STATUS AND PERSPECTIVES OF THE OECD/NEA WORKING PARTY ON NUCLEAR CRITICALITY SAFETY PROJECTS

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Abstract

New issues in criticality safety continue to emerge as spent fuel storage facilities reach the saturation point, fuel enrichments and burn-ups increase and new types of plutonium-carrying fuels are being developed. The new challenges related to the manipulation, transportation and storage of fuel demand further work to improve models predicting behaviour through new experiments, especially where there is a lack of data in the present databases.

This article summarises the activities of the OECD/NEA working groups that co-ordinate and carry out work in the domain of criticality safety at the international level. Particular attention is devoted to establishing sound databases required in this area and to addressing issues of high relevance such as burn-up credit. The activities of working groups are aimed toward improving safety and identifying economic solutions to issues concerning the back-end of the fuel cycle.

In particular the activities of the following groups are reviewed:

- Burn-up credit criticality benchmarks.
- International Criticality Safety Benchmark Experiments Project.
- Sub-critical benchmark experiments.
- Minimum critical values.
- Experimental needs in criticality safety.

Introduction

Nuclear criticality safety was established as a discipline more than 50 years ago in response to several accidents that had occurred in nuclear weapons programmes. The number of documented criticality accidents in “western” facilities over this period is slightly less than 50. Information concerning accidents that occurred in the ex-Soviet Union has been released in recent years, and more is being presented at this conference.

The importance of the safe handling of all fissile materials was recognised at an early stage both by the scientific community and the responsible authorities. At the beginning, intensive experimentation with a large variety of configurations and materials took place in order to establish a basis of knowledge for such systems. Computational methods and basic nuclear data, however, had either not yet properly developed or had not reached sufficient sophistication to reliably predict the critical status of fissile materials.

Over the years, substantial progress has been made in developing nuclear data and computer codes to evaluate criticality safety for nuclear fuel handling. This state-of-the-art knowledge also has an economic impact. The reduction of uncertainties in safety margins allows rational and more economical designs for manipulation, storage and transportation of fissile materials.

There are several working groups active in the Organisation for Economic Co-operation and Development’s Nuclear Energy Agency (OECD/NEA) which seek to promote international understanding. A working party was recently organised to review the activities of the existing working groups and to propose establishing task forces corresponding to new demands on methods development, experimental needs and international handbook data in the field of nuclear criticality safety.

Figure 1 shows the existing relationship between the different working parties reporting to the OECD/NEA Nuclear Science Committee. Members of the different working parties designated with the liaison assure that studies are co-ordinated, particular needs addressed and that feedback is provided. As many issues are concerned with criticality of spent fuels, this liaison assures that there is coherence between the systems proposed for investigation and that data needs for criticality safety are addressed properly.

This paper describes how the existing working groups are achieving successful results through international co-operation. It also discusses what the newly established Working Party on Nuclear Criticality Safety intends to accomplish from a global viewpoint with regard to emerging problems in nuclear criticality safety.

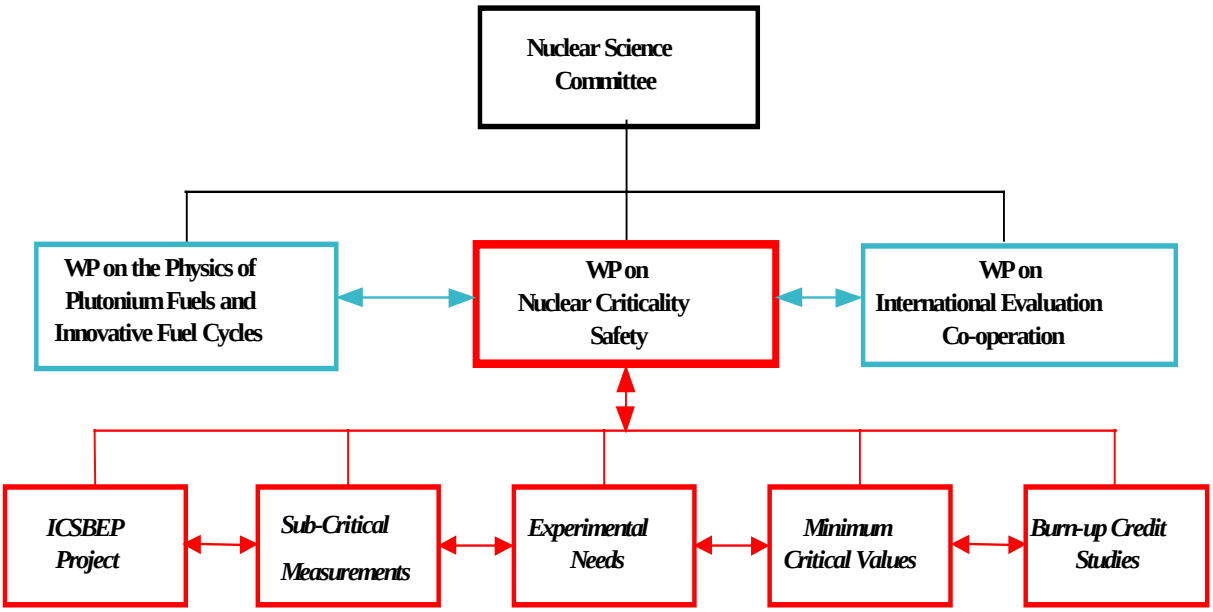
Working Party for Nuclear Criticality Safety (WPNCS)

A series of criticality benchmark studies addressing issues of storage, dissolution and transportation of nuclear materials was carried out several years ago by an OECD/NEA working group established under the leadership of G. Elliott Whitesides. The results of the work have been published both as NEACRP and NSC reports (see References) and presented at international conferences. The results of the benchmarks are widely used; this is confirmed by frequent references made in publications. The issues tackled by the group have evolved over time in line with needs expressed by the international criticality safety community. The technical competence of the group has also evolved through calling in new members with expertise in the specific issues under

investigation. The three criticality areas covered by studies so far encompass:

- Storage and transportation packages.
- Fuels undergoing dissolution.
- Burn-up credit.

Figure 1. Existing relationship between the different working parties reporting to the OECD/NEA Nuclear Science Committee and the criticality safety task forces



An increased interest has emerged in recent years in criticality safety studies with a scope difficult to cover completely at a technical level by a single experts group. It was therefore recommended that a Working Party on Nuclear Criticality Safety (WPNCS) be created that should provide guidance and overall co-ordination of these activities. The WPNCS was set up by the NSC in 1997. It makes proposals to NSC resulting from priority needs expressed in Member countries and reports results achieved. Where necessary the WPNCS delegates more specific technical work to task forces it proposes to set up. Their present structure and inter-relations are shown in Figure 1, and their programmes are briefly described later in this paper.

The scope of the WPNCS covers technical away-from-reactor criticality safety issues relevant to fabrication, transportation, storage and other operations related to the fuel cycle of nuclear materials.

Areas and items of activity include:

- Experiments – critical, subcritical and supercritical.
- Experiments databases – critical, subcritical, spent fuel isotopic composition.

- Code and data validation and benchmarking.
- Basic criticality condition data.
- Criticality safety handbooks and standards.
- Burn-up credit.
- Criticality accidents.
- Criticality safety of fuel cycle installations.

The objectives include:

- Guidance, promotion and co-ordination of high priority activities of common interest to the international criticality safety community, establish co-operations.
- Proposals to NSC on the setting up of specific task forces when needed.
- Maintenance of priority list of needs.
- Promotion of establishing international databases relevant to nuclear criticality safety.
- Monitoring of progress and reporting to NSC.
- Publishing progress report.
- Assisting the Steering Committee of the International Conference on Nuclear Criticality Safety (ICNC) series.

Additional criticality safety issues will be addressed in line with priorities established in Member countries and agreed among working party members as need arises. These may include:

- Criticality accidents (analysis, alarms, dosimetry).
- Databases (needs, developments, monitoring).
- Training and accreditation (exchange of national experience and approaches).
- Technical basis for standards.
- Nuclear data (liaison with WP on International Evaluation Co-operation).
- Codes and methods (Monte Carlo, probabilistic assessments).
- Decommissioning (criticality principles, techniques and monitoring).
- Waste repository issues (criticality issues).

A recent example that shows the different levels of co-ordination for this working method is the following. Within the Burn-up Credit Task Force several issues were identified, which were of wider interest. These were reported to WPNCS for further investigation, e.g.:

- Numerical convergence in computing criticality of de-coupled fissile systems such as spent fuel assemblies. This problem needs to be addressed for both deterministic and stochastic methods (a specific benchmark has been proposed for Monte Carlo methods).
- Effects of geometrical approximations in pin cells, e.g. square versus cylindrical.
- Mixed configurations of different units with fissionable material.

International Criticality Safety Benchmark Evaluation Project (ICSBEP)

The ICSBEP, chaired by Mr. J. Blair Briggs, INEEL, USA, is one of the OECD/NEA task forces. It was initiated in 1992 by the US DOE and became an official activity of the OECD/NEA in 1994. Its purpose is to provide the nuclear industry with qualified benchmark data sets by collecting criticality experiment data from the nuclear criticality laboratories, world-wide, rigorously reviewing and evaluating the information, and making sure it is edited in a consistent format. Both experimental and modelling data are integrated into the benchmark handbook. International Member countries include France, Hungary, Japan, Republic of Korea, Russia, Slovenia, the United Kingdom, the United States and Yugoslavia. The fruit of this effort is a seven-volume benchmark data handbook on CD-ROM; each volume represents different fissile material included in the experiment systems. The data are intended for use in validation of criticality safety computer codes as shown in Table 1. The latest edition contains data for 2 157 critical configurations (263 completed evaluations). The reviewing activity of the ICSBEP ensures that the handbook is continually revised through the addition of new experimental data. This benchmark handbook is now used successfully in thirty-seven countries. A detailed account of the recent progress and the latest edition will be made at this conference [1].

Subcritical measurements

The goals of the Subcritical Measurements Task Force include the development of a methodology for use of subcritical measurements as a means to benchmark Monte Carlo codes, evaluation of subcritical measurements for inclusion in the criticality safety handbook (ICSBEP) [1], assessment of uncertainty and bias associated with the interpretation of measured subcritical parameters in terms of k-effective and promotion of international co-operation in the field of subcritical measurements.

Currently, a benchmark based on subcritical measurements of an HEU uranyl nitrate solution system is being developed. The benchmark is to be used to establish the format required for inclusion in the ICSBEP handbook. This example should be completed by the end of 1999.

Several groups have identified possible subcritical measurements for inclusions in the handbook that include modified source multiplication measurements by AEA Technology, Inc., pulsed neutron and Rossi-alpha measurements by Los Alamos National Laboratory, noise and Feynman variance measurements by the Japanese Atomic Energy Research Institute, and noise measurements by Oak Ridge National Laboratory. The subcritical benchmarks will attempt to resolve issues concerning

code bias as a function of the degree of subcriticality.

Table 1. Distribution of configurations in the ICSBEP data handbook

Plutonium Metal Systems	38
Plutonium Compound Systems	3
Plutonium Solution Systems	24
Vol. 1, Total Plutonium Systems	**65**
Highly Enriched Uranium Metal Systems	44
Highly Enriched Uranium Compound Systems	19
Highly Enriched Uranium Solution Systems	35
Vol. 2, Total Highly Enriched Uranium Systems	**98**
Intermediate/Mixed Enrichment Uranium Metal Systems	10
Intermediate/Mixed Enrichment Uranium Compound Systems	3
Intermediate/Mixed Enrichment Uranium Solution Systems	1
Vol. 3, Total Intermediate/Mixed Enrichment Uranium Systems	**14**
Low Enriched Uranium Metal Systems	2
Low Enriched Uranium Compound Systems	36
Low Enriched Uranium Solution Systems	10
Vol. 4, Total Low Enriched Uranium Systems	**48**
^{233}U Metal Systems	6
^{233}U Compound Systems	0
^{233}U Solution Systems	4
Vol. 5, Total ^{233}U Systems	**10**
Mixed Uranium-Plutonium Metal Systems	10
Mixed Uranium-Plutonium Compound Systems	9
Mixed Uranium-Plutonium Solution Systems	5
Vol. 6, Total Mixed Uranium-Plutonium Systems	**24**
Special Isotope Metal Systems	4
Special Isotope Compound Systems	0
Special Isotope Solution Systems	0
Vol. 7, Total Special Isotope Systems	**4**

Experimental needs in criticality safety

With the declining use of and actual loss of experimental facilities and personnel world-wide, the basis for criticality safety limits has been shifting from physical measurements to reliance on complex computer code calculations. Validation efforts for these codes must include some physical measurements as this is the tie back to reality. Establishments operating criticality safety facilities from the OECD area and outside have been struggling to prevent their permanent closure. Only a very few facilities are still operational today. Discussion at the international level has thus taken place on

the effects such closures would have on future criticality safety work and on current and future needs for critical experiments.

The OECD/NEA organised an international experts meeting on needs for critical experiments in Albuquerque, NM from 25-26 September 1995 [2] covering away-from-reactor criticality issues. Existing criticality safety experimental facilities including the potential in expertise and equipment they represent were reviewed. Computational and experimental requirements were then identified, data from experiments available to the international criticality safety community and their coverage of present and future needs were addressed. Finally it was agreed to draw up a list of necessary experiments, meeting the consensus of experts as far as their importance and priority is concerned and the potential in economy to industry they can represent. The following recommendations were made:

- Given the limited number of operational critical facilities and the international scope of the needs for criticality safety technology, the NEA should encourage the performance of new critical measurements on a multilateral, international basis with regard to the sharing of facilities, staff expertise and funding resources.

- Given the absence of some experimental capabilities in many countries and near-unique capabilities in others, the NEA, through its Member countries' representatives, should recommend to their sponsoring agencies that certain facilities with unique capabilities be made available for international measurement programmes. This policy would reduce the need for redundancy in capabilities and promote stable funding for maintaining staff and equipment.

The new Task Force on Experimental Needs in Criticality Safety has started to investigate more definitive, quantitative processes for demonstrating an experimental need relative to a particular application or application area. Methodologies to help identify/justify experimental needs are being analysed and methods as to the area of applicability of experiments and discussion on a system and methods for extrapolating uncertainties resulting from the existing knowledge base is taking place. The data from the ICSBEP handbook will be used for establishing how much of the parameter space is covered by these experiments and to identify important areas where data are lacking or of insufficient quality.

The quantitative methodologies will allow to focus on high priority needs for which no experimental data or poor quality data are available. Through international sharing of facilities, coverage of the high-priority needs with the limited number of available facilities can be ensured.

In view of the limited number of operational critical facilities and the international scope of the needs for criticality safety technology, the task force will encourage the performance of new critical measurements on a multilateral, international basis with regard to the sharing of facilities, staff expertise and funding resources. Also, given the absence of some experimental capabilities in many countries and the near unique capabilities in others, the task force concludes that the NEA should, through its Member countries' representatives, recommend to their sponsoring agencies that certain facilities with unique capabilities be made available for international measurements programmes. This policy should reduce the need for redundancy in capabilities and promote stable funding for maintaining staff and equipment.

The existing facilities, if shared through international programmes, can still cover the needs in the area of criticality safety. Closing any of these facilities would, however, jeopardise the capability

of acquiring experimental data needed for criticality accident free handling of diverse fissile materials.

Some important criticality safety experimental facilities identified in this context are shown in Table 2.

Table 2: Some important criticality safety experimental facilities

Belgium / Czech Rep.	Critical Experiment with Spent Fuel for Burn-up Credit Validation (REBUS international programme)
France	IPSN – Valduc Facility CEA – EOLE and MINERVE Facility
Japan	NUCEF (STACY and TRACY) and TCA facilities at JAERI, Tokai-mura KUCA facility at Kyoto University DCA at JNC, Oarai
Russia	SPH facility at IPPE. Obninsk FKBN-2M facility at VNIIEF, Sarov, Nizhny Novgorod FKBN-M facility at VNIITF, Snezhinsk RBC-I, ARGUS, IIN facilities at KIAE, Moscow
USA	LACEF facilities at Los Alamos, NM SFSX at SNL, Albuquerque, NM ZPPR at Argonne West, ID

The objectives of this task force include:

- Compiling needs for high-priority experiments, updated and reaffirmed on a regular basis.
- Promoting the exchange of measurement objectives and experimental planning on a national and international basis.
- Encouraging the development of bilateral and multilateral international programmes.
- Facilitating co-operative and comparative studies through the sharing of technology and materials.
- Providing technical reviews of facility capabilities and experimental techniques.
- Co-ordinating activities with other NSC experimental work groups (subcritical measurements, reactor lattice criticals, nuclear data measurements, etc.).

This international compilation will be focused on high-priority needs. The format will be similar to the previously used United States format in that it will contain more specific information on the desired experimental features and parameters, as well as programmatic significance [3].

Burn-up credit criticality benchmarks

Burn-up credit is a term that applies to the reduction in reactivity of burned nuclear fuel due to the change in composition during irradiation.

The main objective of the OECD/NEA Burn-up Credit Task Force is to demonstrate that the available criticality safety calculational tools are appropriate for application to burned fuel systems and that a reasonable safety margin can be established. For this purpose the Task Force established a suite of burn-up credit criticality benchmarks. The benchmarks have been selected to allow a comparison of results among participants using a wide variety of calculational tools and nuclear data sets. The nature of the burn-up credit problem requires that the capability to calculate both spent fuel composition and reactivity be demonstrated. The benchmark problems were selected to investigate code performance over a variety of physics issues associated with burn-up credit: relative performance of fission products and actinides with respect to the multiplication factor (k) for light water reactors (LWRs) and VVERs; trends in k and isotopic composition with burn-up and enrichment for LWRs; effects of axially distributed burn-up in LWRs; effects of void distribution for boiling water reactors (BWRs); and effects for mixed oxide (MOX) fuels. It is important to note that the focus of the working group is the comparison of the results submitted by each participant to assess the capability of commonly used code systems, not to quantify the physical phenomena investigated in the comparisons or to make recommendations for licensing action. Participants used a wide variety of codes and methods based on transport theory, using S_N, nodal and Monte Carlo techniques. Nuclear data (both cross-section and decay data) were taken from a variety of sources – multiple versions of the Evaluated Nuclear Data Files (ENDF/B), the Japan Evaluated Nuclear Data Libraries (JENDL) and the Joint Evaluated Files (JEF). Both multi-group and continuous energy cross-section data were used in the study. Table 3 is a summary of the benchmark problems addressed noting both the primary objective and current status of each.

Since the objective of the Burn-up Credit Task Force thus far has been to assess code capabilities, the results are most often presented as the standard deviation (σ) among participants. There has been no attempt to make a safety case for licensing nor to provide bounding values on the observed trends or physical phenomena (e.g. the effect of axially distributed burn-up). However, the group does discuss specific or suspected sources of discrepancies, leading to the identification of further studies.

The burn-up covered in the study ranges from fresh fuel to 50 GWd/t and cooling periods from one to five years and varying enrichments.

In support of the burn-up credit studies, a Spent Fuel Isotopic Composition Database [4] (SFCOMPCO) has been developed containing data collected from 13 LWRs, including seven PWRs and six BWRs in Europe, the USA and Japan. It is also planned to include measured axial profiles.

Measured axial burn-up profiles of PWR spent fuel from GKN have been released by Siemens/KWU in the framework of the benchmark studies. Additionally computed axial burn-up distributions from 22 PWRs based on data from utilities in the USA have been compiled (YAEC 1997) and are available for use/study by the Task Force.

The group in addition reviews criticality benchmark experiments that are applicable to burn-up credit and provides feedback to the Task Force on Experimental Needs.

A liaison is established with the Working Party on International Evaluation Co-operation (as shown in Figure 1) to co-ordinate data needs. Nuclear data needs in burn-up credit primarily concern

major and minor actinides as well as fission products. As far as fission products are concerned, 15 fission products that are stable, non-volatile and which contribute to about 75% of the total fission products absorption have been selected for the different studies. They are ^{95}Mo, ^{99}Tc, ^{101}Ru, ^{103}Rh, ^{109}Ag, ^{133}Cs, ^{147,149,150,151,152}Sm, ^{143,145}Nd, ^{153}Eu and ^{155}Gd. Important experimental programmes have and are being conducted. They aim at the validation of cross-sections in state-of-the-art evaluations such as ENDF/B-VI.4, JEF-2.2 and JENDL-3.2, and to develop recommendations for needs of re-evaluation. For instance, the JEFF project has set up a specific sub-group on fission product cross-sections addressing these issues.

Table 3. Summary of benchmark problems addressed by the OECD/NEA Burn-up Credit Task Force

Benchmark	Primary Objective	Status
Phase I-A	Examine effects of seven major actinides and 15 major fission products for an infinite array of PWR rods. Isotopic composition specified at 3.6 wt.% ^{235}U at 0, 30 and 40 GWd/MTU and at one- and five-year cooled.	Completed
Phase I-B	Compare computed nuclide concentrations for depletion in a simple PWR pin-cell model, comparison to actual measurements at three burn-ups (27.34, 37.12 and 44.34 GWd/MTU).	Completed
Phase II-A	Examine effect of axially distributed burn-up in an array of PWR pins as a function of initial enrichment, burn-up and cooling time. Effects of fission products independently examined.	Completed
Phase II-B	Repeat study of Phase II-A in 3-D geometry representative of a conceptual burn-up credit transportation container. Isotopic compositions specified.	Completed
Phase II-C	Key sensitivities in criticality safety to burn-up profiles.	Draft specification
Phase III-A	Investigate the effects of moderator void distribution in addition to burn-up profile, initial enrichment, burn-up and cooling time sensitivities for an array of BWR pins.	Report to be published in 1999
Phase III-B	Compare computed nuclide concentrations for depletion in a BWR pin-cell model.	In progress
Phase IV-A	Investigate burn-up credit for MOX spent fuel pin-cell for three plutonium vectors (first recycle, fifth recycle, weapons-grade)	In progress
Phase IV-B	Compare computed nuclide concentrations for depletion in a MOX super-cell.	Draft Specification
Phase V	VVER burn-up credit. Similar to Phases I and II for PWRs but with hexagonal geometry and WWER fuel specification	In progress

The issue of burn-up credit is of particular importance today as it concerns the different operations involving spent fuel storage, transportation and dissolution. The number of sessions and papers in this conference is a clear expression of the real need for methods assessment felt in the different countries.

Minimum critical values

Basic minimum critical values are important physical constants needed for assessing safety margins in criticality and are used for licensing purposes. ISO standards have been established over the years based on computational methods and nuclear data available at the time of their approval. Both methods and data have been refined since, and different countries have undertaken work for establishing a new base for such values. The establishment of a common base of minimum critical masses, and the validation of codes and data used in computing them at the international level meets the interest of all the countries involved in nuclear fuel cycles. In particular, there is interest in the effects of various reflectors on criticality of plutonium and uranium fuels with enrichments higher than 5%; the review of the density formula for nitride solutions. Criticality and fissionability properties of actinide nuclides are addressed today in standards committees. It is the intention to transfer such data in the future to these committees.

The WPNCS recognised the need for a common technical basis for national and international programmes to be formed in support of establishing a standard, especially because new values reported in the literature are discrepant. A specific task force was set up, which met for the first time just before this conference.

The objectives of the task force on minimum critical values are to:

- Clarify the origin of reported discrepancies from the different countries, including the problem of the diverse density formulae.
- Agree on a common way for checking what are the correct values and determine their uncertainties.
- Identify basic important fissile systems with emphasis on plutonium where discrepancies are high.
- Address problems identified in an established priority list.
- Collect data for comparison, at present in the Basic Minimum Values for Criticality (BMVC) database operated by NAIS in Japan.

The establishment of safety limits is outside the objectives of this Task Force. It will compare methodologies used in different countries and provide technical support to ISO. This work involves co-ordinating and discussing issues concerning cross-sections with the WP on International Evaluation Co-operation (WPEC).

Concluding remarks

New realities have emerged in recent decades such as the lack of storage capacity of spent fuel, the escalation of back-end costs of the nuclear fuel cycle and the postponement of the commercialisation of fast reactors. Other issues resulting from the end of the Cold War, i.e. the necessity of criticality safety assessment applicable to unprecedented issues such as massive transportation and long-term storage of LWRs spent fuel, MOX fuel fabrication and its transportation for use in LWR as a means of plutonium stockpile reduction, etc., also need to be addressed.

In the coming years there will likely be further clarification of potential nuclear fuel cycle strategies, each one with its specific needs in criticality safety. Although a wealth of information is available from more than 50 years of cumulative knowledge acquired, case-specific analyses will be needed and will dominate debate and research. Criticality safety calls for constant support and attention. A sound understanding and correct application of the principles of nuclear criticality safety are vital to the nuclear industry. The objective is to pursue an accident-free goal, while keeping in mind the repercussions that an avoidable criticality excursion could have. Current activities and future initiatives will obviously build upon past accomplishments. Events have shown that criticality safety is an international issue. It is therefore in the interest of all that information be widely shared and disseminated, notably through the OECD/NEA.

The OECD/NEA Working Party on Nuclear Criticality Safety has been established to meet these new challenges at the international level. Sharing of information on data and methods and improvement of the common understanding of criticality safety issues will be instrumental in achieving an accident-free future.

Acknowledgements

The work carried out at OECD/NEA in the field of nuclear criticality safety through the different Groups is the results of contributions made by about 100 experts from 20 countries. The authors wish to acknowledge this large and essential contribution. It shows the genuine involvement of the criticality safety community with international co-operation.

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