to access the ICSBEP Handbook on the Internet can be requested from the ICSBEP Internet Site at ⟨http://icsbep.inel.gov/icsbep⟩.

It is important to note that revisions are sometimes made to ICSBEP evaluations and that a revision history is maintained and published with the ICSBEP Handbook. The actual benchmark models are infrequently affected by these revisions, but occasionally new information is found that impact these 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 ICSBEP Handbook. Reference to the ICSBEP Handbook should always include the edition, as shown in Ref. 1.

III. EVALUATION FORMAT

Each evaluation 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 ICSBEP Handbook. Identifiers take the following form:

(Fissile Material)-(Physical Form)-(Spectrum)-

(Three-Digit Numerical Identifier) .

Identifier elements and their meanings are given in Table II.

Including the letters "SUB" at the beginning of the identifier denotes subcritical measurements.

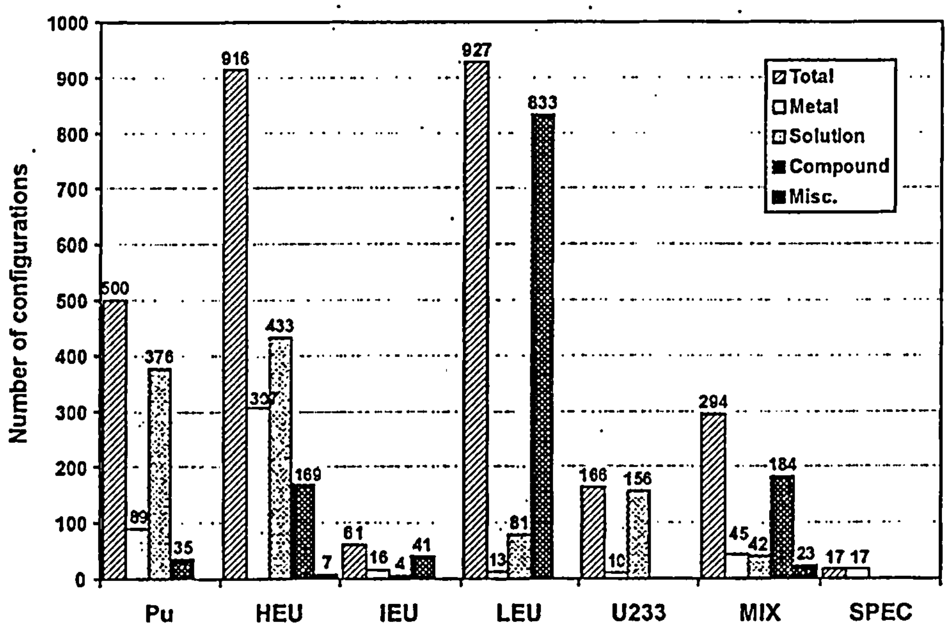

Fig. 3. Distribution of benchmark configurations (2881 configurations).

Examples of identifiers are IEU-COMP-THERM-001 for thermal, IEU systems in which the fissile material is in the form of a compound; HEU-SOL-THERM-001 for HEU solution systems; SUB-HEU-SOL-THERM-001 for subcritical measurements on HEU solution systems.

The standard evaluation format includes five sections, numbered 1 through 5, and at least one appendix.

Section 1.0, "Detailed Description," contains a detailed description of the experiment. All relevant data are provided in the appropriate subsection within this section. Enough information is given in this section so that the derivation of data in Section 3.0, "Benchmark Specifications," is evident. Sources of data include published reports, logbooks, photographs, memos or other records provided by experimenters, and discussions with experimenters.

Section 1.1, "Overview of Experiment," provides a brief overview of the experiment.

Section 1.2, "Description of Experimental Configuration," contains the description of the physical arrangement and dimensions of the experiment. Uncertainties in measurements, if known, are also given. If there is relevant reactivity worth information included in the experiment documentation that pertains to the geometric configuration of the experiment, it is also provided in this section. Subcritical measurements, in general, include more detailed information about the source and detectors than is typically required for critical assemblies.

Section 1.3, "Description of Material Data," contains a detailed description of the materials used in the experiment as well as significant materials in the surroundings. Uncertainties in material compositions, if known, are also given. If there is relevant reactivity worth information included in the experiment documentation that pertains to the materials used in the experiment, it is also provided in this section.

Section 1.4, "Supplemental Experimental Measurements," contains additional experimental data (e.g., flux distributions, spectral indices, β_{eff}, etc.) that are not relevant to the benchmark model. Evaluations of subcritical measurements include a description of the measurement technology and a discussion on the interpretation of the measurements as well as the measured data.

Section 2.0, "Evaluation of Experimental Data," contains an overall evaluation of the experiment. Missing data or weaknesses and inconsistencies in published data are discussed in this section. The effects of uncertainty in the data on k_{eff} are discussed and quantified. Use of data with large uncertainties or data that require assumptions on the part of the evaluator is justified in this section. If all or part of the data is found to be unacceptable for use as benchmark data, this fact is noted in this section, and the reasons are summarized. The evaluation process for the unacceptable data is terminated at this point; i.e., unacceptable data are not included in Sections 3.0 ("Benchmark Specifications"), 4.0 ("Results of Sample Calculations"), and Appendix A ("Typical Input Listing").

Section 3.0, "Benchmark Specifications," contains the data necessary to construct a calculational model of a critical or subcritical system. Data that were determined to be acceptable as benchmark-model data are provided in Sections 3.1 through 3.5 of each evaluation.

TABLE I

Distribution of Configurations in Terms of Energy of Neutrons Causing Fission

	Fast	Intermediate	Thermal	Mixed
Plutonium (500)				
Metal	82	4	2	1
Solution	NA[a]	0	376	0
Compound	6	1	21	7
HEU (916)				
Metal	190	11	81	25
Solution	NA	3	430	0
Compound	0	24	128	17
Compound/solution	0	0	2	0
Metal/solution	1	2	38	0
IEU (61)				
Metal	16	0	0	0
Solution	NA	0	4	0
Compound	1	2	38	0
LEU (927)				
Metal	0	0	13	0
Solution	NA	0	81	0
Compound	0	0	833	0
Uranium-233 (166)				
Metal	10	0	0	0
Solution	NA	29	119	8
Compound	0	0	0	0
Mixed plutonium-uranium (294)				
Metal	42	2	0	1
Solution	NA	0	42	0
Compound	0	0	184	0
Compound/solution	0	0	23	0
Special isotope (17)				
Metal	17	0	0	0
Solution	NA	0	0	0
Compound	0	0	0	0

[a]NA = not applicable.

TABLE II

Definition of ICSBEP Identifier Elements

Fissile Material		Physical Form		Spectrum	
Plutonium	PU	Metal	MET	Fast	FAST
Highly enriched uranium	HEU	Compound	COMP	Intermediate energy	INTER
Intermediate-enriched uranium	IEU	Solution	SOL	Thermal	THERM
Low-enriched uranium	LEU	Miscellaneous	MISC	Mixed	MIXED
Uranium-233	U233				
Mixed plutonium-uranium	MIX				
Special isotope	SPEC				

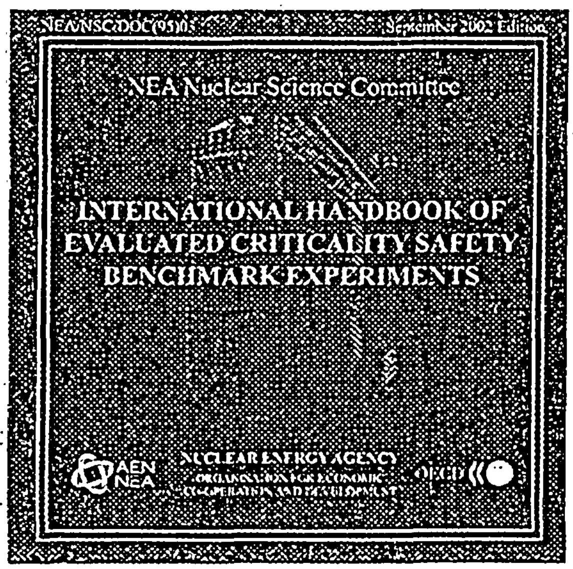

Fig. 4. September 2002 edition.

Section 3.1, "Description of Model," contains a concise description of the model. Any simplifications and approximations made to geometric configurations or material compositions are described and justified.

Section, 3.2, "Dimensions," contains a concise listing of all required dimensions and sketches of the benchmark-model geometry.

Section 3.3, "Material Data," contains a concise listing of atom densities for all materials. Lists are typically broken into subheadings such as core, structural, and reflector materials. Unique or complicated formulas for deriving atom densities are provided. All constituents of the materials used in the experiment description are included, or a justification for leaving them out is provided. (Materials that are not included are, in most cases, replaced with void.)

Section 3.4, "Temperature Data," contains temperature data for the experiment and the model. If temperature data are not provided in references, near room temperature is usually assumed.

Section 3.5, "Experimental and Benchmark-Model k_{eff} and/or Subcritical Parameters," contains experimental k_{eff} values and associated uncertainties, if available. (For replacement measurements, Δk_{eff} is provided. If Δk_{eff} is given as cents, β_{eff} is also provided.) If the effects of actual experimental parameters are carefully quantified, either by experiment or by calculation, and these parameters are omitted from the benchmark specification, an adjusted "benchmark-model k_{eff}" is also included in this section. In most cases, these adjustments are relatively small. Items that have a significant effect on calculated k_{eff} values that are omitted from the benchmark specification data must be well understood, i.e., must have small uncertainties. An uncertainty for the benchmark-model k_{eff}, based on parameter sensitivity studies or experimental estimates, is also included. Additional benchmark model parameters, such as variance-to-mean, decay constant, count rate, or spectral ratio values, may be included for subcritical measurements as well as interpreted k_{eff} values.

Section 4.0, "Results of Sample Calculations," contains calculated results obtained with the benchmark-model specification data given in Section 3.0. Details about the calculations, including examples of input listings, are given in Appendix A. The k_{eff} results are provided for the standard set of codes and cross-section data of the country in which the evaluation was performed. Results from other countries follow the evaluator's results in the order in which they were provided to the ICSBEP. The table format is given in Table III.

Calculated results for replacement measurements are reported in terms of Δk_{eff} rather than k_{eff}.

Additional sample calculated results such as calculated variance-to-mean, decay constant, count rate, or spectral ratio values are included for subcritical measurements as well as calculated eigenvalue results.

Section 5.0, "References," contains a listing of all published documents referenced in the evaluation that contain relevant information about the experiments.

TABLE III

Sample Calculation Results (Country Providing the Results)

Code → (Cross-Section Set) Case Number ↓	Code 1 (Cross-Section Data)	Code 2 (Cross-Section Data)	Code 3 (Cross-Section Data)

References that are not directly related to the experiments, such as material handbooks or computer code manuals, are provided as footnotes at the point they are mentioned in the evaluation.

Appendices contain supplemental information that is useful, but not essential, to the derivation of the benchmark specification. Appendix A, "Typical Input Listings," is required in all evaluations. Appendix A contains brief comments about options chosen for calculations in an introductory paragraph. This paragraph states the version of the code (e.g., KENO-IV, KENO-V.a, MONK6B, etc.) and of the cross-section library used for the calculations and additional information, including quadrature order, scattering order, convergence criteria, and mesh size for discrete ordinates codes, and number of active generations, number of skipped generations, and total neutron histories. Unique or important features regarding the input are also discussed just prior to the input listings.

IV. PEER-REVIEW PROCESS

Evaluations published in the ICSBEP Handbook undergo a rigorous peer-review process. Each experiment evaluation included in the ICSBEP Handbook undergoes a thorough internal review by the evaluator's organization or collaborators. Internal reviewers 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
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, independent peer reviewers verify

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 ICSBEP Working Group members, generally consisting of about 30 individuals, verifies that the benchmark specification and the conclusions were adequately supported.

It is important to note that the work of the ICSBEP is not considered to be a validation of the codes and cross-section data reported as sample calculation results. Furthermore, the sample input listings do not undergo the same formal level of peer review as the rest of the evaluation and should not be used for any purpose without thorough verification of the input data.

V. UNCERTAINTIES

During the evaluation process, missing data or weaknesses and inconsistencies in published data and uncertainties associated with the experimental data are often encountered. A significant effort is made to evaluate and quantify the effects of these uncertainties on calculated k_{eff} values. If modeling approximations are incorporated into the benchmark model of the experiment, these approximations or adjustments, and their uncertainties, are quantified. The current process of evaluating and expressing uncertainties has evolved significantly over the lifetime of the ICSBEP. Therefore, the treatment of uncertainties in earlier evaluations may not meet today's standards.

The "ICSBEP Guide to the Expression of Uncertainties" (the Guide) was developed to assist evaluators to properly express the uncertainties encountered during the evaluation process. The Guide is based on the information provided in the "American National Standard for Expressing Uncertainty—U.S. Guide to the Expression of Uncertainty in Measurement"[2] and the French equivalent.[3] Use of the Guide began informally in June 2000; however, the Guide was not formally accepted by the ICSBEP Working Group until June 2001. Significant revisions to the Guide were made in 2002, and the revised version is included with the ICSBEP Handbook.

Sometimes, a decision is made by the ICSBEP Working Group that a particular experiment is not acceptable for use as a "Criticality Safety Benchmark Experiment." This decision is based on unacceptably large uncertainties, which is generally the result of a lack of adequate experimental data. However, this decision does not imply that the data, if properly interpreted and applied, cannot be used for validation efforts. In particular, experiments for which the uncertainty in the calculated k_{eff} value exceeds 1% are often judged to be unacceptable, especially when the data are not required to fill gaps in existing data. However, if the uncertainty is properly taken into account, the data may still be used in some validation efforts.

VI. SPECTRA AND NEUTRON BALANCE DATA

The ICSBEP Handbook also contains detailed spectra and neutron balance data. Data are available for each configuration that appeared in the 1998 edition of the ICSBEP Handbook and for a significant portion of the configurations that have been added to the ICSBEP Handbook since 1998. It is anticipated that the 2003 edition of the ICSBEP Handbook will contain data for all available configurations. Scientists at the Institute of Physics and Power Engineering (IPPE) in Obninsk, Russian Federation, provided these data, which are based on ABBN-93 cross-section data.[4]

The following information for spectra/neutron balance are included for each configuration[5]:

1. *the energy corresponding to the average neutron lethargy causing fission, EALF*: *EALF* is defined for group calculations as

$$\bar{u} = \frac{\sum_m \sum_g (\bar{u}_g \times \Sigma_{fg}^m \phi_g^m)}{\sum_m \sum_g \Sigma_{fg}^m \phi_g^m} ,$$

where

m = number of a physical zone inside the core

$\bar{u}_g$ = midpoint of the g^{th} lethargy group, defined as lethargy of a neutron with energy $\bar{E}_g = \sqrt{E_g E_{g-1}}$

Σ_{fg} = group macroscopic fission cross section

ϕ_g = neutron flux within lethargy group g.

Lethargy u of a neutron with energy E is defined as $\ln(E_0/E)$, where E_0 is some maximum neutron energy, which here is 10 MeV. Therefore, $EALF = E_0/e^{\bar{u}}$.

2. *the average neutron energy causing fission, AFGE*: *AFGE* is defined for group calculations by linear interpolation between energies of the upper and lower group boundaries corresponding to the value of the Average Fission Group (*AFG*)

$$AFG = \frac{\sum_m \sum_g (N_g \times \Sigma_{fg}^m \phi_g^m)}{\sum_m \sum_g \Sigma_{fg}^m \phi_g^m} ,$$

where N_g is the group number of the g^{th} energy group, and other quantities are as previously defined. Energy-group boundaries are at the same energies as lethargy-group boundaries. A 299-energy-group structure is used.

3. *the neutron gas temperature in the thermal energy range for group calculations, T_n*: T_n is defined as

$$T_n = \frac{\pi}{4} \left(\frac{\sum_m \sum_g \phi_g^m}{\sum_m \sum_g \sigma_g \phi_g^m} \right)^2 T_0 \sigma_0^2 ,$$

where

$$\sigma_g = \sigma_0 \sqrt{\frac{E_0}{\bar{E}_g}}$$

T_0 = 293.6 K

σ_0 = cross section at E_0 = 0.0253 eV (v = 2200 m/s, T = 293.6 K)

ϕ_g = neutron flux in the groups collapsed into the thermal group ($E < 0.625$ eV).

Thus,

$$T_n = 9114.3 \left(\frac{\sum_m \sum_g \phi_g^m}{\sum_m \sum_g \frac{\phi_g^m}{\sqrt{\bar{E}_g}}} \right)^2 ,$$

where $\bar{E}_g = \sqrt{E_g E_{g-1}}$.

4. *the percentage of the neutron flux, fissions, and captures that occur in the fast (energy > 100 keV), intermediate (0.625 eV ≤ energy ≤ 100 keV), and thermal (energy < 0.625 eV) energy ranges*

5. *the percentage of fissions and captures by isotope over the core region*

6. *the average fission neutrons produced per neutron absorbed in the core ($\nu\Sigma_f/\Sigma_a$)*

7. *a graphic presentation of the neutron spectrum for bounding cases in each evaluation*

8. *the percentage of the neutron flux, fissions, and captures that occur in an ABBN 30-group structure.*

These data enable criticality safety practitioners to better judge the range of applicability for each configuration in the ICSBEP Handbook.

VII. DATABASE FOR THE ICSBEP (DICE)

Introduced with the 2001 publication of the ICSBEP Handbook was a searchable database, Database for the International Handbook of Evaluated Criticality Safety Benchmark Experiments[6] (DICE), 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 DICE database is programmed to produce a concise, two-page summary of each configuration. The summary includes

1. basic identification information such as title, author(s), and reference(s)
2. date and place the experiment was performed

3. ICSBEP original publication and latest revision dates
4. purpose for the experiment and the variable parameter(s)
5. description of the core and basic fuel unit
6. isotopic composition of the fissile material
7. fissile concentration (solution experiments)
8. moderator-to-fuel ratios (solution and lattice experiments)
9. type of reflector(s) if applicable
10. type and concentration of neutron absorber material (soluble and/or fixed)
11. sample calculated k_{eff} values for various codes and cross-section data
12. three-group spectra/neutron balance data.

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 occurs 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 neutrons as 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.

VIII. SENSITIVITY, UNCERTAINTY, AND CORRELATION

An International Science and Technology Center (ISTC) project was initiated in 2001 by ICSBEP participants from IPPE with the ICSBEP and the U.S. Department of State as partners. This project is designated as ISTC Project 815. The purpose of this project is to develop a computerized technology to determine the sensitivity of criticality safety calculations to basic neutron cross-section data, the uncertainty in criticality safety calculations that results from the uncertainty in the cross-section data, and the degree of correlation that exists among selected experiments. This technology has been applied to selected HEU solution experiments in the ICSBEP Handbook.[7] The results of this work are also published with the ICSBEP Handbook. Sensitivity coefficients for major nuclides and nuclear processes in a 30-energy-group structure are available in DICE.

IX. FUTURE WORK OF THE ICSBEP: 5-yr PLAN

The ICSBEP will continue to identify, evaluate, verify, and formally document critical and subcritical benchmark data. Within the next few years, evaluation of criticality alarm and fundamental physics measurements will be added to the ICSBEP Handbook. The work of the ICSBEP will continue at approximately the same level

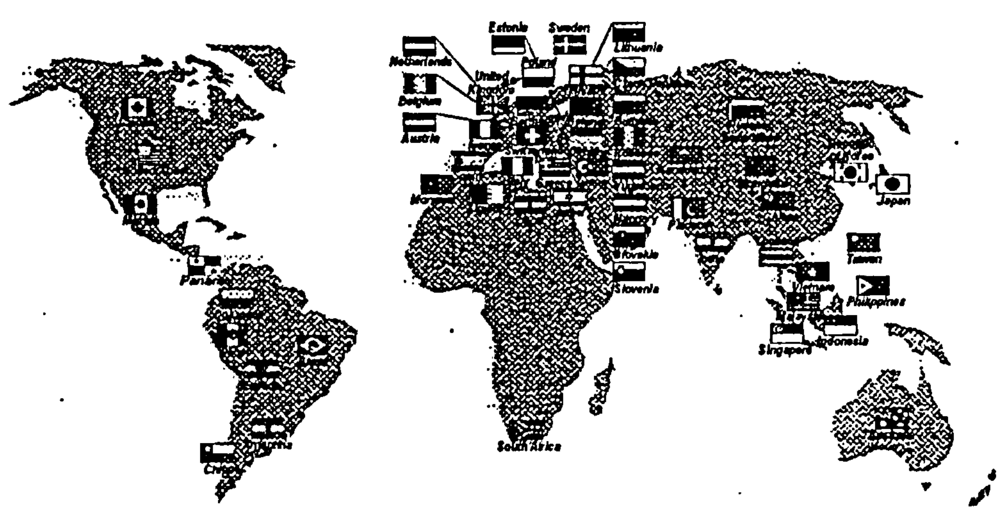

Fig. 5. The 56 countries in which the ICSBEP Handbook is in use.

of effort for several more years; however, the level of effort will eventually decline to an appropriate ongoing base level at a time when only newly generated data are being added to the ICSBEP Handbook. The current 5-yr plan for the ICSBEP is provided on the ICSBEP Internet Site at ⟨http://icsbep.inel.gov/icsbep⟩.

X. CONCLUSIONS

More than 150 scientists from around the world have combined their efforts to produce the ICSBEP Handbook. As a result of these efforts, a large portion of the tedious and redundant research and processing of critical experiment data has been eliminated. The necessary step in criticality safety analyses of validating computer codes with benchmark critical data is greatly streamlined, and valuable experimental data are preserved. The work of the ICSBEP has highlighted gaps in data, has retrieved lost data, and has helped to identify inadequacies in basic nuclear data and cross-section processing codes. The ICSBEP Handbook is currently being used in 56 different countries (see Fig. 5).

ACKNOWLEDGMENTS

The ICSBEP is a collaborative effort that involves numerous scientists, engineers, administrative support personnel, and program sponsors from 12 different countries and the OECD NEA. The authors would like to acknowledge the efforts of all of these dedicated individuals without whom the ICSBEP would not be possible. Specifically, we acknowledge the efforts of D. Y. Chung (DOE) and E. Sartori (OECD NEA), the initial program sponsors; C. White, who works countless hours each year to ensure the quality of the graphics in the annual publication; A. M. Tsiboulia, Y. Rozhikhin, and T. Ivanova (IPPE), who are responsible for the spectra calculations and for ISTC Project 815; G. Poullot, D. Doutriaux, and J. Anno (Institut de Radioprotection et de Sûreté Nucléaire, France) for leading the effort to produce the Guide; P. Nagel (OECD NEA) and T. Ivanova (IPPE) for their work on DICE, with the assistance of students L. Ghander (University of Paris, France), P. Foster, and L. Foster (Brigham Young University), N. Soppera and F. Benoit (Ecole Nationale Supérieure d'Electronique, Informatique et Radiocommunications de Bordeaux, France), and Y. Golovko (State Technical University of Atomic Power Engineering, Russian Federation).

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