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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 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, Yugoslavia, Kazakahstan, 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'. The 2001 Edition of the Handbook contains benchmark specifications for 2642 critical or sub-critical configurations that are intended for use in validation efforts and for testing basic nuclear data. (author)

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The Activities of the International Criticality Safety Benchmark Evaluation Project (ICSBEP)

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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, 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". The 2001 Edition of the Handbook contains benchmark specifications for 2642 critical or subcritical configurations that are intended for use in validation efforts and for testing basic nuclear data.

KEYWORDS: integral benchmark data, criticality safety data, nuclear data, international project, OECD NEA project

I. Introduction

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, Yugoslavia, Kazakhstan, Spain, and Israel (See Fig. 1) 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.

Fig. 1 International Participants.

The work of the ICSBEP is published as an OECD handbook entitled "International Handbook of Evaluated Criticality Safety Benchmark Experiments"[1]. The 2001 Edition of the Handbook spans over 22,000 pages and contains benchmark specifications for 2642 critical or subcritical configurations from 307 experimental series (See Fig. 2). These benchmark specifications are intended for use in validation efforts and for basic nuclear data evaluations. The handbook data are currently being used to support U.S. efforts to improve the ^{235}U and ^{233}U cross sections in the intermediate energy range and in the re-evaluation of a predominate waste matrix material, silicon.

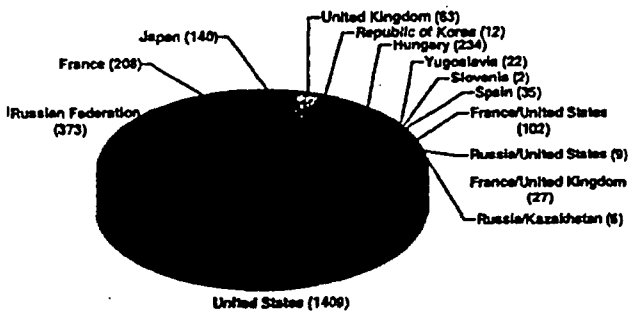

Fig. 2 Contribution by Country (2642 Configurations)

II. International Handbook of Evaluated Criticality Safety Benchmark Experiments

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:

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1. Plutonium Systems
2. Highly Enriched Uranium Systems (wt.% $^{235}U \geq 60$)
3. Intermediate and Mixed Enrichment Uranium Systems ($10 <$ wt.% $^{235}U < 60$)
4. Low Enriched Uranium 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 ≤ Energy ≤ 100 KeV)*, THERMAL *(Energy ≤ 0.625 eV)* and MIXED systems (See Fig. 4 – 10), as determined by the energy at which fission occurs.

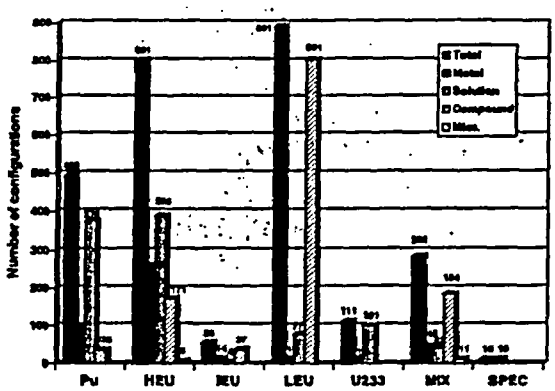

Fig. 3 Distribution of Benchmark Configurations

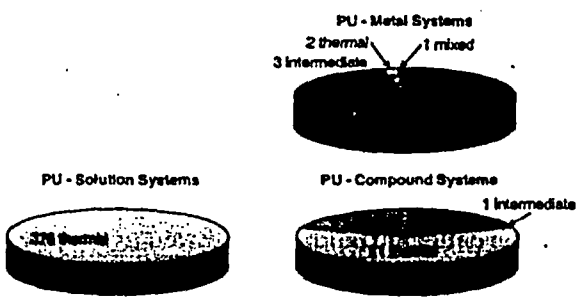

Fig. 4 Plutonium Systems (492 Configurations)

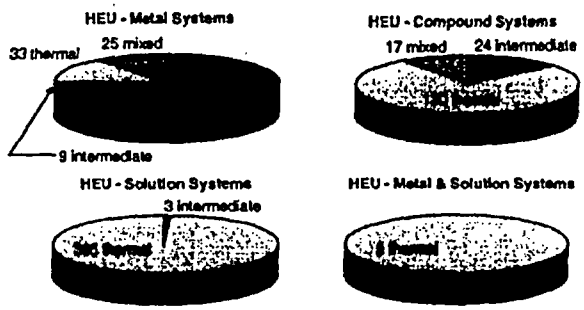

Fig. 5 Highly Enriched Uranium Systems (801 Configurations)

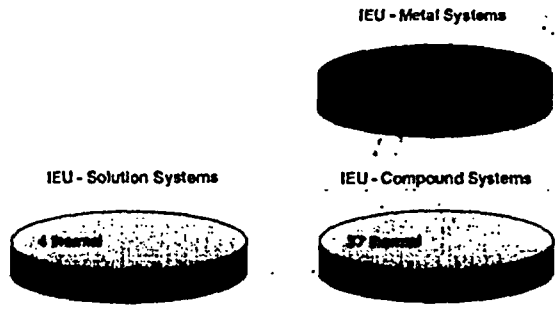

Fig. 6 Intermediate and Mixed Enrichment Uranium Systems (55 Configurations)

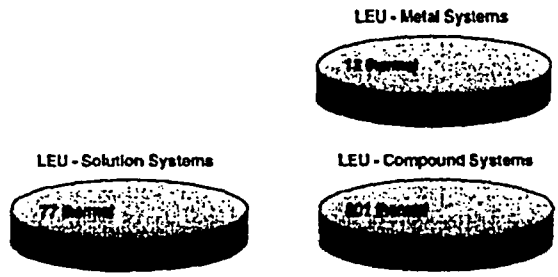

Fig. 7 Low Enriched Uranium Systems (891 Configurations)

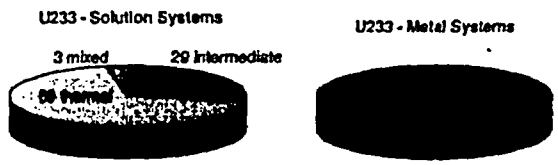

Fig. 8 Uranium-233 Systems (111 Configurations)

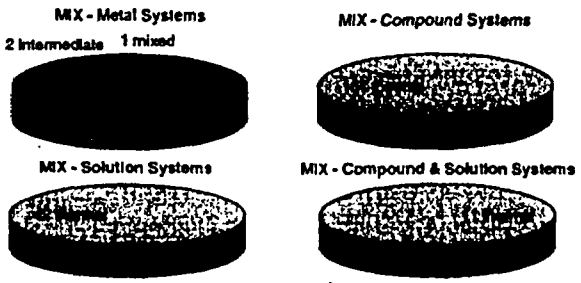

Fig. 9 Mixed Plutonium-Uranium Systems (282 Configurations)

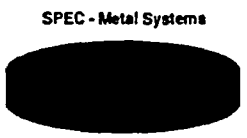

Fig. 10 Special Isotope Systems [10 Configurations -- ^{244}Cm, ^{238}Pu, ^{237}Np, and ^{242}Pu]

The 2001 Edition of the Handbook was published in September of 2001 (See Fig. 11). 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 request from the ICSBEP Internet Site at: http://icsbep.inel.gov/icsbep

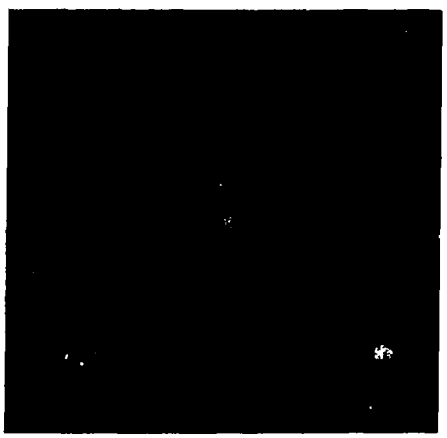

Fig. 11 September 2001Edtion

Several Cross Section Evaluation Working Group (CSEWG) benchmarks appear in the ICSBEP Handbook; however, benchmark specifications are not identical due to several factors associated with methodology used by the ICSBEP. In general, the ICSBEP benchmark specifications are considered to be the most accurate description of the benchmark. A correspondence between the CSEWG benchmark identifiers and the ICSBEP identifiers is given in Table 1 for the CSEWG Fast Reactor Benchmarks and in Table 2 for the CSEWG Thermal Reactor Benchmarks.

III. Peer Review Process

Each experiment evaluation included in the ICSBEP Handbook undergoes a thorough internal review by the evaluator's organization. Internal reviewers verify:

- The accuracy of the descriptive information given in the evaluation by comparison with original documentation (published and unpublished),
- That the benchmark specification can be derived from the descriptive information given in the evaluation,
- The completeness of the benchmark specification,
- The results and conclusions, and
- Adherence to format.

Table 1 ICSBEP Identifiers for CSEWG Fast-Reactor Benchmarks

Name	Benchmark Identifier	
	CSEWG Fast Reactor Benchmarks	ICSBEP
Jezebel	#1	PU-MET-FAST-001
VERA-11A	#2	
ZPR-3I-48	#3	
ZEBRA-3	#4	
Godiva	#5	HEU-MET-FAST-001
VERA-1B	#6	
ZPR-3-6F	#7	
ZPR-3-11	#8	
ZPR-3-12	#9	
ZEBRA-2	#10	
ZPPR-2	#11	
ZPR-6-7	#12	
ZPR-3-56B	#13	
SEFOR	#14	
ZPR-6-6A	#15	
SNEAK-7A	#16	
SNEAK-7B	#17	
ZPR-9-31	#18	
Jezebel-233	#19	U233-MET-FAST-001
BIG TEN	#20	IEU-MET-FAST-007
Jezebel-240	#21	PU-MET-FAST-002
FLATTOP-25	#22	HEU-MET-FAST-028
FLATTOP-Pu	#23	PU-MET-FAST-006
FLATTOP-23	#24	U233-MET-FAST-005
THOR	#25	PU-MET-FAST-008

In addition, each experiment undergoes an independent peer review by another working group member at a different facility. Starting with the evaluator's submittal in the appropriate format, independent peer reviewers verify:

- That the benchmark specification can be derived from the descriptive information given in the evaluation,
- The completeness of the benchmark specification,
- The results and conclusions, and
- Adherence to format.

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

IV. Uncertainties

During the evaluation process, missing data or weaknesses and inconsistencies in published data are often encountered and uncertainties are associated with all measurements. A significant effort is made to evaluate and quantify the effects of the uncertainties that arise from missing and inconsistent data on calculated k_{eff} values.

The "ICSBEP Guide to the Expression of Uncertainties" 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"[2] and the French equivalent[3]. Use of the Guide began informally in June of 2000; however, the Guide was not formally accepted by the ICSBEP Working Group until June 2001.

A decision made by the ICSBEP Working Group that a particular experiment is not acceptable for use as a "Criticality Safety Benchmark Experiment", based on inadequate data or unacceptably large uncertainties, 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. This is especially true when the data are not required to fill gaps in existing data. However, if the uncertainty is properly taken into account, the data may often be used in validation efforts.

V. 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 Handbook and for a significant portion of the configurations that have been added to the Handbook since 1998. It is anticipated that the 2002 version of the 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].

Table 2 ICSBEP Identifiers for CSEWG Thermal-Reactor Benchmarks

Name	Benchmark Identifier	
	CSEWG Thermal Reactor Benchmark	ICSBEP
ORNL-1	#1	HEU-SOL-THERM-013
ORNL-2	#2	HEU-SOL-THERM-013
ORNL-3	#3	HEU-SOL-THERM-013
ORNL-4	#4	HEU-SOL-THERM-013
ORNL-10	#5	HEU-SOL-THERM-032
TRX-1	#6	
TRX-2	#7	
TRX-3	#8	
TRX-4	#9	
MIT-1	#10	
MIT-2	#11	
MIT-3	#12	
PNL-1	#13	PU-SOL-THERM-021 Case 7
PNL-2	#14	PU-SOL-THERM-021 Case 8
PNL-3	#15	PU-SOL-THERM-011 Case 18-1
PNL-4	#16	PU-SOL-THERM-011 Case 18-6
PNL-5	#17	PU-SOL-THERM-011 Case 16-5
BAPL-UO_2-1	#18	
BAPL-UO_2-2	#19	
BAPL-UO_2-3	#20	
BNL-ThO_2-1	#21	
BNL-ThO_2-2	#22	
BNL-ThO_2-3	#23	
PNL-6	#24	PU-SOL-THERM-021 Case 3
PNL-7	#25	PU-SOL-THERM-004 Case 1
PNL-8	#26	PU-SOL-THERM-021 Case 2
PNL-9	#27	—
PNL-10	#28	—
PNL-11	#29	—
PNL-12	#30	PU-SOL-THERM-021 Case 5
PNL-30	#31	MIX-COMP-THERM-002
PNL-31	#32	MIX-COMP-THERM-002
PNL-32	#33	MIX-COMP-THERM-002
PNL-33	#34	MIX-COMP-THERM-002
PNL-34	#35	MIX-COMP-THERM-002
PNL-35	#36	MIX-COMP-THERM-002
L-7	#37*	
L-8	#38*	
L-9	#39*	
L-10	#40*	
L-11	#41*	
HISS/HUG	#42*	HEU-COMP-INTER-004
HISS/HPG	#43*	PU-COMP-INTER-003

* Not yet formally accepted

Included in the spectra / neutron balance information are:

- The energy corresponding to the average neutron lethargy causing fission, *EALF*;

  The average neutron lethargy causing fission is defined for group calculations by:

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

where m is number of a physical zones inside the core, $\bar{u}_g$ is the midpoint of the gth lethargy group, defined as lethargy of neutron with energy $\overline{E_g} = \sqrt{E_g E_{g-1}}$, Σ_{fg} is the group macroscopic fission cross section, and ϕ_g is the neutron flux within lethargy group g. Lethargy u of a neutron with energy E is defined as $ln\left(\frac{E_0}{E}\right)$, where E_0 is some maximum neutron energy, here 10 MeV.

$$EALF = \frac{E_0}{e^{\bar{u}}}$$

- The average neutron energy causing fission, AFGE;

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

where E_g is the midpoint of the gth 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.)

- The neutron gas temperature (T_n) in the thermal energy range for group calculations;

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

where $\sigma_g = \sigma_0 \sqrt{\frac{E_0}{\overline{E}_g}}$, T_0 = 293.6K, σ_0 is the cross section at E_0=0.0253eV (v=2200m/s, T=293.6K), and ϕ_g is the neutron flux in the groups collapsed into the thermal group (E<0.625 eV). Thus

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

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

- The percentage of the neutron flux, fissions, and captures that occur in the fast (Energy >100keV), intermediate (0.625eV ≤ Energy ≤ 100keV), and thermal (Energy <0.625eV) energy ranges;
- The percentage of fissions and captures by isotope over the core region;
- The average fission neutrons produced per neutron absorbed in the core, ($\nu\Sigma_f/\Sigma_a$);
- A graphic presentation of the neutron spectrum for bounding cases in each evaluation; and
- The percentage of the neutron flux, fissions, and captures that occur in a thirty-group structure.

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

VI. Database for the International Criticality Benchmark Evaluation Project (D.I.C.E.)

A new addition to the 2001 publication is a searchable database that will enable users to more effectively identify the experiments that are needed for their work. The database will also make it easier to characterize the information generated by the ICSBEP and identify gaps and inconsistencies in the data. The OECD has created an "on-line" data entry form that is being used by university students in the United States and France to summarize the data contained in each evaluation.

The ICSBEP database is programmed to produce a concise, two-page summary of each configuration. The summary includes:

- Basic identification information such as title, author(s), and reference(s),
- Date and place the experiment was performed,
- ICSBEP original publication and latest revision dates,
- Purpose for the experiment and the variable parameter(s),
- Description of the core and basic fuel unit,
- Isotopic composition of the fissile material,
- Fissile concentration (solution experiments),

- Moderator-to-fuel ratios (solution and lattice experiments),
- Type of reflector(s) if applicable,
- Type and concentration of neutron absorber material (soluble and/or fixed),
- Sample Calculated k_{eff} values for various codes and cross section data, and
- Detail Spectra 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 the database will enable users to more precisely define the experiments of interest. The user will be able to search, for example, for all experiments in which over a desired percentage of the fissions occur in the intermediate energy range. The database also allows users to download data into a file that will enable them to generate plots of calculated k_{eff} values versus various other parameters in the database.

VII. Conclusion

Over 150 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 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 criticality safety experimental data is preserved. The work of the ICSBEP has highlighted gaps in data, has retrieved lost data, and has helped to identify inadequacies and errors in basic nuclear data and cross section processing codes. The handbook is currently being used in 56 different countries (See Fig. 12).

Fig. 12 The International Handbook of Evaluated Criticality Safety Benchmark Experiments is in use in 56 countries

Acknowledgment

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. I would like to acknowledge the efforts of all of these dedicated individuals without whom the ICSBEP would not be possible. Specifically, I would like to acknowledge the efforts of:

- Dr. Virginia Dean, Lori Scott, and Chris White who work countless hours each year to ensure the success of ICSBEP Working Group Meetings and the quality of the annual publication,
- Yevgeniy Rozhikhin, Dr. Anatoli M. Tsiboulia, and Tatiana Ivanova of the Institute of Physics and Power Engineering (Russian Federation) who are responsible for the spectra work,
- Gilles Poullot, Danielle Doutriaux, and Jacques Anno of the Institut de Protection et de Sûreté Nucléaire (France) for leading the effort to produce the "ICSBEP Guide to the Expression of Uncertainties",
- Dr. Ali Nouri and Dr. Pierre Nagel of the Organization for Economic Cooperation and Development (OECD) Nuclear Energy Agency (NEA) for their work on the Database for the ICSBEP (D.I.C.E.) with the assistance of Students Laetitia Ghander (University of Paris), Paul Foster and Leslie Foster (Brigham Young University) and Nicolas Soppera (Ecole Nationale Supérieure d'Electronique, Informatique et Radiocommunications de Bordeaux), and
- Dae Y. Chung (U.S. DOE) and Dr. Enrico Sartori (OECD NEA), the initial program sponsors.
- 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).

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