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Overview of the Activities of the OECD/NEA/NSC Working Party on Nuclear Criticality Safety

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The OECD Nuclear Energy Agency (NEA) started dealing with criticality-safety related subjects back in the seventies. In the mid-nineties, several activities related to criticality-safety were grouped together into the Working Party on Nuclear Criticality Safety. This working party has since been operating and reporting to the Nuclear Science Committee. Six expert groups co-ordinate various activities ranging from experimental evaluations to code and data inter-comparisons for the study of static and transient criticality behaviours. The paper describes current activities performed in this framework and the achievements of the various expert groups.

KEYWORDS: criticality-safety, international co-operation, burnup credit, evaluation of experiments, minimum critical values, source convergence, transient benchmarks.

1. Introduction

The Nuclear Science Committee (NSC) is one of the six technical committees of the OECD Nuclear Energy Agency. Its mission is to help the NEA member countries identify, collate, develop and disseminate scientific and technical knowledge used for peaceful applications of nuclear energy. Several Working Parties and Task Forces co-ordinate the work in the areas of reactor physics, fuel cycle physics and chemistry, radiation shielding and criticality-safety. The Working Party on Nuclear Criticality Safety (WPNCS) was set-up in 1997 to co-ordinate the various activities in the area of criticality accident prevention in nuclear fuel cycle facilities. In the following paragraphs, the achievements of the different expert groups will be presented. References to the Expert Groups web site will be used in these paragraphs. The URL address of a specific Expert Group web site is constructed by adding an extra level to the Working Party's web site. For convenience, the following variable will be used throughout the paper: WEB=http://www.nea.fr/html/science/wpncs

2. Burn-up Credit

The reactivity of nuclear fuel decreases with irradiation (or burn-up) due to the transformation of heavy nuclides and the formation of fission products. Burn-up credit studies focus on accounting for fuel irradiation in criticality studies of the nuclear fuel cycle (e.g. transport and storage of spent fuel). The expert group on Burn-up Credit was established in 1991 to address scientific and technical issues connected with the use of burn-up credit in nuclear fuel cycle operations. Benchmark exercises were defined in order to compare the prediction capabilities of widely used computer codes and cross-section libraries. Basically, two kinds of benchmarks were considered: criticality calculations (where the fuel composition is given as input, the exercise then consists of comparing the calculated multiplication factors and fission densities) and depletion calculations (where the aim of the benchmark is to compare the calculated composition of spent fuel). The group has attempted to cover a range of applications and to be as close as possible to actual configurations (e.g.

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transport flasks). Low-enriched uranium oxide fuels irradiated in pressurized water reactors were considered in four phases (I-A[1], I-B[2], II-A[3] and II-B[4]) and a fifth phase involving this fuel is still on-going (II-C). Phases III-A[5] and III-B[6] considered uranium oxide fuels irradiated in boiling water reactors whereas Phases IV-A[7] and IV-B[8] investigated burn-up credit issues associated with MOX fuels irradiated in pressurized water reactors. Of the aforementioned exercises, three studied the effect of axial burn-up profile with an increasing level of complexity. In Phase II-A, a typical axial profile was adopted in an infinite array of irradiated fuel pins, a typical configuration for wet storage. In Phase II-B, the same axial burn-up profile was adopted in connection with a realistic transport flask configuration, which included some accidental configurations where absorbing materials were removed from the most reactive end. Finally, Phase II-C is being devoted to the study of various axial profiles and to their effect on criticality calculations.

The specifications of all these benchmarks together with the analysis reports of the completed benchmarks are available for free download on the Expert Group's web site at: WEB/buc. It should be noted that throughout the phases of this study, the Expert Group faced the problem of experimental data shortage. In fact, only Phase I-A specifications are based on actual experimental data. JAERI has initiated an effort for the collection of experimental data on spent fuel composition. A relational database called SFCOMPO was created in order to collect and disseminate these data. The database was transferred on the NEA web site (WEB/sfcompo) in Autumn 2002 and is now open for free consultation. Further developments are planned (see the paper by K. Suyama et al.[9]) and will be co-ordinated by the Working Party in close co-operation with the NEA Databank and JAERI.

3. Experimental Benchmark Evaluation

The Criticality Safety Benchmark Evaluation Program was created in 1992 at the initiative of the US/DOE. The program became an activity of the Nuclear Science Committee in 1995 when international experts joined the effort by providing experimental data and participating in the evaluation and review process. The aim of the program is to identify, evaluate, verify, and formally document a comprehensive and internationally peer-reviewed set of criticality safety benchmark data that may be used to validate neutronics codes and nuclear cross-section data. The data are published in the International Handbook of Evaluated Criticality Safety Benchmark Experiments[10]. The Handbook is updated every year to include new experiments and to revise previously published ones when new experimental data are found. The current edition of Handbook spans over 28000 pages. Due to this large content, the publication of the handbook in a paper form stopped in 1995 and the handbook is now published in electronic form as a CD-ROM.

The Handbook contains benchmark data for seven fuel categories: uranium (high enriched uranium (HEU), low enriched uranium (LEU), intermediate and mixed enriched uranium (IEU)) plutonium (PU), mixed uranium and plutonium (MIX), U233, and special isotope (SPEC) fuels [^{244}Cm, ^{238}Pu, ^{237}Np, and ^{242}Pu]. The ICSBEP experiment classification includes two other levels which characterize the fuel form (SOLution, METal, COMPound and a mixture (MISC) of these forms) and the neutron spectra in the fuel (THERMal, FAST, INTERmediate and MIXED).

Most of the experiments contained in the Handbook are critical or near critical configurations. A few evaluations describe sub-critical experiments and their number will hopefully increase in the next editions. It is also planned to extend the scope of the program to include other types of experiments (e.g. criticality alarm benchmarks, criticality transients).

The paper by B. Briggs et al.[11] presented at this conference gives more details about the content of the 2003 edition of the Handbook. Here, we will just mention a few areas on which more emphasis was put in the last couple of years.

The evaluation of experimental uncertainty is certainly an important part of the experimental evaluation process. However, it was recognized that the uncertainties quoted in different sources (e.g. chemical analysis, manufacturing specifications) might have different statistical meanings. An important effort was produced in order to express all these uncertainties in a consistent way that allows the combined uncertainty to have a meaningful confidence interval. A guide to the expression of uncertainties was developed to help the evaluators in this task.

The ICSBEP Handbook contains not only benchmark data but also a set of calculated data (e.g. spectral indices) that provides some insights on the neutronics of each configuration. More detailed information about the neutron spectra was added in the new versions of the CD-ROM. Neutron flux and reaction rates in the fuel region are now available in a 299-group energy structure. A detailed neutron balance in different regions of the configuration is also available. Finally, sensitivity coefficients, which characterize the relative change of k-eff due to a 1% change of multigroup cross-sections are included for HEU solution configurations. All this data was generated by a group of researchers from the IPPE in Obninsk[12].

With the important growth of the Handbook (3073 experimental configurations are contained in the 2003 edition) and the addition of many numerical data, it was decided to develop an efficient and user-friendly means for accessing specific information contained in the Handbook. A relational database was designed and selected data was extracted from the Handbook. The main characteristics of a configuration (e.g. description of the geometry, fuel composition, moderating and reflecting materials...) are thus entered in the database together with all the spectra information described above. A users' interface was then developed to query the database and to extract the information needed by the user. Plotting capabilities were also included to compare the flux and reaction rates in different configurations. The database and the corresponding interface, called DICE, are part of the ICSBEP CD-ROM.

The ICSBEP evaluations and benchmark models are valuable for direct use by criticality safety analysts and nuclear data specialists. The Handbook is now considered as the primary source of experimental benchmarks for neutronic code and cross-section validation. Two special issues of the Nuclear Science and Engineering journal devoted to the ICSBEP work are being prepared (expected to be published in September and October 2003).

4. Experimental needs

The Expert Group on Experimental Needs was created in 1999. The aim was to identify common experimental needs in different countries and co-ordinate possible efforts to address these needs. One of the main questions debated in the first meetings was the justification of these needs, i.e. ensuring that the existing experimental results are insufficient to justify the validation of computer codes and data for a particular configuration. Methods developed to address this issue were presented (see for instance N. Smith [13], E. Gagnier et al.[14] and L. Broadhead et al.[15]).

The group then designed a Web-based form for the expression of experimental needs in criticality safety. This form is available at: WEB/experimental-needs. The idea is to collect these needs and to form a panel of experts able to make a judgment on the appropriateness of these requests. If the need is judged as being sound and shared among several users, the panel can then contact experimental facilities in order to get experimental program proposals. Opportunities for establishing international experimental programs could in principle emerge from these discussions. One area that has been identified, as a candidate for such an international experimental program involves configurations with MOX fuels at relatively low moderation ratios.

5. Minimum Critical Values

The Expert Group on Minimum Critical Values was established in 1999 with the aim of compiling and comparing minimum critical data used in different countries. The group has focused on data for homogeneous aqueous solutions of uranium oxides, plutonium oxides, uranium nitrate and plutonium nitrate. Efforts are being pursued for identifying the origin of discrepancies between the compiled data.

6. Source Convergence

The Expert Group on Source Convergence Analyses started in 2000 to tackle the outstanding difficulty of convergence associated with the calculation of systems composed by loosely coupled fissile units. Four sets of benchmarks were defined and calculated by various Monte-Carlo and deterministic codes. A more comprehensive presentation of the activities of this group is made by R. Blomquist et al.[16] in this conference. Likewise, the Expert Group's web site (WEB/convergence) contains the detailed specifications. This section will only provide some highlights.

The most sensitive parameters vis-à-vis the convergence properties of k-eff series and generation-wise fission source distributions are: the initial spatial distribution of the starters, the number of skipped generations before tallying the results, the number of neutrons per generations and the overall number of generations. These parameters were considered in all the benchmarks.

The geometrical complexity of the benchmarks range from very simple slabs to a complicated arrangement of actual fuel assemblies in a storage configuration. In all configurations, the coupling between fissile units was an important parameter that was either kept extremely weak for all configurations or varied across the benchmark cases. In most cases, an adequate choice of the initial source distribution was not straightforward. Consequently, the simple and widely used assumption of uniform source distribution was inappropriate in all these cases.

One of the benchmarks attempted a statistical analysis of simulation replicas, i.e. simulations performed with exactly the same conditions the only change being the use of different random number sequence. The aim of these simulations study was to study the stability of source convergence vis-à-vis the randomness. Interestingly, this benchmark revealed differences in the properties of convergence stability among the computer codes used. This suggests that differences exist in the way the powering algorithms are implemented in the various codes and that these differences are probably important. Besides the obvious difference concerning the use or not of the super-history powering methods, other non-straightforward differences do exist which lead to different level of noise and randomness in the source convergence process. Among these differences one can quote, the choice of estimator for fission sites (collision estimator or absorption estimator), the way these collision sites are grouped and sampled in the beginning of each generation. A more thorough analysis of these differences would certainly help gain a better understanding of the fission source convergence process.

The analysis reports of the benchmark results are being finalized and the publication of the benchmark reports is foreseen for 2003. Other areas proposed for the continuation of this expert group include:

- The generation of an annotated bibliography on source convergence issues.
- The development and comparison of statistical tests for convergence detection.
- Additional benchmarks oriented to investigate convergence problems encountered by criticality safety practitioners.
- The development and testing of statistical methods that can be used to detect improper source convergence.

7. Criticality excursions

The Expert Group on Criticality Excursion Analyses was established in 2001. Three main areas have been identified and included in the scope of the expert group:

- The evaluation of criticality excursion experiments. A draft format was designed by extending and adapting the format of the ICSBEP evaluation to include the sequence of excess reactivity introduction and to provide the time dependent measured data (temperature, energy release,...).
- Inter-code comparison exercises. Two sets of benchmarks were submitted. These benchmarks are based on experimental programs performed in the SILENE reactor (CEA, Valduc, France) and the TRACY reactor (JAERI, NUCEF, Japan). The specification of the benchmarks are available on the Expert Group's web site (WEB/excursions) and are briefly described below. Only a few participants have expressed their intention to calculate the proposed benchmarks. The number of participants seems to be limited by the availability of appropriate computer codes for the simulation of criticality transients.

- The development of Web-based information resources on criticality excursions including a description of experimental programs and generated data, a short synopsis on existing modeling capabilities, and references to criticality accidents. This information is available at: WEB/excursions

It should be pointed out that the modelling of criticality transients received less interest in the past than static criticality. To our knowledge, there is no available public domain code capable of predicting the behaviour of criticality excursions. This shortage explains why the participation to the benchmark exercises is expected to be quite low. Efforts to establish public access to transient analysis codes are planned.

7.1 Description of transient benchmarks

The SILENE[17] reactor is an annular cylindrical tank with a movable reactivity/control rod (the main absorbing material being cadmium) in the centre of the cylinder. The core contains a highly enriched (U235 enrichment equal to 92.74 wt%) uranyl nitrate solution with a uranium concentration of 70.78 g/l. Let H_c be the critical height of the solution in the core without the control rod. The three proposed benchmarks are based on pulse mode experiments. Starting from a configuration where the control rod is inserted, the core is filled with the nitrate solution up to a certain height, H, where $H > H_c$. The transient experiment is triggered by a quick withdrawal of the control rod leaving the core above the critical state. This simulates a sudden reactivity insertion, the level of which depends on the solution height before the control rod withdrawal. The proposed benchmarks describe reactivity insertions of 0.51 $, 0.97 $ and 2.31 $.

The TRACY[18] reactor is also an annular cylindrical tank with a movable reactivity/control rod made of B_4C. The core contains a low-enriched (U235 enrichment equal to 9.98wt%) uranyl nitrate solution with a uranium concentration of 390 g/l. Five TRACY configurations are proposed as benchmarks. They also correspond to pulse mode experiments with inserted reactivity of 0.3 $, 0.7 $, 1.10 $, 2.00 $ and 2.97 $.

Future plans

It is recognized that the WPNCS is a valuable forum for international co-ordination in the field of criticality-safety including:

- The exchange of information on on-going and projected national programs.
- The organization of the ICNC series of International Conferences on Nuclear Criticality Safety (selection of host country, set-up of the international advisory and program committee).
- The co-ordination of international activities in different areas relevant to the analysis of reactivity of systems in the nuclear fuel cycle and associated properties (evaluation of experiments, code and data inter-comparison exercises...).
- To support other international initiatives (other committees within the OECD/NEA, IAEA and ISO) by providing technical basis needed for investigations related to the safety of nuclear installations.

The WPNCS will continue to establish and co-ordinate co-operative efforts aimed at developing the scientific knowledge in the area of criticality-safety. It is also recognized that the criticality-safety field is so wide that the number of subjects of interest to the community is potentially large and calls for various fields of expertise. The WPNCS will adapt its structure and composition to make the best use of available resources in addressing the technical challenges of the criticality-safety community.

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