# Overview of the NEA Activities Related to Experimental Needs

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**Abstract**. The paper presents activities of the OECD/Nuclear Energy Agency (NEA) related to research reactors for scientific and safety applications. It briefly describes the Projects, Databases and Expert groups dealing with data obtained on the research reactors and new NEA activities on experimental needs.

**Key Words**: benchmark, database, experimental needs, research, safety.

## 1. Introduction

The goal of the Organization for Economic Cooperation and Development (OECD) Nuclear Energy Agency (NEA) nuclear science programme is to help member countries to identify and disseminate scientific and technical knowledge to ensure safe, reliable and economic operation of current nuclear systems and to develop next generation technologies. The main areas covered are reactor physics, fuel cycle physics and chemistry, criticality safety and material science.

In this context, experimental data hold an essential place, providing the basis for validation, verification and uncertainty quantification (VV&UQ), design support, study of material performance and system behaviour.

The advanced measurements on research reactors provide an indispensable contribution to experimental support for basic research and engineering physics as well as for materials and equipment testing. A particular emphasis has been recently on the improvement of deep burn-up and radiation damage measurements, realistic imitation of operation regimes and corrosive environment in the relevant loop facilities including modelling of reactivity insertion accidents (RIA) in transient and pulse experiments. High flux together with advanced post-irradiation instrumentation are required for performing measurements of innovative nanostructured materials (NsM) capable to withstand high level of radiation damage. To meet these growing demands and with a background of reduced availability in the current fleet of research reactors, projects on reactor modernization and construction are currently in progress, worldwide: MBIR will replace BOR-60 (Russia), which represents a unique facility for fast reactor research; ATR (USA) and CABRI (France) are enhancing their experimental capabilities as part of modernization programmes; and the Jules Horowitz Reactor (JHR) being constructed in France will augment availability of high-flux capacity in Europe.

Growing costs of experimental studies and decreasing experimental capabilities drive the interest of the nuclear community in preservation and best possible use of the existing experimental information as well as in optimization of new experiments.

An extensive programme of work to preserve data from integral experiments has been established by the NEA Nuclear Science since the mid-1990s. A big collection of data has been gathered, evaluated, linked and made accessible to a wide range of users. The NEA Databank maintains and distributes several databases of the integral experiments. The work has been focused on reactor physics and shielding applications but may be extended to include other areas such as fuel performance and thermal-hydraulics as well as coupled multi-physics. Collected data are made available for the nuclear science community to provide high fidelity benchmarks against which modelling methods can be validated. More recently programmes of work have been established to preserve data from various experiments related to minor actinide studies, such as portioning and transmutation.

With these new trends in industrial and regulatory requirements, design of nuclear installations, and experimental capabilities, the need for new integral experiments at large scale remains a high priority requiring a cross-disciplinary approach and highlights the necessity for regular review of experimental needs and capabilities. As a response, a new Nuclear Science activity has initiated a broad-based review to provide experimental needs for neutronics, thermal-hydraulics, material studies, fuel behaviour and multi-physics methods.

Research reactors have been an important source of experimental information for the existing NEA projects, providing important and, sometimes, unique data on neutron cross sections, criticality, reactor-type parameters, flux and dose distribution for shielding application, fuel and material performance/test, radiation effects. The experimental programmes conducted on the research reactors are essential for safety demonstration and nuclear driven multi-physics studies.

This paper describes on-going work associated with the new NEA activity. It also provides current status of the NEA databases, scientific projects and joint projects with a particular focus on information originated from research reactors.

## 2. Nuclear Science

### 2.1. Reactor Physics and Criticality Safety

A major source of data used for code validation in criticality safety and neutron physics are the NEA Handbooks of the International Criticality Safety Benchmark Evaluation Project (ICSBEP) [1] and the International Reactor Physics Experiment Evaluation (IRPhE) Project [2]. They provide the nuclear community with peer reviewed benchmarks that include critical, subcritical, shielding, radiation-transport, fundamental physics and reactor physics benchmark experiments performed at nuclear facilities around the world.

The International Criticality Safety Benchmark Evaluation Project (ICSBEP) became an official activity of the NEA Nuclear Science Committee (NSC) in 1995. The ICSBEP has been focused mainly on critical and subcritical configurations and radiation transport measurements.

The IRPhE Project was endorsed as an official activity of the NSC in 2003. It is patterned after the ICSBEP and closely coordinated with the ICSBEP as some benchmark data are applicable to both nuclear criticality safety and reactor physics technology. Besides the criticality, reactor-type parameters are included in the IRPhE Handbook: buckling, reactivity effects, reactivity coefficients, flux distributions, spectral indices, reaction rate distribution, kinetic parameters, and others.

The purpose of the Handbooks is to provide an extensively peer-reviewed set of integral data that can be used by criticality specialists, reactor designers and safety analysts to validate the analytical tools used to predict criticality of fuel cycle installations, to design next-generation reactors, to establish the safety basis for operation of these reactors.

The Projects consolidate and preserve the information that already exists worldwide, retrieve lost data, identify areas where more data are needed, draw upon the resources of the international reactor physics community to help fill those needs, identify discrepancies between calculations and experiments due to deficiencies in reported experimental data, cross section data, cross-section processing codes, and neutronics codes, eliminate a large amount of tedious and redundant research and processing of reactor physics experiment data, and improve future experimental planning, execution, and reporting.

Selected data from each experimental configuration is entered into the corresponding databases: Database for the International handbook of evaluated Criticality safety benchmark Experiments (DICE) [3] and the IRPhE Database and Analysis Tool (IDAT) [4]. Both the content and search capabilities of the DICE and IDAT databases are being constantly refined.

The DICE first published in 2001 and IDAT released in 2013, are included in the Handbooks DVD. The databases and corresponding user interfaces allows easy access to handbook information, such as the measurements performed, benchmark values, calculated values, geometry and materials specifications of the benchmark. In many cases this is supplemented with calculated data such as neutron balance data, spectra data, k-eff nuclear data sensitivities, spatial reaction rate and others.

A combined total of twenty-four countries have contributed to these Projects. Cases within the ICSBEP Handbook have increased from 406 in 1995 to 4839 in the latest 2014 version. The 2015 edition of the IRPhE Handbook contains data from 143 experimental series performed at 50 nuclear facilities. 47 series originates from experiments performed on research reactors. They include 315 benchmark configurations for calculation of reactor-type parameters. FIG 1. demonstrates the IDAT search pane that displays the identifiers of the benchmarks derived from the experiments conducted on research reactors.

Research reactors have been an important source of information for the ICSBEP and IRPhE Project. They contain evaluated cases of the experiments performed on the TRIGA type reactors, the Advanced Test Reactor (ATR), USA, the High Temperature Engineering Test Reactor (HTTR), JOYO, Japan, HTR-10, Chinese small pebble-bed test reactor and many others.

Some experiments, performed on the Training, Research, Isotopes, General Atomics (TRIGA) Mark II reactor, are presented in the Handbooks. One of them is located in Ljubljana, Slovenia. The experiments in steady-state operation were performed with fresh standard commercial TRIGA fuel elements of 20 wt.% uranium enrichment in a compact and uniform core. The neutron radiography (NRAD) reactor is also a 250 kW TRIGA Mark II tank-type research reactor located at the Idaho National Laboratory (INL). The NRAD benchmarks have been derived from the configurations refueled with low enriched uranium fuel.

JOYO is the first experimental 50/75/100/140-MWt sodium cooled fast reactor in Japan that was constructed in 1977 to acquire various aspects of fast reactor performances including nuclear, thermal-hydraulic and safety-related characteristics. The plutonium-uranium mixed oxide (MOX) core was surrounded by radial/axial blanket of depleted uranium oxide or stainless steel. Experimental results and operational experience from JOYO were invaluable in the development of MONJU, prototype of the Fast Breeder Reactor (FBR). Several IRPhE benchmarks have been derived from the extensive experimental programme conducted on JOYO reactor: criticality, control rod worth, sodium void reactivity, fuel replacement reactivity, isothermal temperature coefficient, and burn-up reactivity coefficients. The latter is the unique evaluated data in the Handbook. The JOYO data have been extensively used for validation of fuel isotopes' neutron cross section and iron in fast energy region.

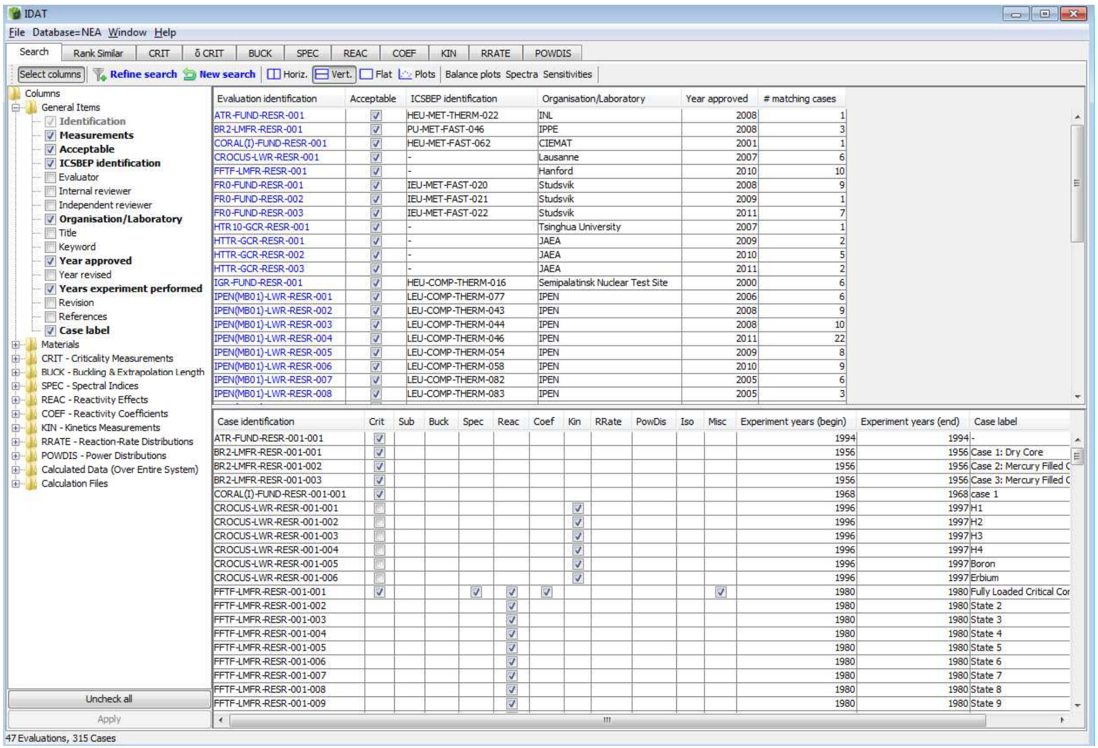

*FIG. 1. IDAT Search Pane: Displaying the benchmarks derived from the experiments conducted on research reactors and some their parameters.*

The Advanced Test Reactor (ATR), located at Idaho National Laboratory (INL), is a 250-MW (thermal) high flux reactor - one of only a few high-power research reactors of its general type in the world. Its capabilities support a variety of missions involving accelerated testing of nuclear fuel and other materials in a very high neutron flux environment, medical and industrial isotope production, and several other specialized applications. Currently, the ATR is reconfigured to operate on low-enriched monolithic U-10Mo fuel [5].

The collection of the experiments in the Handbook has been updated every year with several new evaluations. The IDAT and DICE have undergone upgrades and continual adaptation to users' needs over the years. A progress has been made in provision of the users with $k_{eff}$ sensitivity coefficients to nuclear data. The work is currently conducted to extend matrix of correlations between benchmark uncertainties. These new data allow application of the high-fidelity validation approach in reactor physics and criticality safety.

### 2.2.Radiation Shielding

The Shielding Integral Benchmark Archive and Database (SINBAD) project, initiated more than 20 years ago, aims at preserving and making public the information on the radiation shielding experiments. This work is jointly carried out by the NEA Data Bank and the

Radiation Safety Information Computational Center (RSICC) at Oak Ridge National Laboratory (ORNL).

The SINBAD contains compilations for 46 reactor shielding, 31 fusion neutronics and 23 accelerator shielding experiments. The major emphasis has so far been on fission reactor shielding [6]. Many experiments carried out at research reactors are particularly useful for advanced shielding designs for new research or power reactors and for nuclear data validation. The database contains descriptions of the ten research reactors: NESTOR, 30kW, UK; LENA (TRIGA MARK-II), 250 kW, Italy; HARMONIE, 1kW, France; PROTEUS, 1kW, Switzerland; NTI (Nuclear Training Reactor), 100 kW, Hungary; TSR-II, 1MW, US; PCA(MTR), 10kW, US; YAYOI, 2kW, Japan; zero-power LR0, Czech republic; zero-power VENUS-3, Belgium; RA, 300kW, Kazakhstan; and ZOE, 100kW, France.

More data sets are in the process of being identified for future release. Currently the work is focused on uncertainty evaluation for the presented evaluation and refinement of benchmark models.

### 2.3.International Fuel Performance Experiments (IFPE) Database

The aim of the project is to provide in the public domain, a comprehensive and well-qualified database on Zr clad $UO_2$ fuel for model development and code validation. The data encompasses both normal and off-normal operation and include prototypic commercial irradiations as well as experiments performed in Material Testing Reactors. This work is carried out in close co-operation and co-ordination between NEA, the IAEA and the IFE/OECD/Halden Reactor Project.

Emphasis has been placed on including well-qualified data that illustrate specific aspects of fuel performance. To date datasets about 1452 rods/samples from various irradiated in power and research reactors (Halden Reactor Project, ATR, OSIRIS and others).

## 3. Studies on Support of Safety Assessment

Research reactors play an important role in providing data for safety assessments. Several experimental projects are conducted on the research reactors under the auspices of the NEA Committee on the Safety of Nuclear Installations (CSNI). Major ones among them are the Halden Reactor in Norway, the Cabri reactor in France, the Japanese HTTR and the Loss-of-Fluid-Test (LOFT) reactor in the USA.

### 3.1. Halden Reactor Project

The Halden Reactor Project has been in operation since 1958 and is the largest NEA joint project. It brings together an important international technical network in the areas of nuclear fuel reliability, integrity of reactor internals, plant control/monitoring and human factors. The programme is primarily based on experiments, product developments and analyses carried out at the Halden establishment in Norway, and is supported by more than 130 organisations in 19 countries.

One of the programmes of work - the Fuel and Materials programme - includes fuels safety and operational margins, including loss-of-coolant accidents (LOCAs); plant aging and degradation; and International Gen IV Research. The work programme in the nuclear fuel area emphases on fuel behaviour and properties after prolonged in-core service and at burn-ups in excess of current discharge levels, as extended fuel utilisation remains an industry priority. The materials programme aims to contribute to the knowledge on plant aging and degradation required for lifetime extension. The programme addresses radiation induced failure, embrittlement and corrosion processes which are active in in-reactor component materials together with corrosion and creep testing of Gen IV reactor internal and cladding material.

### 3.2 CABRI Project

The NEA joint project CABRI began in March 2000 and intends to run until 2021. The experimental work will be carried out by the *Institut de Radioprotection et de Sûreté Nucléaire* (IRSN) in Cadarache, France, where the CABRI reactor is located. Programme execution may also involve laboratories in partner organizations (e.g., in relation to fuel characterisation or post-irradiation examinations).

Twelve tests are proposed as a basis for co-operation among the CABRI Water Loop Project partners: these experiments include R&D tests combined with suitable tests to validate the extrapolation to a broad spectrum of reactor cases.

The CABRI Water-Loop Project is investigating the ability of high burn-up fuel to withstand sharp power peaks that can occur in power reactors due to rapid reactivity insertion in the core. These are referred to as reactivity-initiated accidents (RIA). The CABRI project aims to extend the database for high burn-up fuel performance in RIA conditions and, more importantly, perform relevant tests in coolant conditions representative of PWRs.

## 4. Review of Experimental Needs

With the new trends in nuclear power generation and regulation, design of nuclear installations, and experimental capabilities, the need for new integral experiments at large scale remains a high priority and requires a cross-disciplinary approach. After reviewing the integral experiments, several NEA Expert Groups have identified a lack of experiments and insufficient accuracies in several areas.

For example, the Expert Group on Integral Experiments for Minor Actinide Management (EGIEMAM) has pointed out that many integral data are still necessary to improve knowledge of MA nuclear data and to support the MA management technology development with reliable accuracy and sufficient anticipation. The EG recommended integral measurements, complementary to parallel efforts for differential measurements, for several nuclides of MA. From the lessons learnt, two major categories, reactor physics and irradiation experiments, require specific actions through international collaboration.

Under the guidance of the NEA Nuclear Science Committee, the Expert Group on Multi-physics Experimental Data, Benchmarks and Validation (EGMPEBV) launched in 2014 deals with the certification of experimental data and benchmark models along with establishing the processes and procedures for using the data and benchmark models for validation of modelling and simulation tools and data. The EG has identified and surveyed experimental gaps in both low-length scale phenomena and multi-physics interactions.

It has been recognized that there exist only a limited number of facilities and limited expertise and resources (materials, manpower and funding). In many cases, useful results are not available because of proprietary considerations. Specific actions are required through international collaboration: revising experimental needs, pooling resources and identifying qualified facilities, personnel, measurement techniques and available supplies of materials to target experiments to meet specific data needs.

In this context, a new Nuclear Science activity on experimental needs has been launched as follow up of previous undertakings in this area. It will be focused on the review of experimental needs for neutronics, thermal-hydraulics, material studies, fuel behaviour and coupled multi-physics method. The anticipated output from this activity will be establishment of a framework that will bring together international experts in order to revise the experimental needs, rank priorities for validation and identify experimental facilities where the needs could be addressed.

Work on revision of experimental needs for safety of nuclear installations has been performed by the CSNI. Thus, a collection of internationally agreed matrices of experimental benchmarks derived from the separate [7] and integral effect [8] tests was developed for validation of best estimate thermal-hydraulic computer codes. These data support the validation process in order to increase confidence in the predictive capability of codes for existing and advanced systems, including the quantification of the uncertainty range for the simulation models and methods.

The NEA Research and Test Facilities Database (RTFDB) that contains description of about 700 experimental facilities, including research reactors, worldwide, was created in 2007. Recently, work has been started on modernization of the RTFDB. The work is focused on checking and extending the data collection as well as providing users with easy access to the parameters of experimental facilities and links to the information available in existing NEA databases.

Development of advanced simulation methods, particularly coupled multi-physics methods, has been a significant trend in recent years. Along with the progress made in computational capabilities and a new generation of tools, new requirements for integral data arise in order to meet the validation process demands. The operational flexibility of most research reactors allows them to address the major needs identified for the nuclear industry providing testing and calibration experiments, integral experiments, benchmarking, code validation analyses, and cross-section measurements.

## 5. Conclusion

The extensive programme of work on preservation of integral experiments data, established by the NEA for support of scientific developments and safety, has been focused in the reactor physics and shielding applications. Collected data are made available for nuclear science community to provide high fidelity benchmarks against which modelling methods can be validated. Recently programmes of work have been established to preserve data from various experiments related to minor actinides measurements, fuel performance, thermal-hydraulics and multi-physics.

The article presents major experimental projects and databases developed and maintained by the NEA Nuclear Science and Databank teams and by the NEA Committee on the Safety of Nuclear Installations: the IRPhE Project and IDAT database, the SINBAD and the IFPE database under Working Party on Scientific Issues of Reactor Systems (WPRS); the ICSBEP and IDAT database, the Spent Fuel Isotopic Composition Database (SFCOMPO) under the Working Party on Nuclear Criticality Safety (WPNCS); Haden reactor and CABRI joint projects supported by CSNI. The focus of the paper in on how the experiments performed on research reactors have contributed to the knowledge preservation programme and two of several joint projects related to safety assessment.

Several NEA activities have identified a lack of experiments and insufficient accuracies in several areas: MA management, thermal-hydraulics and multi-physics, emphasizing a need to prepare a concerted effort paving the way for a common experimental programme where resources can be optimised.

In this context, the Nuclear Science and Data Bank teams have initiated activities to help establish a framework for identifying suitable existing experiments, for carrying out uncertainty and sensitivity analysis, and for identifying experimental facilities to meet the needs for new experiments. The work is currently focused on reactor physics, criticality safety and shielding applications but may also be extended to include other areas such as fuel performance and thermal-hydraulics. The anticipated output from this activity will be a set of database tools which can be used to identify significant gaps, where further experiments are considered to be of high priority, to provide quantitative rankings of the best-matched experiments in existing sets of experimental benchmarks as well as helping to identify facilities capable of conducting the experiments.

## 6. Acknowledgment

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