IRPhE - INTERNATIONAL REACTOR PHYSICS EXPERIMENTS DATABASE

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ABSTRACT

The OECD/NEA Nuclear Science Committee (NSC) has identified the need to establish international databases containing all the important experiments that are available for sharing among the specialists. The NSC has set up or sponsored specific activities to achieve this. The aim is to preserve them in an agreed standard format in computer accessible form, to use them for international activities involving validation of current and new calculational schemes including computer codes and nuclear data libraries, for assessing uncertainties, confidence bounds and safety margins, and to record measurement methods and techniques. The databases so far established or in preparation cover the following areas related to physics issues: **SINBAD -** a radiation shielding experiments database encompassing reactor shielding, fusion blanket neutronics, and accelerator shielding; **ICSBEP -** International Criticality Safety Benchmark Experiments Project Handbook, with about 3000 critical configurations with different combination of materials and spectral indices; **IRPhE -** International Reactor Physics Experimental Benchmarks Evaluation Project

The **IRPhE** project is described in the following including results achieved, work in progress and planned.

1. INTRODUCTION

A large series of essential experiments concerned with nuclear energy and technology have been carried out over the last several decades in different research laboratories. This has required a large investment in terms of infrastructure, expertise and cost. Results from these experiments remain of great value today, as they provide the record on which development and validation methods are based and represent a significant collection of data for past, present and future research.

These data represent a cultural heritage of the nuclear age and the nuclear community believes in the high value of this heritage. This information will certainly be extremely useful in finding the promising solutions, in avoiding deadlocks, and also in guiding the design of promising new experiments, whenever the further development of nuclear energy takes off again. The gap between the old and new generations of experimenters is growing and special attention should be given to the transfer of this heritage of the old generation to the new ones.

The OECD/NEA Nuclear Science Committee (NSC) has identified the need to establish international databases containing all the important experiments that are available for sharing among the specialists. The NSC has set up or sponsored specific activities to achieve this. The aim is to preserve them in an agreed standard format in computer accessible form, to use them for international activities involving validation of current and new calculational schemes including computer codes and nuclear data libraries, for assessing uncertainties, confidence bounds and safety margins, and to record measurement methods and techniques. Reactor physics experiments do not represent the only heritage of the previous generations, but preservation of their results is especially important, since the disappearance of experimental facilities is more typical in this area than in other important fields of nuclear energy related experiments.

Experimental benchmark information exists in various forms, in many instances in a form inconvenient for the user, and with an educated effort and personal contacts with experts, the information is pieced together, but this requires a considerable amount of time of professionals and risks to be duplicated by different organisations. The amount of time for computational work is not dominated by computer run times in such a situation, but instead by the gathering and checking of data for input and for method validation. A significant saving results from disseminating a standard benchmark set to be used worldwide. A framework for professionals that use the standard benchmark set to validate and verify modeling codes and data for radiation transport, criticality safety and reactor physics applications guarantees a comparative set of analyses. It represents also a good basis for pinpointing important gaps and where efforts should be concentrated.

2. IRPhE - REACTOR PHYSICS EXPERIMENTS

2.1 REASONS OF AND NEEDS FOR CO-ORDINATED PRESERVATION ACTIVITIES

It was recently recognised that there is an urgent need to establish an effort to preserve valuable reactor physics data and techniques. In the spring of 2000, the OECD/NEA Nuclear Science Committee (NSC) established the International Reactor Physics Experiment Evaluation Project (IRPhE) to meet this objective. This project focuses specifically on Reactor Physics experiments, the basis for today's methods used in design, analysis, and the operation of nuclear energy systems pertaining to the core and its behavior during different operating conditions. This project is part of a more general issue concerned with Knowledge and Competence Preservation & Management addressed in the different OECD Member countries and beyond.

The need for preserving experimental data beyond the normal archiving of previous results emerges because of the following factors

- in many cases, the direct local archiving is incomplete from the point of view of the description of the reactor, the measurement methods, and the primary experimental information.
- in the case of earlier experiments, archiving did not take place in a computerised format and, consequently, its availability is very limited.
- the experimenters who may help in the complete recovery of the experimental results are ageing and, after a short time, will no longer be available.
- experimental facilities are being closed, one after the other, and the preservation of the old

archives is sometimes not ensured.

The NSC consequently agreed to establish an inter-national inventory of relevant reactor physics experiments and measurements, with the following Scope and Objectives

2.2 SCOPE

- Maintenance of an international inventory of relevant reactor physics experiments and measurements, preservation in computer readable form of their primary documentation and data describing the facilities, characterising the experimental techniques, the experimental results and interpretation thereof.
- Development and maintenance of an international database containing a sub-set of high priority reactor physics benchmark specifications derived from the experiments performed at various nuclear facilities around the world, relevant for or including data from power reactors or for the development of future nuclear reactors such as Generation IV concepts.

The following types of measurements are to be included:

- fundamental mode lattice experiments;
- heterogeneous core configurations;
- power reactor start-up data;
- core follow experiments;
- specific applications experiments (e.g. fission-product integral data, irradiation experiments).

The benchmark specifications and experimental data are intended for use by nuclear reactor physicists and engineers to validate current and new calculational schemes, including computer codes and nuclear data libraries, for assessing uncertainties, confidence bounds and safety margins, and to record measurement methods and techniques.

2.3 OBJECTIVES

To provide the nuclear community with qualified benchmark data sets by collecting reactor physics experimental data from nuclear facilities world-wide. More specifically the objectives of this activity are as follows:

1. maintaining an inventory of the experiments that have been carried out and documented;
2. archiving the primary documents and data released in computer readable form;
3. promoting the use of the format and methods developed and encouraging their adoption as a standard.

For those experiments in which interest and priority is expressed by Member countries or Working Parties and Executive Groups within NEA, provide guidance or co-ordination in:

4. compiling experiments into a standard, internationally agreed upon format;
5. verifying the data, to the extent possible, by reviewing original and subsequently revised documentation, and by talking with the experimenters or individuals that are familiar with the experimenters or the experimental facility;
6. analysing and interpreting the experiments with current state-of-the-art methods;
7. electronically publishing the benchmark evaluations.

2.4 METHOD

This project, it was agreed, should follow methods and principles established successfully for ICSBEP and keep formats completely compatible in order to prevent duplication of activities and take advantage and benefit of work carried out in each of the projects. Close co-ordination and co-operation between the projects is established.

Among the acceptance criteria for an evaluation the following are cited:

- Description of experimental method
- Description of data handling method
- Specification of corrections if any
- Specific handling of technological uncertainties
- Estimation of biases
- Compliance with formal requirements
- Presentation of sample calculations

Even though one of the main goals is to provide high quality information for supporting code and data validation, the applied experimental methods need to be documented carefully, but only such methodical details need to be presented which are necessary for interpreting the measured reactor physics parameters. In that case, however, a special handbook will be necessary which discusses the experimental methods applied for obtaining the preserved reactor physics data. The set of well documented experiments in standard format could form the basis for a handbook for the **experimental methods**, applicable for studying reactor lattices or, more generally, reactor cores.

Experts have agreed that the work should be carried out at different levels of sophistication as concerns the quality of the final data sets, each meeting different needs. This subdivision is a convenient way of establishing quality of data, priorities of work and its scheduling.

First a comprehensive list of experimental sets of data containing the potential candidates for the database has to be established indicating those that are judged of particular importance and are under threat of being lost. This **inventory** will be prepared on the basis of the input provided by the different laboratories, both governmental and industrial and should include information that characterises the system, types of tests, quantities measured and methods used. This list should be used to establish rankings and priorities.

2.5 GOALS OF PRESERVATION

There are two basic standpoints:

- One can stimulate the preservation of all the data, which are correct and valid, since it is really hard to forecast that certain data will be certainly unimportant in the future.

- It is almost sure that many of the results will not be used in the future and the future developments will be based on well-established benchmarks. Benchmarking is possible only based on reliable data.

If everything is processed with such an effort, as it is needed for setting up a benchmark problem, the investment needed for preservation might well exceed available financial and human resources.

2.6 LEVELS OF PRESERVATION

The different **levels** comprise:

1. **Storing the primary information**: simple preservation of primary documents in computer readable image form and optical character recognition.
2. **Preparing the description of the reactor and experimental results**: compilation of the information and data in an agreed standard form, including all information required such as

experimental methods to carry out computer code-aided modeling and interpretations can be achieved.

3. **Evaluation of results, their interpretation and review**: analysis of the experiment with state of the art computer codes and data, sensitivity and uncertainty analysis. Documentation produced in the interpretation process.
4. **Storing in a database:** the peer reviewed benchmark data is integrated into a database management system (such as ACCESS, ORACLE etc.).

The first level is the preparatory work for the qualified preservation effort. The archive containing the primary reports and data is essential as it allows the later extraction of the data that needs to be compiled and reevaluated, based on requirements expressed and on the basis of the priority list established. The database level would be a last step that requires an additional effort of maintenance across changing generations of computer systems.

3. SUMMARY OF IRPhE ACTIVITIES

3.1 PILOT EVALUATION PROJECT

In order to test the designed format and methodology, especially as concerns levels 2 and 3, a **pilot project** was established covering 7 sets of experiments:

1. **BFS-RESR-EXP-001**: Critical Experiments with Heterogeneous Compositions of Plutonium, Silicon Dioxide, and Polyethylene (IPPE Obninsk)

2. **BFS-RESR-EXP-002**: Critical Experiments with Heterogeneous Compositions of Highly Enriched Uranium, Silicon Dioxide, and Polyethylene (IPPE Obninsk)

3. **DIMPLE-RESR-EXP-001**: Light Water Moderated and Reflected Low Enriched Uranium (3 wt.% ^{235}U) Dioxide Rod Lattices Dimple S01 (Serco Assurance)

4. **KRITZ-RESR-EXP-001**: KRITZ-2:19 Experiment on Regular H_2O/Fuel Pin Lattices With Mixed Oxide Fuel at Temperatures up to 245^{o}C (Studsvik)

5. **PFACILITY-VVER-EXP-001**: VVER Physics Experiments: Hexagonal (1.27-cm Pitch) Lattices of U(4.4 wt.% $^{235}UO_2$ Fuel Rods in Light Water, Perturbed by Boron, Hafnium, or Dysprosium Absorber Rods, or by Water Gap With/Without Aluminium Tubes (KIAE)

6. **VENUS-PWR-EXP-001**: VENUS-2 PWR MOX Core Measurements (SCK-CEN)

7. **ZR6-VVER-EXP-001**: The VVER Experiments: Regular and Perturbed Hexagonal Lattices of Low-Enriched UO_2 Fuel Rods in Light Water (AEKI) (331 configurations)

In the pilot project it was demonstrated that the procedures set up, and the formats defined could be applied without major difficulty. The results will be available on a demonstration CD-ROM. In conclusion, the methodologies are adequate and make the realisation of the project possible.

The pilot project can be considered as successful as positive results were achieved, such as:
- Definition of scope and objectives
- Design and issue of standard format for evaluations
- Preparation of a large inventory list of experiments
- Definition of procedures for evaluation and peer review
- Carrying out the compilation, evaluation and review of 7 sets of pilot experiments

- Preparation of a draft IRPhE demonstration CD-ROM

The demonstration CD-ROM, result achieved in the pilot project contains the following:

- Scope and Objectives
- Participants and Contributors to IRPhE Project
- Last issued Format: IRPhE 8.5 (May 2002)
- Guide for Evaluation, Review and Expressing Uncertainties:
- Summary of Pilot Evaluations
- Pilot Evaluations
- IRPhE Inventory List

3.2 PRIMARY DOCUMENTS / DATA

During the Pilot Phase of the IRPhE project an inventory was established and many primary documents and data were released which are breifly described in the following:

Belgium

- Results from Critical Experiments in **VENUS- Project on the Physics of Plutonium Recycling**. This includes data for 28 configurations, SCK-CEN and Belgonucléaire: Documentation in electronic form., tables in Excel, 3 configurations translated into English
- **VENUS-1 & 3 (UOX) and VENUS-2 (2D & 3D MOX) ;** benchmark study completed, report published, reformatting into IRPhE Format to be completed

Germany

- The **SNEDAX** - the European Fast reactor **database** has been set up in 1996. It includes part of the experiments carried out at MASURCA(F), RRR/SEG(D), SNEAK(D), ZEBRA (UK). The database with all data was released (except data from MASURCA). (AEAT/CEA/FRK,FZR)
- The best **SNEAK** data is preserved within the SNEDAX database established in Cadarache. All relevant documents providing further technical information on these SNEAK experiments have been made available. The archive documents of SNEAK have been scanned with optical character recognition and are stored on CD-ROM. (FZK)
- **SEG RRR**, fast reactor experiments. The primary reports have been released. Part of the data are stored in the SNEDAX database. (FZR)
- Experiments have been carried out at the **KNK-II.** Data with the irradiation histories are available in computer readable form (delivered in Excel format**)**. The archives of primary documents and further data have not been released yet. (FZK)

Japan

- **JOYO start-up** and **on power** data: 100MW thermal core (JOYO Mk- II) Data and report released on CD-ROM, April 2002. Contains: Core configuration: core arrangement, refuelling record, Subassembly library data: atomic number density, neutron fluence, burnup, integral power, Output data: calculated neutron flux, gamma flux, power density, linear heat rates, coolant and fuel temperature distribution, Core characteristics data: measured excess reactivity, control rod worth calibration curve, temperature reactivity coefficients, power and burnup. The relevant reports will be translated into English from Japanese. (JNC)
- **Fast Reactor Experiments**. One report was released and scanned. (JNC)
- Research & Development on **Subcriticality Measurement** System Reactor Noise Experiment, 3 reports have been released and scanned. (JNC)
- **DCA** Experiments for Development of ATR (D_2O Moderated MOX Fueled Core). 14 reports released and scanned.(JNC)
- **TCA** Light- Water Moderated UO_2 and/ or PuO_2 -UO_2 Lattices: Critical Experiments,

Temperature Effects on Reactivity in Cores with Soluble Poisons, Reactivity Worths for Aqueous Solution Samples, Aqueous Solution Samples : Sm, Cs, Gd, Nd, Rh, Eu, B and Er, Beta-eff. The 5 papers available have been released and scanned. 18 core configurations have been included into ICSBEP (critical configuration data only). The extension with reactor physics data for inclusion into IRPhE will be carried out. (JAERI)
- **MuITR TRIGA Mark II** (100 kW) Benchmark: multiplication factor, excess reactivity, fuel element reactivity worth, 20% enrichment. Three primary documents released. Scanning completed. (Musashi Inst. of Technology)

The Netherlands

- "**Burn-up Benchmark** Book – A Survey of Literature", released with the data in electronic form (IRI)
- **STEK-facility** fission product sample reactivity worth measurements data. (fast-thermal coupled critical system). Archive of primary documents released (except analyses made at CEA Cadarache). Scanning of most of the documents to be done. (NRG-NL, JNC, Dietze).

Switzerland

- Experiments for **HCLWR lattices** in the **PROTEUS** facility. Part of the **PROTEUS-1** data has been released within a NEA benchmark study. (PSI)
- Experiments carried out on **HTR** at the **PROTEUS** facility (PSI Switzerland). Measurements include control rod worth, reactivity, reaction rates (using fission chambers) looking at different graphite/U ratios (2:1 and 1:1) as well as packing geometries. Electronic version of reports and data available (IAEA, PSI)
- "**Kinetic Parameters** Experiment in **CROCUS**" Released in the framework of a NSC benchmark study (EPFL Lausanne, PSI).

United Kingdom

- **ZEBRA cores,** BTN, MTN, ZTN series. Part of the data is included in the SNEDAX database. The full archive of the ZEBRA documents has been released. The reports have been scanned with optical character recognition and are available on 2 CD-ROMs (AEAT, SERCO Assurance)

United States

- The **ANL** fast cores: **ZPPR, ZPR3, ZPR6, ZPR9 (128 assemblies).** L.LeSage: "An Overview of the Argonne National Laboratory Fast Critical Experiments 1963-1990", ANL, April 2001. This report has been contributed this inventory in computer readable form. Scanning of primary documents is in progress in the USA. (ANL)
- **CSWEG benchmarks.** These widely used benchmarks have been issued in the US in paper form only. These have been scanned at the NEA Data Bank**.** Part of the information is included in ICSBEP. It contains 25 fast and 36 thermal systems (DOE)
- The **ICSBE** (International Criticality Safety Benchmark Evaluation) **Project** contains nearly 3000 configurations covering data for thermal, intermediate and fast systems. A consistent number describes critical cores and contains occasionally data relevant for reactor physics. (INEEL, DOE, OECD/NEA)
- **B&W Lattice Experiments.** The relevant reports including microfiches with design graphs and computer code analyses have been scanned in PDF form with background text and are available. Complete analyses of a subset with full data have been released also (DOE/OSTI - OECD/NEA)

NEA activities

- **Light Water Lattice Data**, Edited by E. Bernocchi and R. Martinelli, NEACRP-U-190, (December 1977). (Total Number: 122) This report was scanned, OCRd and all tables are accessible in Excel format at the NEA Data Bank. (completed: April 2001). Analysis of a large set of these benchmarks including the WIMSD computer program models have been prepared (NEA, IAEA)

- **Heavy Water Lattice Data**, from NEACRP. (EACRP-L-42) for a total of 251 configurations. European American Committee on Reactor Physics. (1958-63). This report was scanned, OCRd and all tables are accessible in Excel format at the NEA Data Bank. (completed: April 2001). Analysis of a set of these benchmarks including the WIMSD computer program models have been prepared (NEA, IAEA)
- Compendium of clean **Neutron Spectra** measurements: EACRP-L-62 (1966) - 105 experiments with varying geometrical configurations and scattering materials such as H_2O (borated, unborated, covered by Cd etc.), D_2O, BeO, benzene, Dowtherm A, paraffin (with or without B), polyethylene, graphite (unpoisoned, poisoned with B or Sm), ZrH. This information was scanned with OCR at the Data Bank.

3.3 ADDITIONAL EXPERIMENTS IDENTIFIED THROUGH THE INVENTORY

Several countries have provided extensive lists of reactor physics experiments they have carried out and have provided brief descriptions thereof. Some of the data is being processed within national projects, others have committed the release of the data to the IRPhE Project. The full list can be obtained on request and will be available on the 'IRPhE demonstration CD-ROM'.

Countries with large sets of experimental data not yet released are:

- *The Russian Federation* : **BFS-1** and **BFS-2** (more than 50 cores), **KOBR** Critical facility (more than 20 configurations) (IPPE).
- *Brazil* : reactivity coefficient measurement at the **IPEN/MB-01 reactor**, Sao Paolo, Brazil.
- *Canada* : large sets of the early heavy water lattice experiments. (AECL)
- *Czech Republic*: the **LR-0** with **VVER-440** & **VVER-1000** assemblies experiments and for RPV dosimetry (NRI-Rez).
- *France* : well-known **fast reactor** data measurement campaigns - RACINE, BERENICE, CONRAD in MASURCA. (CEA), experiments from the zero-power fast reactor experimental facility **HARMONIE** should be produced. **LWR programmes** :EOLE, EPICURE, ERASME, MINERVE, MISTRAL, MORGANE etc. programmes. Part of these data are stored in the CEA owned BDE database. Extensive physics start-up and operation data were gathered for prototype power reactors . These are **RHAPSODIE, PHENIX**, and **SUPERPHENIX.** Efforts to preserve these data are being organised. (CEA)
- *Japan* : **Jupiter program**: Critical Experiments performed in ZPPR: data are open, the release of the data has been promised. DOE approval/ agreement is being secured. (JNC, DOE). **MONJU physics start-up and operation.** Release of the data is being sought. (JNC). **KUCA** Experiment **-** tank with enriched uranium, thorium. Water, graphite and polyethylene moderated**..** **VHTRC** Split table facility, enriched uranium, graphite moderated **of JAERI. FCA** Split table type fast facility, enriched uranium/plutonium. Experimental data collected since 1980 (JAERI)
- *United Kingdom:* **OECD HTR Dragon Project** 1960 - 1976 experiments. (HTR, UOX, MOX and Th fuels). **DIMPLE** lattices. (SERCO Assurance)
- *USA*: prototype **Fast Reactors**, physics data were measured in the following reactors:: **SEFOR** (General Electric), **EBR-I, EBR-II, FFTF** (US DoE) and **FERMI-I** (Detroit-Edison), an inventory list of valuable experiments should be produced. **MOX bundle irradiation** in the Quad Cities BWR and in the San Onofre reactor (ORNL) **Bettis criticals (TRX and BAPL) "Strawbridge and Barry" Westinghouse criticals'**. Reactor Physics experimental data from **the LOFT facility.** In the USA a very large number of facilities were built over the last 50 years and the construction of a comprehensive archive of experiments and identification of primary documents and data thereof would be a major undertaking. For example **INEEL** has carried out experiments /measurements in an impressive number of reactors (52):

This list is not fully comprehensive. Some countries, not having experimental data available for release to the project have agreed to provide cost free expertise to the project (e.g. Republic of Korea).

4. CONCLUSION

A large number of experimentalists, physicists, evaluators, modelers have devoted large amounts of their efforts and competencies to produce the data on which the methods we are using today are based. These data are far from having been exploited fully for the different nuclear and radiation technologies. This wealth of information needs to be preserved in a form more easily exploitable by modern information technology and for use in connection with novel and refined computational models with limitations of the past removed. These data will form the basis for the studies of more advanced nuclear technology, will be instrumental in identifying areas where there is a lack of knowledge and thus provide support to justifying new experiments that would reduce design uncertainties and consequently costs. The reactor physics experimental data represents a massive amount of data that needs to received full attention now if it is not to be lost. The effort has received some attention in the frame of knowledge and best practice management requirements in different organisations and countries. Improvement of comprehensiveness of the databases, experiment re-interpretation and re-evaluation using state-of-the-art methods will require a large further effort and all laboratories wishing to manage and share this knowledge are invited to contribute.

The ANS Joint Benchmark Committee (JBC) has adopted the formats and procedures used in this project. Also other institutions have expressed the intention to document results from ongoing and future experiments following these procedures and guidelines. No organisation alone can cover such a vast field. The co-operation established with the IAEA covers fast reactor experiments.

Based on the experience gained the Members of the OECD/NEA Nuclear Science Committee stressed the importance of this activity and concluded that in view of the success demonstrated in the pilot phase, this activity should continue. Several members announced that they would make an effort to provide expertise and manpower that would help realising the project.

It was agreed that priorities should be established on the basis of needs expressed in member countries. This is of particular importance as the number of experiments identified in the inventory list is large. Priority should be given to evaluation of data that is part of the NSC benchmark activity and that is important for the development of reactors such as Generation-IV concepts.

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REFERENCES

1) J.B. Briggs, J. Gadó, H. Hunter, I. Kodeli, M. Salvatores, E. Sartori: International Integral Experiments Databases in Support of Nuclear Data and Code Validation, International Conference on Nuclear Data for Science and Technology, ND-2001, Tsukuba, Japan (being published)
2) J. Blair Briggs, “The Activities of the International Criticality Safety Benchmark Evaluation Project (ICSBEP)”, International Conference on Nuclear Data for Science and Technology, ND-2001, Tsukuba, Japan (being published)
3) J. Gadó: “Preservation of the Results of Reactor Physics Experiments”, OECD/NEA Nuclear Science Committee Meeting, Paris, June 2002