OECD/NEA Data Bank scientific and integral experiments databases in support of knowledge preservation and transfer

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Abstract. The OECD/Nuclear Energy Data Bank was established by its member countries as an institution to allow effective sharing of knowledge and its basic underlying information and data in key areas of nuclear science and technology. The activities as regards preserving and transferring knowledge consist of the:

— Acquisition of basic nuclear data, computer codes and experimental system data needed over a wide range of nuclear and radiation applications.
— Independent verification and validation of these data using quality assurance methods, adding value through international benchmark exercises, workshops and meetings and by issuing relevant reports with conclusions and recommendations, as well as by organising training courses to ensure their qualified and competent use.
— Dissemination of the different products to authorised establishments in member countries and collecting and integrating user feedback.

Of particular importance has been the establishment of basic and integral experiments databases and the methodology developed with the aim of knowledge preservation and transfer. Databases established thus far include:

— IRPhE – International Reactor Physics Experimental Benchmarks Evaluations,
— SINBAD – a radiation shielding experiments database (nuclear reactors, fusion neutronics and accelerators),
— IFPE – International Fuel Performance Benchmark Experiments Database,
— TDB – The Thermochemical Database Project,
— ICSBE – International Nuclear Criticality Safety Benchmark Evaluations [1],
— CCVM – CSNI Code Validation Matrix of Thermal-hydraulic Codes for LWR LOCA and Transients [2].

This paper will concentrate on knowledge preservation and transfer concepts and methods related to some of the integral experiments and TDB.

1. Introduction

1.1. Knowledge and information

Knowledge is often defined as having experience and comprehension that are both subjectively and objectively certain, wherefrom judgements and conclusions can be drawn that appear sure enough to be considered knowledge themselves. Such recursive definitions show that the concept is difficult and not without ambiguity. The contrary is often called ignorance, and is often said of someone not well informed. This is a first indication that acquiring knowledge first requires information. Some use the word "knowledge" interchangeably with "information". But information is merely the basis on which knowledge can develop and grow. Knowledge is not an abstract external entity, it is a vibrant process inside the mind. In fact it arises from sense-experience (or experiments/measurements) and intellectual processes such as abstraction, judgement and inference. Information, on the other hand, can exist independently of human beings and live a "fossil life".

Knowledge management is a process involving many aspects: acquisition of objective information through observation and recording, interpretation through a model that helps the understanding process, validation through application to concrete situations and feedback to our mental models; in brief, it consists of experience and reflection. For it to be maintained and preserved it must also be transferred. This involves communication and obviously education, including teaching to teachers. Experimental equipments and facilities, the development and maintenance of measurement techniques and interpretation methodologies are another set of important components in this respect. In summary, knowledge management and preservation is a complex process, involving a large number of activities.

The basis for knowledge development is information: a vast territory. Our interest in this article concerns mostly information in the form of data gathered from observation and experimentation and its modelling and interpretation. In the modern world the modelling itself and thus the use of a more practical tool for knowledge management, is based on simulation through computing. The computing requires sets of algorithms describing the relations between the observed phenomena as investigated by the different natural sciences such as physics, mathematics, chemistry, biology ,etc. This represents a most concise tool for managing accumulated scientific knowledge. An important aspect of this tool is the human interface to computing, be it through the user-friendly translation of the problem into instructions for the computer or a sense-oriented display of results as an aid to the interpretation and understanding of simulations.

In the specific field of nuclear knowledge a vast amount of data has been gathered from experiments and their interpolation through verified models. Today, much of it is sitting in dusty cupboards on paper or on decaying magnetic tapes, already with reduced possibility of recovery. The question being posed is: “Should we save it all, as the investment was a large one?” The answer is no. Not everything was good, not everything was of adequate quality or is relevant for today’s needs. A comprehensive preservation project would also be too expensive. It would draw away too many of the scarce resources available and would not necessarily lead to increased inventiveness or revolutionary technological developments. Thus we have to be selective. A preservation project must create added value and must ensure that the essential data on which we base today’s technological knowledge is accessible to future generations – a basic principle of quality assurance.

1.2. The role of the Data Bank

The OECD Nuclear Energy Agency Data Bank was established by its member countries as an institution for the collection, verification, validation, dissemination and enrichment (through user experience and feedback) of the basic tools used today for nuclear energy system design and the simulation of their functioning under different operating conditions. These tools comprise standardised databases with microscopic basic nuclear and chemical-thermodynamic data, computer programs for a wide range of applications, integral experiments on fissile material systems, reactor or radiation shielding mock-ups and on in-core fuel behaviour. The Data Bank co-operates with similar institutions in the United States, namely the Energy Science and Technology Software Center (ESTSC) and the Radiation Safety Information Computational Center (RSICC).

The OECD/NEA Nuclear Science Committee (NSC) has identified the need to establish international integral experiments databases containing all the important experiments that are available for sharing among the specialists. Specific activities to achieve this have been set up with the aim of preserving them in an agreed standard format in computer accessible form, to use them for international activities involving validation of current and new calculational schemes comprising computer codes and nuclear data libraries, for assessing uncertainties, confidence bounds and safety margins, and to record measurement methods and techniques.

The following sections describe some of the principles and methods developed and provides concrete examples of databases and their roles in knowledge preservation and transfer.

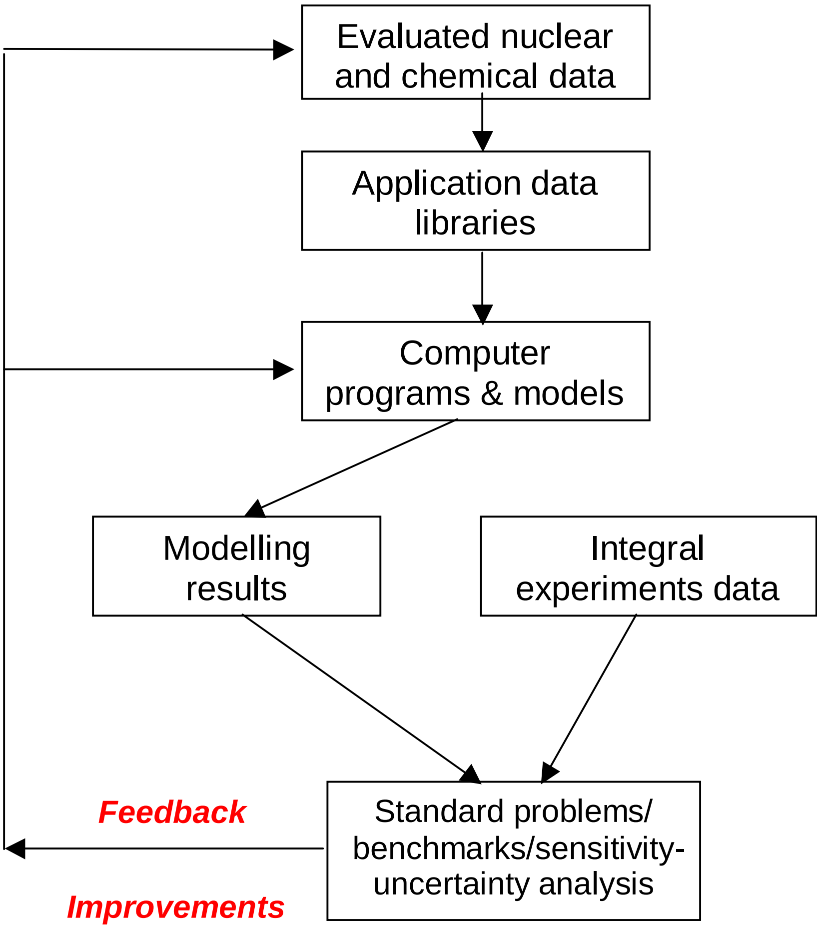
2. The components and their role

When studying applications in nuclear technology there is a need to understand and be able to predict the behaviour of systems manufactured by human enterprise. First, the underlying basic physical and chemical phenomena need to be understood. We have then to predict the results from the interplay of the large number of different basic events, *i.e*. the macroscopic effects. In order to be able to build confidence in the modelling capability, these results must then be compared with measurements carried out on such systems. The different levels of modelling require the solution of different types of equations using different type of parameters. The elements required for carrying out a complete validated analysis are:

— The basic nuclear or chemical data,
— The computer codes, and,
— The integral experiments.

The manner in which these different components are linked to one other and the roles they play are shown in Fig 1.

FIG. 1. Linkage of the various elements required for carrying out a complete validated analysis.



2.1. The basic nuclear and chemical data

The basic data describing atomic and nuclear properties of matter have been measured, compiled and evaluated over the past 50 years in a rather systematic way by different centres set up for the purpose, one of which is the OECD/NEA Data Bank. The databases consist of an index to the literature (called CINDA) describing experiments carried out and methods to unfold the basic data for the interactions of technological particles (neutron, proton, photon, electron), a database using standard compilation and verification methods (called EXFOR) for the experimental data and their uncertainties over the energy range of interest for technological applications, and finally evaluated data libraries containing the best-estimate values derived from these experiments and their interpretation with basic nuclear models. Examples include the ENDF/B, JEFF and JENDL libraries, all of which use the same format and rigorous, well-established quality assurance procedures. The evaluated nuclear data libraries contain the accumulated knowledge concerning the basic underlying microscopic phenomena and are used as input to computer codes for modelling the macroscopic behaviour of nuclear reactors or other facilities using radiation. An international effort of continuous knowledge improvement in this area, particularly as needed for advanced system, is underway (for further information: http://www.nea.fr/html/dbdata/).

Basic chemical-thermodynamics data are also of great importance for a number of applications, as the following paragraphs will demonstrate.

*2.1.1. **NEA TDB** from a knowledge management and preservation perspective*

Born as a response to a need identified in OECD member countries by the radioactive waste management community, the NEA TDB Project aims at providing a database containing chemical thermodynamics information that meets the quality criteria required for the assessment of underground radioactive waste repositories. For a full description of the project and its scientific basis see Ref. [3].

It is recognized that the relevant chemical thermodynamics information is largely available, albeit scattered over the scientific literature published both recently and in past decades and frequently outside the nuclear community. In other cases, gaps in knowledge exist due to lack of experimental work or disparity in the results from different laboratories. Thus, it is necessary to critically collect the existing data and to examine their chemical consistency prior to their safe use.

The core of the NEA TDB review work is the identification and critical review of all the published literature by teams of internationally recognized experts under a common set of published guidelines [4]. The output of the NEA TDB reviews is not only a database of selected thermodynamical values, but a detailed documentation of the review process together with the rationale for the selections. This documentation also serves as a pointer to the current experts in the field, as a learning tool for new generations of specialists and to stimulate further research; in short, it constitutes a true “knowledge base”.

The NEA Data Bank co-ordinates the work of the various review teams, the publication of the review reports and maintains the corresponding databases. As a result of this work, started in 1984 under the auspices of the NEA Radioactive Waste Management Committee, a total of five reports have been published (on U, Np, Pu, Am and Tc) so far, four others are in the final stages before publication (on Se, Ni, Zr and organic complexes) and three new reviews have begun (on Th, Fe and Sn). Some 60 internationally recognized scientists have been or are currently involved in the effort, which has so far resulted in the critical review of more than 10 000 literature items (the oldest dating back to 1842) stemming from the original work of nearly 12 000 scientists.

2.2. Modelling using computer codes

Modelling in the field of technological applications requires predicting the macroscopic behaviour of the system considered in a given situation.

The models we use in computer codes and the associated basic data libraries somehow contain the cumulative knowledge acquired over several decades of research. These do a good job if used by qualified, knowledgeable staff in the parameter range for which they were validated and qualified. This has been done by comparing the computed predictions with the results of integral experiments, *i.e*. data describing some macroscopic quantities of the system. In essence, predictions with computer code models are valid as long as they consist in interpolating amongst the sound knowledge that has been accumulated. Calculations outside that range are extrapolations into the unknown.

Computer codes carrying out different modelling schemes of interest with regard to nuclear and radiation technology such as:
- Nuclear models,
- Experimental data processing,
- Basic and evaluated data processing,
- Spectral calculations, reactor cells and lattices,
- Multi-dimensional radiation transport, criticality, power distributions,
- Radiation shielding, heating and damage,
- Isotopic inventories, burn-up and build-up,
- In-core fuel management, economic aspects of the fuel cycle, optimisation,

— Reactor dynamics, coupling of neutronics and thermal-hydraulics,
— Heat transfer and fluid flow,
— Fuel behaviour,
— Deformations, stress and structural analysis,
— Radiological safety, hazard and accident analysis,
— Environmental impact, confinement and dispersion in the geosphere, biosphere and atmosphere,

have been developed around the world; about 2 000 of these are shared internationally and have been acquired, verified and used in international benchmark exercises, maintained through feedback from users with the help of the authors, and finally disseminated on request to authorised users by the Data Bank (http://www.nea.fr/html/dbprog/). This work is shared with two centres in the USA: ESTSC (Energy Science and Technology Software Center, DOE-OSTI Oak Ridge) http://www.osti.gov/estsc/ and the RSICC (Radiation Safety Information Computational Center, ORNL Oak Ridge) http://rsicc.ornl.gov/ [5]. A co-operative agreement is also in place with the International Atomic Energy Agency (IAEA). The scope of these codes encompasses practically all the important aspects of modelling in nuclear technology applications.

The computer codes used in most nuclear applications have the role of bridging the gap between the underlying microscopic phenomena and the macroscopic effects. Using a mathematical and algorithmic language, they accumulate, in a readily usable, concise way, the wealth of physics knowledge that science and technology have acquired over the last half-century. In many cases these computer codes can have a relatively complex structure; in addition to several modules they also contain associated data libraries (for generic or project-oriented applications), application-dependent code/data sequences, test problems, documentation including validation reports, etc. This represents an extensive knowledge base managed at international level.

2.2.1. Role of code comparison and benchmarks

Essentially, three elements are required to ensure that modelling tools meet the requirements of nuclear industry and licensing needs:
— State-of-the-art computer code design and programming according to quality assurance principles,
— Quality assurance in maintenance of the code,
— Model assessment and validation of codes through benchmarking and code comparison exercises.

There is a further element of a different nature. Even though a code has undergone the best development and validation praxis, in the end the quality of the results depend on the user. Therefore user qualification through training courses is essential. One of the best training methodologies is benchmarking and comparison. In such a procedure much is learned about how a well-defined problem can be translated into input to a code. The sensitivity and uncertainty analysis that normally accompanies benchmarks provides much insight into the role of the basic data used and the implication of their uncertainty on the results; in other words, a wealth of understanding is achieved.

Over the years the OECD/NEA NSC has organised a large number of comprehensive international comparison exercises.

2.2.2. A General Environment for Radiation Analysis and Design

Though successful, the codes are invariably cumbersome to use and their learning curve steep. This is deeply unsatisfactory in light of today’s very high computational modelling needs and expectations. Furthermore, extension and development of the codes and their combined application is very difficult in view of their incompatible data structures and programming style.

An effort is being made to create a unifying software environment in which the user can seamlessly define, solve and analyse a nuclear radiation transport problem using available numerical tools. This environment will serve many purposes: teaching, research, industrial needs. It will also help to preserve the existing analytical and numerical knowledge base. This could represent a significant step towards solving the legacy problem.

This computational environment will also be an enabling technology that will allow users to move from the present descriptive view of the world to a more prescriptive one in which codes/methods are employed as computational engines for exploiting new scenarios. A flexible radiation transport environment will also facilitate the coupling of radiation physics methods to other physical phenomena and their application to other areas of application such as medical physics and the environment.

Basically what is proposed is the development of a graphical user interface that will allow/guide the user through the various steps necessary to solve a radiation transport problem. Toolboxes will be available in which users can build mathematical and numerical models and solve them using established numerical techniques. Results are then analysed in detail making use of visualisation resources. This enables the user to concentrate on theory and methodology rather than expending the effort to write dedicated one-off computer programs. Such a tool would address issues of teaching, research development, visualization, legacy, etc.

An expert group is being set up to explore such a possibility and deliver within a few years a preliminary version of a computing environment which would be able to demonstrate its features and capabilities using well known codes in the public domain.

2.3. Integral experiments databases

The cornerstone of knowledge is measurement. Without it a hypothesis in a physics model cannot be proven.

A large series of essential experiments concerned with nuclear energy and technology have been carried out over the past 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 and the basis for the development and validation of methods and represent a significant collection of data for past, present and future research and a knowledge base.

Integral experiments concern measurements on a system consisting of different components. The measured values are the macroscopic behaviour of the system (e.g. attenuation of dose through a complex shield, level of reactivity of a reactor or a spent fuel transportation cask, decay heat, level of burn-up, etc.). They allow gauging the combined use of computational methods and basic data used to the real world values. At the beginning of nuclear reactor development, computational methods were still in their infancy, and the models used did not include sufficient knowledge to make reliable predictions. Integral experiments were then the reference to be used for any design.

Integral experiments come with clearly stated and documented uncertainties in the form of confidence bounds of the measured values and a correlation matrix describing the relative independence of the measurements carried out. An integral experiment is complete if it includes a final phase interpreting the results. The interpretation is the part that provides insight into the phenomena and into the way they are appropriately modelled.

Computer codes and basic nuclear data have been thoroughly checked in a number of cases, be it through known reference solutions or experiments. However, the number of possible combinations of their use is so big that a large and possibly comprehensive database of well-characterised experiments is needed. With such databases, sufficient confidence can be established that the methods and procedures used for design, operation and safety analysis are adequate.

Nuclear industries and licensing authorities need to be able to rely on the good performance of computer programs and nuclear data for all important nuclear energy calculations. It is important that the methods and data issued be internationally accepted. This is best achieved through validation and benchmarking on an international scale, with all countries concerned participating in the testing. This is one of the key activities carried out at the OECD/NEA Data Bank with the guidance of the Nuclear Science Committee.

In the following a selection of integral databases are described that have been established through the OECD/NEA. These concern:

- Radiation shielding experiments,
- Reactor core and lattice experiments, and data from reactor operation,
- Fuel behaviour experiments,

Integral experiments are the references necessary for model development, verification and validation.

*2.3.1.. **SINBAD** – Shielding Benchmark Experiments and Interpretation [6]*

Many shield mock-up experimental facilities for reactor applications have been dismantled in recent years. The experiments carried out and the interpretations made have allowed acquiring state-of-the-art knowledge in support of design, operation and research concerning nuclear power facilities. With the dismantling, however, the experimentalists and expert analysts have retired. The knowledge they have was at risk of being lost. An initiative was thus put into place at the OECD/NEA in co-operation with research institutions to save the information and know-how for the current and future generation of workers in this field. Other experiments have been and are still being carried out in the field of fusion blanket neutronics and for accelerator shields needed for research and medical applications. The SINBAD project incorporates at present about 70 benchmark experiments covering about 20 different shielding materials and mixtures thereof. Thirty research organisations have contributed. Further data is being collected to improve comprehensiveness and address current and future needs.

SINBAD data include benchmark information characterizing:

- The experimental facility and the source,
- The benchmark geometry and composition,
- The detection system, measured data and an error analysis,
- The model used for interpreting the experiment.

All information that is compiled for inclusion with SINBAD has been verified for accuracy and independently reviewed by two scientists. The set of primary documents used for the benchmark compilation and evaluation are provided in computer readable form. The data and information included in the database and the results from the analysis represent the synthesis of the knowledge acquired by the experts from experiment. Feedback from re-interpretation of the results by others and the use in validation of more advanced simulation tools allows a continuous improvement and an accumulation of the state-of-the-art knowledge.

*2.3.2. **IFPE** – International Fuel Performance Experiments [7]*

With increasing emphasis on economic as well as safe reactor operation, the approach to fuel performance assessment is now very much more detailed and closer to 'best estimate' evaluation than in the past. The principal function of a fuel performance code is to describe the behaviour of reactor fuel in the most accurate way possible under whatever conditions – both normal and off-normal – that are required by the licensing authority. By aiming to be a best estimate calculation or one that is intentionally biased, the uncertainties in the conditions under which the code is applied are under the control of the user. The need for calculations to be best estimate necessitates that the code be developed and validated against good quality data. The most obvious source of these is the power reactors for which the calculations are to be applied. However, this source is insufficient, as data are also needed for fuel experiencing transients and other off-normal operating conditions which cannot be reproduced under experimental conditions in power reactors. For this reason, code development and validation must have access to both types of information and therefore it is of importance to include data obtained from dedicated experiments in test reactors.

In order to ensure an improved access to data and know how for improved fuel modelling development the OECD/NEA has developed and established, in co-operation with the IAEA, the International Fuel Performance Experiments (IFPE) database. In response to the needs expressed emphasis is given to high burn-up in water reactors under normal operating conditions. Priority goes to completed international programmes, the data of which would otherwise be lost, but also to data released from national programmes. The qualification of these data is co-ordinated through review and by organising user group meetings. In this co-operation computer code validation and benchmark studies are also co-ordinated.

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 (BWR, CAGR, PHWR, PWR and WWER irradiation conditions). This work is carried out in close co-operation and co-ordination between OECD/NEA, the IAEA and the IFE/OECD/Halden Reactor Project.

Activities within the IFPE Database Project that enhance the preservation of the information and the know-how comprise:

- acquisition of data through discussion and negotiation with originators
- compilation of the data into a standard form and content as agreed by an Expert Group set up for supervising the work
- peer review of the data by independent experts
- integration and indexing of the data into the IFPE database, inclusion of all used reports in electronic form.
- distribution to interested parties and assistance where necessary in use of datasets.

The current version contains the following type of data represented by 510 fuel rods:

- Instrumented tests providing on-line data on fuel behaviour
- Post irradiation examination data
- Steady state, long term operation
- Power ramps (single, multiple ramps)
- Test reactor data and data after irradiations in commercial reactors
- Failed fuel data

The database is used today widely by modellers in industry and in the FUMEX-II (FUel Modelling Exercise) co-ordinated by the IAEA.

2.3.3. ***IRPHE*** *– International Reactor Physics Benchmark Experiments [8]*

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 2003, 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 behaviour 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 and both information and knowledge acquired will be lost...
- experimental facilities are being closed, one after the other, and the preservation of the old archives is sometimes not ensured.

The aim of the IRPhE project is the maintenance of an international inventory of relevant reactor physics experiments and measurements, the preservation in computer readable form of their primary documentation and data describing the facilities, characterising the experimental techniques, the experimental results and interpretation thereof. For 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 an international data base is developed and maintained. The work includes:

- Compiling experiments into a standard international agreed format
- 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.
- Analysing and interpreting the experiments with current state of the art methods
- Publishing electronically the benchmark evaluations

IRPhE includes the following types of measurements:

- 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.

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, when 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 and know-how of the old generation to the new ones.

The work carried out within the IRPhE Project is in support of activities that will benefit the evolution of present reactor systems, in particular for stabilising the stockpile of reactor-grade plutonium and to prepare for the concepts adopted for Generation IV systems. It is very expensive to construct new mock-ups for studying new reactor systems. The information and data collected in the frame of the IRPhE project will allow improving predictive modelling for new reactor system behaviour. For that reason the Executive Group of IRPhE has recommended to concentrate on experiments that will benefit improved predictions for higher enrichments and higher burnups and for past experiments in the field of VHTR, FR and others relevant for Gen IV.

3. Preservation of records and information

One important issue, which is not specific to the nuclear domain, concerns the preservation of information – the basis of knowledge. This is not within the scope of this paper, but it is sufficiently relevant to merit mention. This problem is concisely described in an article by J. Rothenberg [9] from which we wish to cite the following:

> *"The digital medium is replacing paper in a dramatic record-keeping revolution. But such documents may be lost unless we act now. Information technology is revolutionizing our concept of record keeping in an upheaval as great as the introduction of printing, if not of writing itself. The current generation of digital records has unique historical significance. Yet these documents are far more fragile than paper, placing the chronicle of our entire period in jeopardy."*

It is of great importance that methods become available allowing important records from the past to be transferred across the changing recording technologies and that they remain intelligible.

4. Conclusions

A wealth of qualified sets of data, information and tools are being shared internationally in the field of nuclear and radiation applications. This information forms the knowledge base and the instruments of work for designing, building and operating modern research and industrial facilities. The acquisition, verification, standardisation, validation and dissemination of such information are key activities in support of knowledge preservation and management. Additional methods concern knowledge transfer, including training courses to ensure qualified and competent use of the tools, workshops, and meetings in which international standard problems or benchmarks are organised; these aim at sharing insight and build common understanding among the experts world-wide. Finally, the resulting knowledge is recorded in reports and databases for further use and is made available through modern methods of accessing the information. These methods are applied by the OECD/NEA Data Bank for the benefit of research, industry and university in member countries.

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