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Contents

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The OECD Nuclear Energy Agency (NEA) is an intergovernmental organisation established in 1958. Its primary objective is to assist its member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for a safe, environmentally friendly and economical use of nuclear energy for peaceful purposes. It is a non-partisan, unbiased source of information, data and analyses, drawing on one of the best international networks of technical experts. The NEA has 28 member countries: Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Korea, Luxembourg, Mexico, the Netherlands, Norway, Portugal, the Slovak Republic, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The European Commission takes part in the work of the NEA. A co-operation agreement is in force with the International Atomic Energy Agency.

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Cover page: Civaux 2 control room (EDF, France), aerial view of Ringhals nuclear power plant (Ringhals AB, Sweden), spent fuel pool at the Cabri research reactor (P. Stroppa, CEA, France).

Growing international co-operation

One of the major strengths of the NEA is its capacity to provide an efficient conduit for international co-operation in the nuclear energy field. In addition to the in-depth, international studies it carries out as part of its regular programme of work, it supports numerous other multinational projects.

Seventeen joint projects and information exchange programmes are currently being carried out under NEA auspices. The projects under way address specific aspects of nuclear safety, radioactive waste management and radiological protection (see pages 26-29 for details).

In January 2005, the NEA was confirmed as Technical Secretariat of the Generation IV International Forum (GIF), which is exploring new nuclear energy systems and the related research and development needed for their deployment by 2020/2030. Just this autumn, the NEA also took on the function of Technical Secretariat of Phase 2 of the Multinational Design Evaluation Programme (MDEP). This Programme and its objectives, which include identifying common regulatory practices and regulations that enhance the safety of new nuclear reactor designs, are described on page 24.

Another example of expanding international co-operation is in the recent approval by the NEA Steering Committee of a Joint Declaration on Co-operation between the NEA and the Government of the Russian Federation in the Field of the Peaceful Uses of Nuclear Energy. Following formal approval by the OECD Council, the Joint Declaration will pave the way for experts from the Russian Federation to share their knowledge and

experience with NEA member country experts in all NEA standing technical committees and their working groups. The Agency looks forward to mutually beneficial exchanges and progress worldwide regarding the safe, environmentally friendly and economical use of nuclear energy for peaceful purposes.

All of these developments are a reflection of the importance being accorded by numerous countries around the globe to the continued, and likely growing, use of nuclear energy. Its benefits as a nearly carbon-free source of energy with stable and affordable prices are no longer questioned. At the same time, its safety record grows stronger, and progress is being made to find and implement acceptable, long-term solutions for radioactive waste management. Experts agree that the natural resources required for producing nuclear energy are largely sufficient, and not a limiting factor for its further deployment. Set against this backdrop, policy makers across the OECD area and beyond are giving increasing consideration to the nuclear option and its future development.

Luis E. Echávarri
NEA Director-General

Advanced fuel cycles and radioactive waste management

E. Bertel *

In a new NEA publication, the effects of various advanced fuel cycles on the management of radioactive waste are assessed relative to current technologies and options, using tools such as repository performance analysis and cost studies. The results of the study show that advanced fuel cycles offer possibilities for various strategic choices regarding uranium resources and optimisation of waste repository sites and capacities, while keeping almost constant both the radiological impact of the repositories and the financial impact of the complete fuel cycle.

Reducing the volume and radiotoxicity of radioactive waste to facilitate its management and ultimate disposal is a major goal for developers of advanced nuclear systems. High-level waste (HLW) containing long-lived isotopes is the focus of this effort because it requires long-term stewardship to ensure its isolation from the biosphere. Many innovative nuclear fuel cycle schemes, at various stages of development and technology preparedness, are being considered by researchers and designers aiming at lowering the amount of HLW waste generated per unit of electricity produced. Reprocessing of spent fuel, recycling of fissile materials in light water or fast neutron reactors and eventually partitioning and transmutation of minor actinides are various options that may contribute to this goal.

A study[1] examining the impacts of advanced fuel cycles on radioactive waste management policies, carried out by a group of experts under the umbrella of the NEA Nuclear Development Committee (NDC) was published by the OECD mid-2006. The experts investigated and analysed various fuel cycle schemes (see Table 1) to assess their qualitative and quantitative impacts on the performance of different repository concepts.

Table 1. **Fuel cycle schemes analysed**

Cycles based on industrial technology and possible extensions	
1a	Once-through pressurised water reactor (PWR), reference
1b	Plutonium (Pu) recycled once in mixed-oxide fuel (MOX) for PWRs
1c	Same as 1b, adding recycling of neptunium
1d	Direct use of spent PWR fuel in Candu reactors (DUPIC)
Partially closed cycles	
2a	Plutonium burning in PWRs
2b	Plutonium and americium burning in PWRs
2c	Heterogeneous americium recycling
2cV	Storage and disposal or recycling of americium and curium
Fully closed fuel cycles	
3a	Transuranic (TRU) burning in fast reactors (FR)
3b	Pu burning in PWRs and FRs; double strata
3bV	Pu burning in PWRs and accelerator-driven systems (ADS)
3cV1	All gas-cooled fast reactor strategy with carbide fuel
3cV2	All sodium-cooled fast reactor strategy; uranium not recycled

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In addition, the study addressed natural resource requirements and economics from a broad sustainable development perspective.

The fuel cycle schemes considered include options already at the industrial and commercial development stage, as well as very innovative variants which have not yet been fully demonstrated. They pertain to three main families: existing technologies; partially closed cycles; and fully closed cycles. The reference scheme is pressurised water reactors operated with a once-through fuel cycle.

Participating experts from 13 countries provided information on existing and advanced fuel cycles. Although some processes that will be used in the most innovative schemes are at an early stage of design, it was possible to compile reasonably reliable data on mass flows for the full range of all these fuel cycles. Based on those data, estimates of waste streams for systems at an equilibrium state were calculated using validated computer codes and the outcomes were peer reviewed by the group of experts. Taking into account the uncertainties remaining on the future performance of advanced processes, ranges of values were considered for many parameters and sensitivity studies were carried out when appropriate.

Although emphasis was placed on HLW, the impacts of advanced fuel cycle schemes on low- and intermediate-level waste generation, management and disposal, are addressed briefly in the study. Results indicate that issues raised by secondary waste should not be neglected, in particular for innovative schemes leading to the generation of new types of waste with chemical and isotopic compositions different from those generated by current fuel cycles.

The HLW repositories assessed in the study cover various deep geological formations that are considered adequate for long-term isolation of radioactive waste from the biosphere. The assessment was carried out for hypothetical, conceptual repositories in granite, clay, salt and tuff formations. The parameters affecting repository performance analysed in the study include HLW isotopic composition, heat load and volume.

The indicators selected to illustrate the main results from the analyses (see Table 2) represent key aspects of the schemes in terms of their capabilities to address sustainable development goals. The metrics used in the evaluation are the ratios of the indicator values for a given scheme to their values for the reference PWR once-through scheme 1a.

A number of other parameters are evaluated and compared in the study to complement the assessment and provide a comprehensive overview of the fuel cycle schemes analysed. Those parameters include the flows of separated plutonium and the volumes of short-lived, low and intermediate waste.

Table 2. **Selected comparative assessment indicators**

Indicator	Unit
Consumption of natural uranium	kgU/TWh
Volume of conditioned HLW, including spent fuel	kg heavy metal/TWh
Transuranic losses/transfer to HLW	kgTRU/TWh
Activity of HLW after 1000 years	TBq/TWh
Decay heat of HLW after 50 years	W_{th}/TWh
Decay heat of HLW after 200 years	W_{th}/TWh
Maximum dose from HLW disposal in clay*	Sv per annum/TWh
Maximum dose from HLW disposal in granite*	Sv per annum/TWh
Maximum dose from HLW disposal in tuff*	Sv per annum/TWh
Fuel cycle cost	US$/TWh
Total cost of generating electricity	US$/TWh

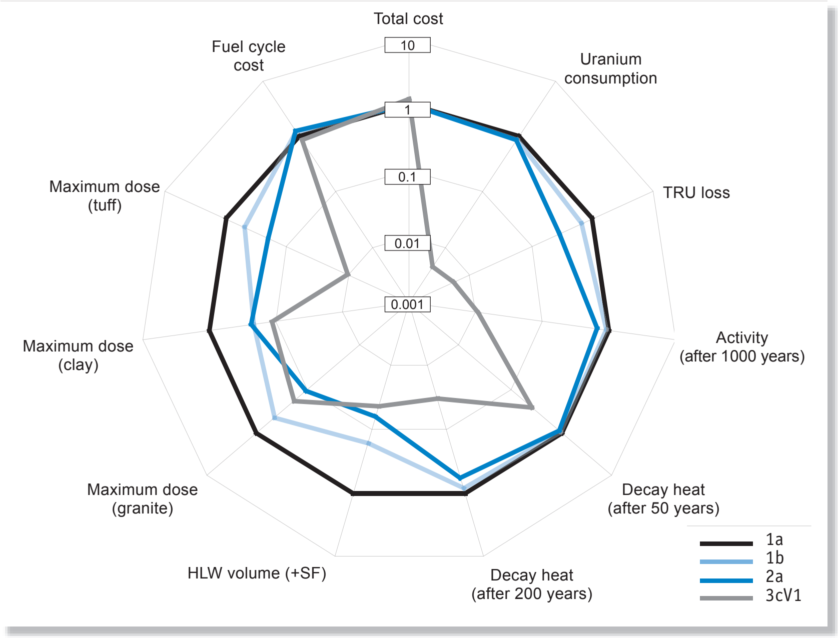
* The maximum doses calculated for disposal of HLW in salt are extremely low and differences between fuel cycle schemes in this regard are not significant enough to serve as a comparative indicator.

Uranium consumption is driven by the fraction of fast reactors included in the fuel cycle scheme; an all gas-cooled fast reactor scheme provides a theoretical potential reduction by two orders of magnitude as compared with the reference PWR once-through scheme. Transuranic losses to waste are reduced by a factor up to six with partially closed schemes, and by up to two orders of magnitude with fully closed schemes.

The activity of HLW after 1000 years is not modified significantly by partially closed schemes, but fully closed schemes can reduce it by nearly two orders of magnitude. The HLW volume is reduced significantly by any scheme, including reprocessing and recycling, with a reduction factor up to 24 for some fully closed schemes.

The decay heat of HLW after 50 years is not reduced by more than a factor of four by any scheme as compared with the reference scheme. However, the decay heat after 200 years is reduced by a factor up to 30 with schemes including minor actinide partitioning and transmutation.

Figure 1. **Comparison of selected indicators for illustrative schemes**



The repository performance assessments are based on analysing the effects of different HLW isotopic composition and heat load on repository capacity and maximum doses released. According to the approach adopted in OECD countries, all the repository concepts considered guarantee that maximum doses released to the biosphere at any time in normal conditions remain well below accepted radiation protection thresholds and authorised limits.

The comparative advantage of any scheme over the reference once-through scheme, in this context, is the additional quantity of HLW that could be disposed of in a given repository while respecting the dose limits. Heat load and waste volume are the most-affected parameters. For example, some advanced fuel schemes could allow a repository to accept waste produced from five to twenty times more electricity generation than the reference PWR once-through cycle scheme.

The analyses of the evolution of radioactivity in the waste over time illustrate the complementarities and time range of relevance of the three major courses of action in waste management: conditioning, geological disposal, and partitioning and transmutation. Partitioning followed by transmutation, storage, embedding in durable matrices, conditioning and deep geological disposal are redundant and complementary means to achieve the safe confinement of waste.

The economic analysis carried out in the study shows that the differences in total electricity generation cost between the schemes considered are not significant because waste management and disposal costs represent a very small fraction of those costs. All schemes, even the most advanced ones, may be implemented without jeopardising the competitiveness of nuclear electricity. Differences regarding fuel cycle costs are more visible, but clearly not a decisive factor to assess and compare alternative schemes.

The main results from the analysis are summarised in Figure 1. The spider web diagram displays indicators on a logarithmic scale: the closer the indicator is to the centre, the better is the performance of the scheme.

A key message drawn from the conclusions of the study is that, for all fuel cycle schemes considered, all the repository concepts analysed provide reliable and safe solutions for HLW disposal. Given the flexibility of the advanced fuel cycles under development, it is possible to design new reactor cycles that use resources more efficiently and generate less waste at acceptable costs. ■

Reference

1. NEA (2006), *Advanced Nuclear Fuel Cycles and Radioactive Waste Management*, OECD, Paris.

Impacts of nuclear power plant life management and long-term operation

P. Kovacs *

Nuclear energy is an important component of electricity supply in many OECD countries and is increasingly gaining the attention of policy makers and the public in light of its real potential role in long-term energy strategies aiming at sustainability and minimising the risk of global climate change. For many operating nuclear power plants, it has been demonstrated to the satisfaction of regulators that the plants can be operated safely and efficiently for a significantly longer period than was envisaged when they were designed, with lifetimes of 50 to 60 years being likely in many cases.

In most OECD countries with established nuclear power programmes, longer-term operation (LTO) of the nuclear power plants has already been accepted as a strategic objective to help ensure adequate supplies of electricity over the coming decades. In that context, the NEA has recently conducted a study whose main objective was to review and analyse the impacts of plant lifetime extension on fuel cycle and waste management requirements, on the economics of nuclear energy, on knowledge management and preservation, and more broadly on the future of nuclear energy in OECD member countries. Its scope includes technical, economic, social and strategic issues raised by plant life management and longer-term operation in countries planning an extended reliance on nuclear energy, in countries wishing to keep the nuclear option open, and in countries having decided a progressive phase-out of nuclear energy. OECD member countries in each of these categories as well as one member country without a nuclear programme were represented in the expert group that conducted the study.

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The group's report, published under the title *Nuclear Power Plant Life Management and Longer-term Operation,* presents trends, advantages and technical-economic challenges as well as environmental impacts of nuclear power plant lifetime management for longer-term operation. This article provides excerpts of the study's main findings.

Advantages of longer-term operation

The study concludes that the principal advantages of longer-term operation are economic in that:

- Extending the life of a major generating asset avoids the need for immediate investment in new generating capacity.
- The capital costs of plant life management for LTO will be much smaller than investment in any type of replacement capacity, although there might be a need for some additional investment in plant upgrading.
- Per kWh costs for waste management and decommissioning can be reduced.
- With nuclear fuel costs being generally lower and more stable than fossil fuel costs, this means that LTO can be expected to provide electricity at a lower cost than any other available option, which has a clear benefit to the national economy.

During the operating lifetime of several decades, it will often be possible to enhance plant safety levels by upgrading systems, structures and components (SSCs). Some such upgrades may be required by regulators, while others will be made by plant operators as part of regular maintenance or in pursuit of improved operating performance. Thus, while a nuclear power plant (NPP) may have been in operation for 30 or 40 years, many of its SSCs will be much younger. LTO helps to justify the investment in such upgrades, which means that it can also help to raise safety levels.

Longer-term operation of existing nuclear power plants contributes to sustainability by maintaining security and stability of energy supply and the diversity of energy sources; throughout, safety remains of paramount importance. Furthermore, LTO can provide nuclear energy without the significant environmental impacts that would be created by alternative power generation options (notably CO_2 emissions). Most countries with operating NPPs consider that nuclear energy contributes to the sustainability of their overall energy supply system, in that it minimises the long-term and irreversible impacts on the environment of meeting current energy demand.

Nuclear safety and the regulatory framework

When the current fleet of nuclear reactors was built, safety requirements of the existing plants were sufficiently stringent to ensure a considerable amount of conservatism in the design. Conservatism as such can facilitate LTO of existing nuclear power plants. Operating experience, improved analytical techniques and training of personnel also contribute to ensuring the safety of LTO, though proper regard must be given to the possibility of unknown ageing mechanisms. To the extent that the systems, structures and components of the nuclear power plants are correctly managed, LTO can potentially provide a bridge between the present generation of nuclear power plants and future energy systems, be they nuclear or non-nuclear.

Plant SSCs can be classified as either critical or non-critical. Critical items are those whose failure would cause concerns for the safety and reliability of the plant, and which therefore need to be repaired or replaced before they fail. Current preventive maintenance programmes help to improve plant safety and reliability by maintaining and replacing critical components.

Although the great majority of critical SSCs in an NPP can be replaced when necessary, there are a few major components (notably the reactor pressure vessel in most plants) which can be considered non-replaceable, either for technical or economic reasons. For such components it is necessary to implement ageing management programmes.

This process of optimising the upgrading and ageing management of the plant is vital in preparing for LTO. It includes ongoing research and development efforts to understand and mitigate the effects of ageing mechanisms, particularly on non-replaceable components, and involves plant operators working closely with reactor vendors and other nuclear engineering companies.

To achieve LTO it is important to have a clear and predictable regulatory framework. Timely investments need to be made in upgrading the plant and replacing the SSCs, and these will be influenced by the prospects for LTO. This process will be optimised only if the requirements that will need to be met are clear many years in advance. The process of consultation between regulators and plant operators therefore needs to begin well in advance. Once decided, the necessary licensing and approval processes need to be carried out in a timely manner.

The energy policy framework and political background are also important factors. If national energy policy regards LTO of NPPs as valuable and facilitates it, then clearly this will encourage plant owners to plan accordingly and to make the necessary investments well in advance. A decision to allow LTO to go ahead may often be easier to take from a political perspective than the alternative decision to construct replacement generating capacity. However, in some cases NPP owners have continued to plan for possible LTO even where political support for it is unclear.

More broadly, it is vital to build public confidence in the LTO of NPPs. While the public living in the immediate area around an existing nuclear plant is usually supportive, LTO might raise concerns about safety. The public needs to be properly informed about plans for LTO and the basis for ensuring that safety will not be compromised. Furthermore, it is necessary to discuss the advantages and concerns associated with LTO.

Operational experience

One important aim of plant life management for LTO is to improve a plant's operating performance. This includes upgrades to improve reliability, and hence achieve increased capacity factors. In many cases a plant's power output can also be increased, through uprating the reactor (see Table) and/or the turbine systems, while continuing to comply with all licensing and regulatory requirements.

Plant life management (PLiM) programmes have already resulted in significantly improved operational performance at many NPPs in OECD countries, which has often greatly increased the value of these nuclear generating assets. Further increases in operating performance have been achieved by optimising fuel management (e.g. higher enrichment levels and increased burn-ups), while reducing specific (per kWh) production of radioactive waste and spent fuel.

Planned and potential results of power uprating and PLiM programmes for LTO in selected NEA member countries

Country	Capacity uprating	LTO
Belgium	Yes	Phase-out policy
Czech Republic	Planned	Planned to 40 years, potentially to 60 years (4 units)
Finland	Capacity increase of 18 MWe completed in 2005 for Olkiluoto unit 2, completed in 2006 for Olkiluoto unit 1	Planned lifetime of 60 years for units 1 and 2, and for unit 3 (EPR) at Olkiluoto; planned lifetime for Loviisa (2 units) raised to 50 years
France	No	Lifetime of 40 to 60 years (58 units)
Japan	No	Lifetime of 40 to 60 years
Germany	Yes	Phase-out policy
Hungary	Under way for 4 units, capacity increase of up to 150 MWe	Planned to 50 years (4 units)
Republic of Korea	Yes	Lifetime of 40 to 60 years
Mexico	Yes	Lifetime of 40 to 60 years
Slovenia	Yes	Lifetime of 40 to 60 years
Slovak Republic	Under way for 4 units, capacity increase of up to 220 MWe	Planned to 40 years, potentially to 60 years (4 units)
Spain	Completed for 8 units, capacity increase of 550 MWe	Planned, possibly to 60 years (8 units)
Sweden	Under way for 8 units, capacity increase up to 1 296 MWe	Planned, up to 60 years or more (8 units)
Switzerland	Yes	Lifetime of 40 to 60 years
United Kingdom	No	Planned to 35 years (5 plants) or 30 years (2 plants), further extensions possible
United States	Continuing for many units, total capacity increase of over 4 000 MWe by 2012	Licence extensions granted to 41 units as of May 2006, for up to 60 years of operation

Human aspects of LTO

Certain human aspects of LTO were also analysed in the study. With LTO, NPPs may well operate for a total lifetime of 50 to 60 years. For this reason, management and preservation of knowledge are of critical importance. NPPs can be considered multi-generational projects, which will be the responsibility of several generations of engineers and other specialists over their lifetime. Steps should be taken by plant owners and by governments to support education programmes and to provide suitable career opportunities for young scientists and engineers to guarantee a sufficiently large, skilled workforce for the nuclear industry.

International co-operation and co-ordination are important in building confidence in LTO. There is a need to ensure that internationally recognised norms apply to all NPPs in order to address the concerns of governments and the public in neighbouring countries. At the regulatory level, there is considerable scope for exchanging experience and information about plants with similar reactor designs, and this is likely to result in a considerable degree of harmonisation of requirements for LTO. International organisations have an important role to play in this regard.

At the industrial level, international co-operation between plant operators, reactor vendors and technical support organisations in the areas of planning and R&D will help ensure that best practice is followed in implementing PLiM programmes for LTO of nuclear power plants in all countries. This is especially true where plants have been built to similar designs in several countries. Such co-operation can also help ensure that the expected benefits of LTO can be realised as widely as possible.

Conclusions

The continued, longer-term operation of existing NPPs beyond their original design lifetime has become an important option for countries with established nuclear programmes. In most OECD countries, LTO has already been accepted as a strategic objective to ensure adequate supplies of electricity over the coming decades.

LTO has significant economic advantages, but can also help improve plant safety and minimise CO_2 emissions. While the LTO of each plant must be considered individually in the light of its particular condition and economic circumstances, the general conclusion from studies carried out in several OECD/NEA member countries is that, for most reactor types, there are no significant technical challenges known which would limit plant lifetime to less than 50 to 60 years. The remaining challenges lie *inter alia* in proper planning and management, working with the existing regulatory and energy policy frameworks, obtaining public confidence, realising the R&D required and ensuring knowledge management. International co-operation, in the public and private sectors, can contribute to the successful implementation of LTO. ■

International peer review of a nuclear regulatory self-assessment

L. Högberg, J. Gauvain *

The OECD Nuclear Energy Agency (NEA) has an acknowledged role to assist its member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for a safe, environmentally friendly and economical use of nuclear energy. In this context, the NEA Committee on Nuclear Regulatory Activities (CNRA) provides a forum for senior representatives from nuclear regulatory bodies to exchange information and experience on nuclear regulatory policies and practices in NEA member countries and to review developments which could affect regulatory requirements. It also promotes co-operation among member countries to use feedback from experience to develop measures to improve safety, to enhance efficiency and effectiveness in the regulatory process and to maintain adequate infrastructure and competence in the nuclear field.

CSN request for a peer review

On 25 August 2004 an event occurred at the Vandellós II nuclear power plant which affected the operation of its essential service water (ESW) system. The subsequent follow-up to this safety-related event and the licensee's associated activities carried out by the *Consejo de Seguridad Nuclear* (CSN), the Spanish nuclear regulatory authority, resulted in a CSN report entitled *Lessons Learnt from the Essential Service Water System Piping Degradation Event at the Vandellós II Nuclear Power Plant*, referred to hereafter as the "CSN Lessons Learnt Report".

In October 2005 the CSN, based on a request it had received from the Spanish Congress, officially asked the NEA to perform an international peer review of this CSN Lessons Learnt Report. The purpose of the review was to prepare a report regarding the adequacy and completeness of the lessons learnt, as identified by the regulator. The NEA accepted the request to organise this review, since it was clear that its result would not only benefit the CSN but would also be useful to other nuclear regulators of the member countries. The NEA established an international review team composed of senior-level experts[1], who produced a report within three months, according to the agreed schedule. The report[2] was well-received by the CSN, and its findings, which were presented at the June 2006 meeting of the CNRA, are summarised below.

Overview of the event and related regulatory actions

On 25 August 2004, a manhole ruptured in the piping of the essential service water (ESW) system at Unit 2 of the Vandellós nuclear power plant. The function of that system is to provide the ultimate heat sink for most safety systems of the plant. During the event, train B of that system was completely lost and cooling of the plant systems was ensured by train A. The licensee informed the CSN that the plant had been shut down to repair the ruptured manhole in train B as well as the symmetrical one in train A, and to make some additional checks of the system. The CSN checked that the plant had followed its established internal review procedures for repairs, and on 29 August,

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the plant safety committee approved the start-up of the plant. No CSN approval was deemed necessary according to the Spanish legal framework and licensing process.

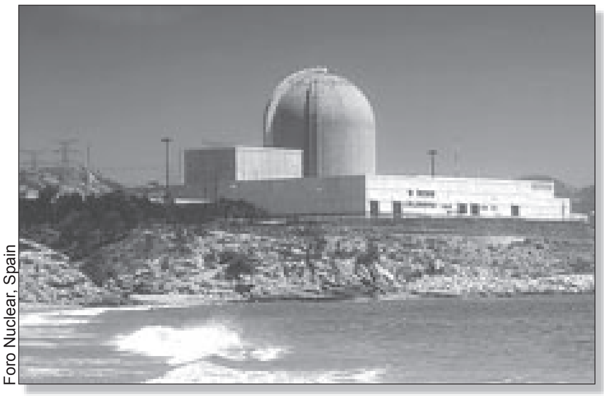
The CSN Resident Inspector promptly informed the CSN main office of the event and subsequently reported on the actions taken by the licensee. On 31 August, the Resident Inspector sent a note to the CSN mentioning a number of circumstances meriting further attention. The safety significance of the event was recognised at the CSN, and there were internal discussions about whether to send a reactive inspection team to the plant. In the end, it was decided to include the ESW event as a special issue on the agenda of the CSN multidisciplinary inspection, already scheduled to begin on 20 September.

The multidisciplinary inspection and subsequent investigations performed by the CSN revealed that the licensee apparently knew of the degradation of the ESW system for some time before the actual event occurred. A root-cause analysis by the CSN showed that the licensee's routine inspections of the system had identified pervasive corrosion in the outer part of the manhole necks in both trains in 1998. Despite these findings, the licensee did not take any appropriate corrective actions or inform the regulator about the degraded state of the ESW system. The regulatory inspection programme carried out independently by the CSN over the years had also failed to uncover the degradation situation.

The widespread corrosion of the ESW system presented a risk of a common-cause failure in both trains of the system, and hence degradation of the defence-in-depth and the safety of the plant. Given the safety significance of the event and the weaknesses revealed in the licensee's safety culture, the incident was finally classified by the CSN as INES level 2.

Once the full safety significance of the event had been appreciated, the CSN took a number of regulatory actions to require the licensee to make safety improvements. Recently, the CSN also proposed legal actions against the licensee.

Furthermore, an internal CSN review was performed to identify lessons learnt from the event. This internal review process was subsequently developed in several steps, resulting in the Lessons Learnt Report approved by the CSN Plenary on 18 November 2005. The report analyses aspects of the event related to the licensing and inspection process, internal communication within the regulatory body, the interaction between the licensee and the regulator, and the regulator's communication with national and international institutions, the media and the public. In each of these four areas, the report contains conclusions on lessons learnt and proposals for actions by the CSN, aiming at preventing the occurrence of similar situations in the future. It is the final version of this report, as approved by the CSN Plenary, that was used as the basis for the international peer review.


Foro Nuclear, Spain

Vandellós II nuclear power plant, Tarragona, Spain.

Key conclusions and recommendations of the peer review

The Review Team considered the CSN Lessons Learnt Report to be a commendable effort of regulatory self-assessment. The performance of such self-assessments is consistent with best international practices. The CSN Lessons Learnt Report, complemented by the outcome of the international peer review, should enable the regulator to take the proper actions to ensure that its regulatory supervision is also in line with best international practices.

The Review Team largely endorsed the actions proposed in the CSN Lessons Learnt Report. To these proposed actions the Review Team added its own suggestions, amplifying, developing and widening the scope of many of the actions proposed in the report. Most of the actions suggested, both in the report and by the Review Team, are of a fairly detailed technical nature. In order to provide an overview, and to facilitate turning the proposed actions into an appropriate action plan, the Review Team developed the following key conclusions and recommendations, which summarise the key actions proposed in the CSN Lessons Learnt Report, as complemented by the Review Team.

The Review Team concluded that the most important safety concerns raised by the event are first and foremost related to the significant weaknesses revealed in licensee performance with regard to safety management. The degradation of the essential service water (ESW) system was known within the licensee organisation for several years prior to the event, but appropriate corrective actions were not taken, nor was the regulator informed. However, while the primary responsibility for safety rests with the licensee, the event also raised concerns about the weaknesses revealed in the regulatory oversight, which contributed to the regulator's failure to detect both the degradation of the ESW system and the weaknesses in licensee safety management prior to the event. The Review Team offered the following overarching recommendations:

- The regulator should benchmark the differences between its regulatory programme and associated oversight processes and tools with those of its reference programme (US NRC), while also taking into account good regulatory practices applied elsewhere, notably by other nuclear regulators within the European Union. This benchmarking review should use a holistic and systematic approach, looking beyond the specific weaknesses revealed by the Vandellós event. In particular, the review should include a thorough assessment of the regulator's approach to regulatory supervision of licensee safety management in relation to good practices both in the United States and in Europe.
- The regulator should assess the various ways in which it interacts with licensees, to ensure that there are clear and appropriate internal policies and guidelines for different types of interactions and information exchange between the regulator and the licensees. This should include a review of the way that the regulator obtains, analyses, documents and reacts to safety-related information from nuclear power plant licensees, both as a part of the normal regulatory supervision process and in the case of unexpected events.
- The regulator's Plenary should initiate an internal review of the actual working processes, identifying and implementing appropriate actions in order to ensure and facilitate the effective functioning of the organisation, with regard to both regulatory decision making and the internal management of the regulatory body. In this context, the regulator should develop clear internal guidelines for the initiation and performance of self-assessments.
- The regulator should consider the added value of having a technical expert advisory group, such as is found in the nuclear regulatory organisations of many other countries, to provide independent technical advice to the Plenary on safety issues, thereby also playing an important role in the internal quality-assurance processes of the regulatory body.
- The regulator should develop and implement a proactive information policy and strategy, drawing on the experience available through the NEA/CNRA Working Group on Public Communication of Nuclear Regulatory Organisations (WGPC). A clear distinction between the respective roles of the licensee and the regulator in providing information to the public should be included in this information policy and strategy.

Last but not least, the regulator should turn the proposed actions in the CSN Lessons Learnt Report, together with the recommendations and suggestions of the Review Team into a specific action plan, with identification of priorities, responsibilities and associated resources for the various tasks, as well as milestones for the completion of the tasks and for the evaluation of the effectiveness of the actions taken. This action plan should start with activities aimed at creating a shared understanding within the regulatory body of current weaknesses in its regulatory oversight and how these are rooted in the prevailing attitudes and internal decision-making processes.

Closing remarks

The international peer review would not have been as successful without the active involvement of the CSN staff who took part in the review and the helpful and open manner in which they responded to the review and the team's requests for information. This "first-of-a-kind" NEA peer review in the area of nuclear safety and regulation has proven the Agency's capability to set up very quickly and efficiently "focused safety reviews", which are complementary to other activities performed by the NEA and of interest to other member countries. ■

Notes

1. The international review team was composed of the following senior-level experts: Mr. Lars Högberg (Chair, Sweden), Dr. Samuel A. Harbison (United Kingdom), Mr. Jean-Pierre Clausner (France), Mr. Ellis W. Merschoff (United States) and Mr. Jean Gauvain (NEA Secretariat).
2. NEA (2006), *Learning from Nuclear Regulatory Self-assessment: International Peer Review of the CSN Report on Lessons Learnt from the Essential Service Water System Degradation Event at the Vandellós Nuclear Power Plant*, OECD/NEA, Paris.

Releasing the sites of nuclear installations

J.L. Santiago, C. Pescatore, T. Eng *

The scale of future nuclear installation decommissioning challenges may be judged from the fact that over 500 nuclear power plants have been constructed and operated worldwide. OECD/NEA member countries account for more than 80% of the total number of plants, and most of these (some 350 plants with an average age of about 20 years) will need to be decommissioned in the next few decades. Recent planning indicates[1] that decommissioning activities will peak around the year 2015.

Decommissioning activities involve a number of steps which help lead to the ultimate goal of releasing facilities and sites from regulatory control. To date, considerable experience has been acquired in the clearance of materials and buildings. However, releasing the sites of nuclear installations from radiological control has been practised in a limited number of decommissioning projects only, as most decommissioning projects have not yet advanced to a state where release of the site is imminent or because the sites are, or will be, re-used for nuclear activities.

An attempt to address the different topics involved when releasing a site from radiological control has recently been undertaken by the OECD/NEA Working Group on Decommissioning and Dismantling (WPDD). The results of the study are expected to benefit a number of decommissioning projects where the release of the site is planned or has already started. This article summarises the main findings of the study, which can be found in the NEA publication entitled *Releasing the Sites of Nuclear Installations: A Status Report* [2].

Main topics to take into account when releasing a site

The NEA status report identifies a number of topics and considerations relevant to the release of sites. The report emphasizes the role of the concepts of clearance and release, and provides guidance on establishing release criteria. Other topics covered are the development of a plan for the final survey, including determination of "nuclide vectors" (see explanation below), measurement techniques, subtraction of background radiation levels, the statistical criteria and data assessment, and the issue of underground contamination.

- **The appropriate authority in a country where the release of sites shall be implemented needs to make a decision on the appropriate dose criterion which shall be used.**

There is no unanimous opinion on whether the same criterion should be used for the release of land as for clearance of materials (10 μSv/a) or whether more flexibility should be allowed. Some countries have used dose values up to 250 μSv/a for sites, others prefer 100 μSv/a. A few even go as far as 10 μSv/a. However, while materials can be traded across borders, land cannot. Compliance with 10 μSv/a in all cases might be a waste of effort. There are many types of installations which certainly could meet 250 μSv/a quite easily, while clean-up to a standard of 10 μSv/a would create additional effort which may not be justified by the reduction of potential individual dose. Nevertheless, it might currently be prudent to allow countries a

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flexible approach until more experience is gained with site releases. A flexible approach offers the possibility of applying the ALARA or optimisation principle and making best use of available resources.

Release levels are usually derived on the basis of radiological models, which in turn consist of scenarios describing a multitude of exposure situations and pathways.

- Site-specific approaches will usually concentrate on a smaller number of exposure pathways and scenarios which are tailored to the conditions of the site. Site-specific models will take account of site-specific parameters, such as the size of the site, the exact nuclide vector, known details of the future use of the site, and meteorological, hydrological and other parameters relating to the site.
- Generic approaches need to accommodate a larger number of different sites, the details of which are not known *a priori* therefore cannot be incorporated into the models. Generic models have to include all pathways and scenarios that might become relevant for any site in the country or in the region for which the derived release/clearance levels shall be valid. Such models may therefore have a tendency to be conservative when compared with site-specific approaches.

The models which have been used in a number of countries usually contain scenarios that cover all exposure pathways. A general overview of such pathways is given in the Figure. The radiological models are used to calculate release levels for a number of radionuclides which are or are deemed to be relevant for the release measurements.

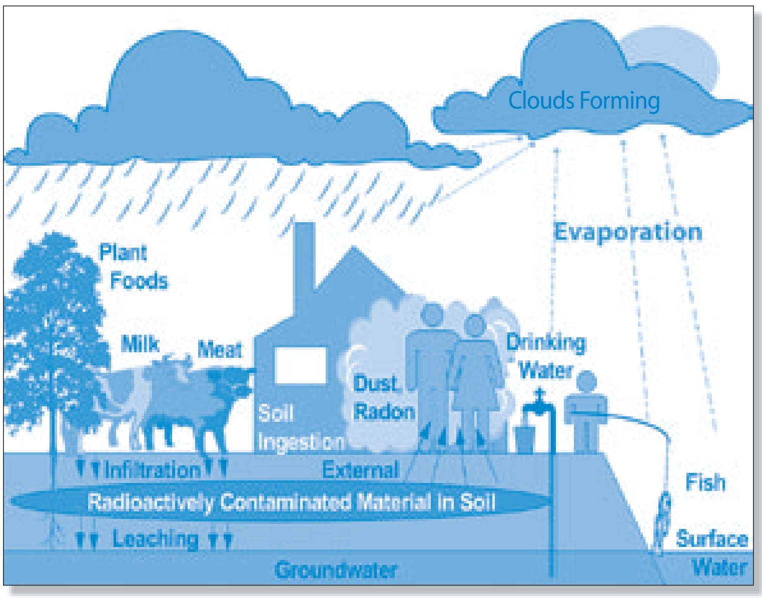
If the site complies with the appropriate release criteria when a reasonable set of possible future uses have been considered, the site should be released for unrestricted use, which is the preferred option. If this is not feasible, the site may still be released after remediation for restricted use. In case of restricted use, the restrictions should be designed and implemented to provide reasonable assurance of compliance with the dose constraint for as long as they are necessary.

Some sites may be released using a phased approach. This means that a substantial part of the site will be released prior to the end of institutional control of the whole site, for example to enable the setting-up of new (non-nuclear) companies there or to reduce the size of the licensed nuclear site. Such a situation may occur when one reactor is decommissioned to green-field at a multi-block nuclear power plant site where the other units remain operational, or at a large nuclear site where some part of the land is not necessary due to changes in the nuclear programme.

➠ **A plan for the release and final radiation survey of the site needs to be developed well before the release measurements.**

When the release of a site becomes imminent, a plan for the release and the final radiation survey needs to be developed. This plan must demonstrate how it will be assured that the site complies with the release criteria. On the basis of the site

Pathways used in the RESRAD (Residual radiation) computer code



characterisation, the plan should identify the radiological contaminants and classify or categorise the impacted areas by their potential or probability for residual radioactivity. The plan also needs to establish the methods and performance criteria used to conduct the survey and to define the number and location of measurements or samples necessary to ensure that the collected data will be sufficient for statistical analysis.

The concept of radionuclide vectors (also called nuclide vectors and "fingerprints") is useful. The activity percentages of the radionuclides which are or might be present on or in the top layer of the site's soil is determined before the release measurement takes place. One of the particular aims of establishing a radionuclide vector is to determine the activity ratios between the radionuclides which are easy to measure, for example cobalt-60 or cæsium-137, and those which are hard to measure, including alpha emitters and pure beta emitters such as strontium-90. The radionuclides which are easy to measure are often referred to as "key nuclides" because the activity of the other nuclides is derived from them.

The subtraction of the background activity is an important issue as soil contains non-negligible amounts of radionuclides of the natural uranium and thorium decay chains as well as potassium-40. In addition, land has been exposed to fall-out which usually may be subtracted as well as it does not originate from the practice which has been carried out on the site.

➠ **Appropriate techniques for release measurements of sites in combination with statistical approaches are available.**

Most direct measurement techniques can be applied in cases where the nuclide vector contains a sufficient amount of gamma- or beta-emitting radionuclides. For areas with a substantial amount of alpha emitters or other radionuclides which are hard to measure, and which cannot be correlated to an easy-to-measure radionuclide, sampling may be the only reasonable approach.

When activity measurements are taken one must define the area to which they relate. A measurement with, for example, a collimated *in situ* gamma spectrometer measures an area of the order of 1 m². Radiological evaluations for site release show that only the knowledge of activity concentrations averaged over much larger areas (100 m² to 10 000 m²) is relevant. This has been demonstrated by several countries which have even introduced such averaging areas in their national legislation (e.g. Germany). These averaging areas match in particular the approach of *in situ* gamma spectrometry combined with statistical approaches.

As it is not desirable to carry out measurements on the entire surface area of the site to be released, there must be statistical criteria to decide which percentage of the area needs to be measured and how reliable the result will be. Such statistical evaluations depend on many factors, such as the measurement technique, the likelihood of contamination and the desired confidence level.

➠ **Underground soil contamination must be taken into consideration in the release of sites.**

Release criteria and survey methods are generally developed for surface residual radioactivity (in the upper 5-15 cm of soil). If significant amounts of residual radioactivity have penetrated the soil deeper than this range, this should be taken into consideration when performing the radiological modelling and when developing the final survey plan.

Conclusions

Releasing the sites of nuclear installations or places where a licensed use of radionuclides has taken place is a mature practice in those countries with a number of advanced or completed decommissioning projects. Appropriate measurement techniques combined with statistical approaches enabling the calculation of the measurement density in accordance with the contamination level of the site are available. Release measurements can be applied swiftly in cases where a substantial amount of gamma-emitting nuclides is present in the radionuclide vector.

A number of countries have carried out site releases successfully by using different dose criteria, ranging from the trivial dose range (~ 10 µSv/a) up to a larger fraction of the individual dose limit of 1 mSv/a (~ 100 to 300 µSv/a). In addition, different models for deriving suitable release criteria have been applied. As a site is immobile, there should be less need for an international harmonisation of release criteria and approaches than, for example, for the clearance of metal scrap and building rubble, which may be transported across borders and for which an international harmonisation is desirable. ■

References

1. NEA (2002), *The Decommissioning and Dismantling of Nuclear Facilities: Status, Approaches, Challenges,* OECD/NEA, Paris.
2. NEA (2006), *Releasing the Sites of Nuclear Installations: A Status Report,* OECD/NEA, Paris.

Very high fuel burn-ups in light water reactors

K. Hesketh, C. Nordborg *

Historically, average fuel discharge burn-ups in light water reactors (LWRs) have steadily increased with time as technological developments have advanced. The practical limit is currently in the region of 50 gigawatt days per tonne of initial heavy metal (GWd/t). The main driving force behind this increase has been to reduce fuel cycle costs and to benefit from the increased operational flexibility that high burn-ups allow. The question is whether this trend will continue, or whether there are scientific and technological limits to LWR fuel burn-ups.

An NEA expert group has performed a technical assessment of very high burn-up fuel cycles in current light water reactors (LWRs), spanning a discharge fuel burn-up in the range between 60 GWd/t and about 100 GWd/t. The study assessed the impacts for the fuel cycle, for reactor operation and safety, and for fuel cycle economics. This article summarises the findings of the recently published NEA report[1].

Front-end of the fuel cycle

The single most important requirement to reach very high burn-ups is the need to relax the present 5.0% fuel enrichment limit that applies to current fuel fabrication plants and also to fresh fuel transport. This limitation is especially penalising for boiling water reactors (BWRs), since they use a heterogeneous enrichment distribution and the highest enriched fuel rods must be below the 5.0% limit.

The highest average fuel burn-up attainable within the 5.0% enrichment limit is approximately 65 GWd/t and this would have to be extended to about 8.0% to reach a burn-up of 100 GWd/t in pressurised water reactors (PWRs). However, to reach this burn-up, the maximum fuel rod enrichment in BWR assemblies will need to be higher (up to about 10%), because of the heterogeneous enrichment distribution used to counteract local flux peaking. Figure 1 illustrates the linear relation between initial enrichment and average discharge burn-up for various PWR fuel cycles; this clearly points to a maximum burn-up of 65 GWd/t at the 5.0% enrichment ceiling and correspondingly lower for BWRs, since the average enrichment will necessarily be lower than 5%. The increased fuel enrichments needed for higher burn-ups will significantly impact fuel fabrication plants as well as fuel transport.

Fuel management strategies and their impact on reactor core design and safety

The NEA study considered the implications of very high fuel burn-ups on in-core fuel management, as well as core design and the safety characteristics of a reactor. Although the particular details vary depending on reactor type (PWR, VVER or BWR), a VVER-440 reactor was used as an example to illustrate the following two fuel management strategies investigated:

- The first approach was to decrease the reload fraction, leaving the cycle length and reactor power unchanged. For example, the reload fraction could be reduced from one-third to one-quarter, so that the fuel residence time increases from three to four cycles. For a fixed cycle length, the discharge burn-up increases in inverse proportion to the reload fraction.

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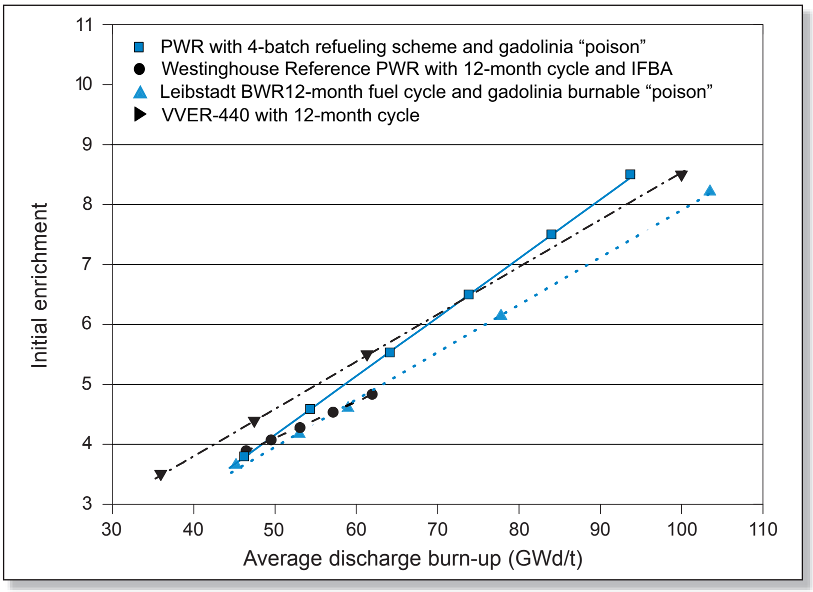
Figure 1. **Relation between initial fuel enrichment (percentage ^{235}U), as a function of average discharge burn-up**



- The other approach of increasing the cycle length while keeping the reload fraction constant could potentially provide a larger economic benefit. Assuming refuelling outage times to be the same, longer cycles imply higher capacity factors and therefore higher income from electricity generation. With this approach, the discharge burn-up increases in direct proportion to the cycle length.

Irrespective of the approach chosen, increasing the discharge burn-up requires higher initial enrichments. Because of the higher initial enrichment, both approaches significantly affect in-core fuel management and care is needed to ensure that the in-core parameters, particularly power peaking factors, reactivity feedback coefficients and shutdown margins remain within acceptable ranges. Higher discharge burn-ups can also be attained by uprating reactor power. If the reload fraction and the time elapsed during a cycle is kept the same, the burn-up increases in proportion to the uprating.

As regards core design and safety aspects for higher average burn-ups, when using high average ^{235}U enrichments in the core, it has been shown that:

- The moderator temperature coefficient becomes more negative.
- The boron coefficient becomes smaller in magnitude.
- There is a reduction in the control rod reactivity worths, causing a reduction in the shutdown margins.

These slightly unfavourable trends for nuclear design and safety parameters at very high burn-ups are mostly manageable, but work on experimental validation, as well as on the validation of nuclear data libraries and core design methods, needs to be extended to very high burn-ups.

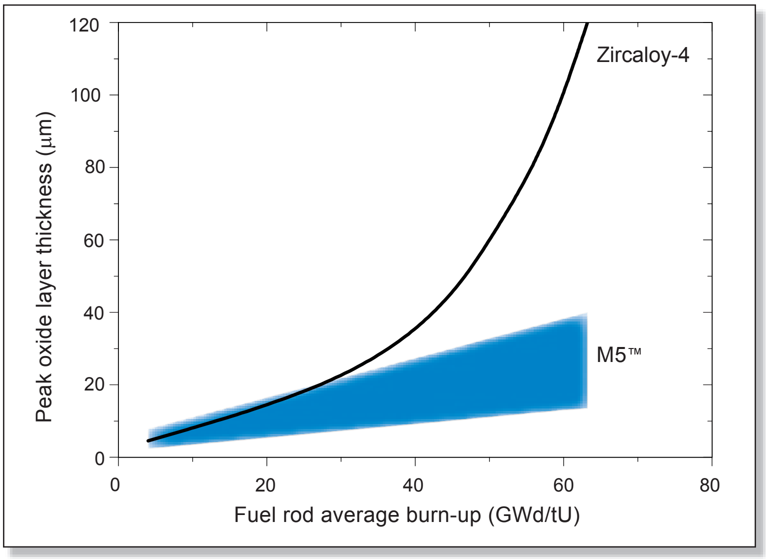
Concerning the irradiation of the reactor pressure vessel, it has been noted that low leakage loading patterns have been very effective in reducing pressure vessel fluences. However, at very high burn-ups there may be constraints in applying this pattern because of radial power peaking effects.

Issues related to reactor operation and thermo-mechanical performance of the fuel

The impact of very high burn-ups on reactor thermal hydraulics and issues related to the thermo-mechanical performance of the fuel has also been reviewed. In the case of thermal hydraulics, there is a need to develop a better understanding of the effects of corrosion, crud build-up and core axial and radial power distributions on the critical heat flux at higher burn-up, and to obtain measurements for high burn-up cladding. The accuracy of current steady state and transient temperature models needs to be verified at higher burn-ups and adaptations of assembly designs may be required.

All fuel thermo-mechanical behavioural aspects are affected at higher burn-ups, notably fuel pellet

Figure 2: **Maximum corrosion depth in M5 alloy compared to Zircaloy 4**



restructuring, gas release, cladding corrosion and dimensional stability. For example, recently developed cladding alloys have demonstrated considerable improvements in high burn-up corrosion resistance, as illustrated in Figure 2. As current fuel behaviour experience will no longer be valid at very high burn-ups, fuel behaviour codes will need to be extensively validated, possibly with new theoretical methods and costly irradiation trials to demonstrate satisfactory performance.

Back-end of the fuel cycle

The higher decay heat outputs and neutron emissions of very high burn-up fuels, due to an increased minor actinide inventory, have unfavourable implications for criticality assessments and spent fuel management, including transport, storage and reprocessing.

The isotopic compositions of uranium and plutonium degrade with higher burn-up, with possible repercussions for reprocessing plants that may necessitate changes of design and/or operating procedures. For example, the inventory of ^{232}U in irradiated fuel shows a steep increase with burn-up. This has an impact on the personnel dose in fuel fabrication operations, as the decay chain of ^{232}U contains an isotope (^{208}Tl) which emits very intense gamma rays.

The isotopic composition of plutonium recovered from very high burn-up fuels will be of a poorer fissile quality. This has particular implications for plutonium recycling as mixed-oxide (MOX) fuel in thermal reactors because a higher initial plutonium concentration will be necessary if the fissile quality is poor. Moreover, MOX fuels are restricted by a 12% total plutonium content to ensure that the void coefficient of the MOX assemblies does not become positive. The maximum average discharge burn-up attainable within this 12% plutonium limit is approximately 75 GWd/t, depending on the isotopic composition of the plutonium used. This is a potential future limitation on MOX recycling, which could possibly be circumvented using innovative designs.

An additional factor is the incorporation of high-level waste in glass, which in current plants is limited by neutron emissions. At very high burn-ups, the increased inventory of ^{244}Cm may reduce incorporation rates and lead to increased volumes of vitrified waste.

Although the radiotoxicity of the irradiated fuel, in sieverts per tonne of heavy metal (Sv/tHM), increases with higher burn-up, this does not account for the fact that each tonne of fuel generates a higher energy output at high burn-ups. The net effect is that the radiotoxicity of spent fuel is practically independent of burn-up when expressed in sievert per terajoule of electricity produced.

Interim storage of spent fuel is potentially an area where very high burn-up fuel could be very advantageous for a utility. A doubling of discharge burn-up would halve the volume of spent fuel accumulated over the lifetime of an LWR. However, the higher decay heat output and neutron emissions of high burn-up fuels will need longer cooling times. Hence, a doubling of the burn-up does not necessarily lead to a doubling of effective storage capacity, because the fewer number of assemblies discharged per year is offset by the increased cooling time.

There is a lack of knowledge as to whether the direct disposal of very high burn-up fuels in a geological repository may have an adverse impact on the subsequent long-term integrity and leach rates from the waste packages. The implications for any conditioning process to which spent fuel may be subjected prior to disposal are also unknown.

Economics

Although there may be some countries in which back-end concepts and strategies are already established and where flexibility for increasing burn-ups may be limited, for the majority of LWR utilities the motivation for adopting very high burn-up cycles is potentially very strong. In some circumstances, very high burn-ups may reduce fuel cycle costs and this is very important for utilities; fuel cycle economics is an area where a utility can directly influence costs and many utilities, particularly those operating in a competitive market, are under very strong cost-competitive pressures.

For many utilities, direct fuel cycle cost reductions may play a secondary role to reducing spent fuel arisings. Many utilities operate with rigid operating constraints, such as limited spent fuel storage capacity, that need careful management to maximise their plant's operational lifetime. For utilities in this position, potential reductions in spent fuel arisings with very high burn-ups may be the key to maximising generating revenue over their plant's lifetime and may therefore equate to a very large economic benefit. Very high burn-ups also allow a utility increased flexibility in choosing an optimal combination of cycle length and refuelling fraction, potentially yielding significant economic and operational benefits.

For very high average discharge burn-ups in the range of 60 to 100 GWd/t, the fuel cycle cost assessment has not shown a clear-cut economic incentive. The case for continued increase in burn-ups is only clear with an undiscounted economic model, and then only under the assumption that back-end unit costs do not rise too steeply with burn-up. Discounted economic models show a benefit from increased burn-ups only with an optimistic relation between initial enrichment and average discharge burn-up (in which the cycle length is constant and the refuelling fraction decreases), and with back-end unit costs that are independent of burn-up. Since there is no single economic model that applies to all utilities, depending on the local circumstances, some countries or utilities may see a benefit in very high burn-ups while others may not.

Conclusions

Attaining very high burn-ups will necessitate technological developments in almost every aspect of the fuel cycle. Most of these are considered achievable if there is sufficient incentive to go to higher burn-ups. Future progress towards very high burn-ups can be expected to be made in small incremental steps, just as has happened historically. However, there are several technological barriers to very high burn-ups. The most significant is the 5% criticality limit that currently applies in fuel fabrication plants. Relaxing this limit is not just a technological issue, but will also require significant investment decisions by fuel fabricators. The successful relaxation of this limit to, say, 6 or 7% may determine the highest practical average discharge burn-ups that will eventually be attainable.

Other technological areas where further development will be required for very high burn-ups include fuel assembly design, fuel assembly materials, in-core reactor physics behaviour and fuel thermo-mechanical behaviour. There are also implications for the back-end of the fuel cycle. Where a once-through fuel cycle is chosen, there may be implications from the higher decay heat output and neutron output of irradiated fuel assemblies on transport and/or interim storage. For a reprocessing cycle, the elevated decay heat and neutron outputs are likely to have significant technological ramifications. More specific recommendations regarding future technological directions are given in the NEA report.

The economics part of the study has highlighted a complicated situation, where some utilities might see definite cost benefits with very high burn-ups, and others seeing a less clear benefit. The economics versus burn-up dependence is in a very fine balance, with opposing effects almost cancelling each other out. In these circumstances, small differences specific to individual utilities can tip the balance against or in favour of high burn-ups. At this stage, it has not been possible to make any definitive conclusions and it will be necessary to see how fuel vendors and other fuel cycle service providers respond commercially to utility demand for higher burn-ups. ■

Note

1. NEA (2006), *Very High Burn-ups in Light Water Reactors*, OECD/NEA, Paris.

Differences in regulatory criteria for the long-term safety of radioactive waste disposal

R. Ferch, C. Pescatore *

Internationally, underground disposal of certain long-lived radioactive wastes such as spent nuclear fuel and high-level radioactive waste is the most widely accepted approach to ensure confidence about the long-term protection of future societies. Regulatory acceptance criteria, and in particular radiological protection criteria for humans and the environment over long timescales, are a prerequisite to the realisation of any underground repository for these long-lived wastes. A number of countries have established such regulatory criteria, while others are now discussing what constitutes a proper regulatory test and suitable time frame for ensuring the safety of long-term disposal.

Current regulatory criteria are meant to ensure protection and safety for periods of time that are exceptionally long. Because of differences in attitudes towards safety and the methods by which protection is established and ensured in different societies, it is not surprising that national differences exist among these criteria. On the other hand, it has been recognised for many years now that national differences in criteria may make it difficult to establish the necessary levels of acceptance of national repository proposals. It is thus important that the differences can be understood and explained.

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Under the auspices of the NEA Radioactive Waste Management Committee (RWMC), two initiatives were undertaken to study and compare the ways in which a suitable level of confidence is attained in different countries. One of these is the Timescales initiative of the Integration Group on the Safety Case (IGSC), which focuses on the technical arguments by which safety is demonstrated over the long timescales involved. The other is the RWMC Regulators Forum's Long-term Safety Criteria (LTSC) initiative, which looks at the bases of current long-term safety regulation and their applicability. Although these two initiatives deal with different aspects of the demonstration of safety, there is considerable overlap and convergence of the results achieved to date.

When the RWMC Regulators Forum was formed in 1999, one of its first tasks was to review the arrangements in member countries for regulating radioactive waste management. This work resulted in a comparative study of regulatory structures in member countries[1]. Part of the work leading to this comparative study was a review of the long-term radiological protection criteria for disposal of long-lived waste, and an examination of their consistency across countries. After this initial comparison, which revealed a broad range of differing criteria and practices, a follow-up initiative on Long-term Safety Criteria was undertaken. The objective of this ongoing initiative is neither to set nor to judge existing standards, but rather to study the criteria used by various member countries and to provide a forum for discussion. Ultimately, it is hoped that this will help provide guidance and information to those programmes still developing criteria, and assist national programmes in communicating the context and meaning of regulatory standards for long-term disposal.

How regulatory criteria differ

Although regulatory criteria for long-term safety normally address several aspects related to safety and protection, the focus of the group's work was initially on radiological (dose and/or risk) criteria. The group found significant numerical differences among the criteria, ranging over roughly two orders of magnitude. The differences are due, in some part, to concrete differences in technical factors such as geology and engineering approaches to both design and performance assessment. These technical differences appear to be greatly overshadowed, however, by differences of a more cultural nature, namely differing attitudes towards the questions of establishing and interpreting safety-related targets, criteria and margins of safety. These cultural differences are reflected in differences in the choice of appropriate indicators for protection in the long term, differences in the ways numerical criteria are applied, and different expectations regarding the desired level of confidence in the calculations. Regardless of these differences, the criteria used in all countries are well below levels at which actual effects of radiological exposure could be observed either directly or statistically.

The LTSC group found that the fundamental bases for long-term radiological protection criteria vary among member countries, with at least three differing approaches observed. Of these approaches, two are based on radiological dose criteria, with one approach using criteria derived from the dose limits and constraints that are used for current practices, and the other approach using criteria derived from arguments related to naturally-occurring levels of background radiation. The third approach rests directly upon the concept of acceptable levels of risk, without direct reference to radiological dose criteria. Of course, these three fundamental approaches are interrelated, and combinations of them are often used.

In addition to differences at the level of fundamental bases for the criteria, the group also observed the existence of several other factors that lead to differences in numerical criteria among countries. For example, in some cases current dose-constraint criteria are adopted directly, whereas in others the criteria are reduced by an additional factor which may reflect either the possibility of the existence of multiple sources of exposure as time elapses or increasing uncertainties in the calculations at more distant times. Criteria based on background-dose rates may either rest on direct comparisons to existing, natural dose rates, or on comparisons to the observed variability in those dose rates. When risk criteria are used, the calculations are used to produce an aggregated risk number in some cases while, in others cases, the probabilities and consequences are left disaggregated.

It is generally recognised that the outcomes of calculations of radiological doses received by future populations are best regarded not as predictions of actual impacts, but rather as somewhat stylised performance indicators. However, when used as the basis for regulatory decision making, in some cases the regulatory criteria are used as limits in much the same way as they are used for current practices. In other cases, the regulatory criteria are used as targets rather than as firm limits.

From the point of view of implementing those criteria and decision making, differences also exist at a less explicit and, therefore, less obvious level. Thus, even when similar computational models are used, the assumptions and data that are used in these models may vary depending on whether the calculations are viewed – by choice or regulatory demand – as "best-estimate" calculations of future impacts, as "conservative" safety analyses for licensing, or as attempts to provide an upper bound on the possible consequences. These differences in the expected or intended role of the analyses are often accompanied by differences in the treatment of uncertainties in data, models and numerical techniques.

For all of these reasons, a simple numerical comparison of criteria listed in a table can be highly misleading, if not meaningless, in order to compare required levels of safety. In its ongoing work, the LTSC group has therefore focused on some of the more fundamental reasons behind the differences among national criteria for long-term safety of radioactive waste, rather than on the numerical criteria themselves.

Some deeper reasons for the apparent discrepancy

While considering the underlying reasons for the current differences in criteria, the LTSC group's investigations identified a number of important contributing factors, among them the complexity and non-uniformity of the regulatory decision-making process, a lack of consensus on how to characterise and measure protection in the distant future, and fundamental ethical issues related to the nature of current society's obligations to the future. Discussion of these factors led to consideration of such matters as the role of the regulator, the meaning of safety and protection, building confidence in decision making, and ethical issues related to the means by which fairness to future generations should be provided.

The disposal of long-lived radioactive waste differs in significant ways from most practices involving radioactive materials in that by design the impacts are unlikely to become apparent until far into the future, if at all. Therefore, regulatory follow-up after granting a disposal licence, in order to see that the desired long-term effects are being achieved, is effectively impossible over the full design life of the disposal system. This means that an important conventional component for ensuring continued safety is unavailable to regulatory bodies, at least over the majority of the design life of the facility, namely the ability to monitor for non-compliance and take corrective action. Hence an important difference between countries is a result of different views on the meaning of safety in the absence of monitoring and direct control. Safety, as understood technically, is the absence of (or reduced potential for) physical harm resulting from the existence and operation of the system over a given period of time. Harm, in turn, is an impact that is judged, within a social and temporal context, to be unacceptable. Criteria for defining acceptability normally involve value judgments and can change with the context. This judgment may vary from one country to another, and also change with time within a given country. This poses problems for those who are charged with defining criteria to be applied to a repository whose design lifetime is expected to considerably exceed the duration of recorded human history and where contexts may vary greatly.

Any consideration of long-term safety criteria for disposal of radioactive waste inevitably raises questions of intergenerational equity – waste is generated today, beneficiaries are today's consumers of energy, but the waste can potentially impact future generations for a very long time. Initially, the most widely-adopted approach to the ethical question of intergenerational equity was based on the principle, simply stated, that the impacts of actions carried out in the present on future generations should not exceed the levels of impact that are considered acceptable today. More recently, however, thinking with respect to intergenerational equity recognises that as the time frame becomes longer, our ability to guarantee that current limits will be met to an acceptable level of confidence diminishes because of uncertainties not only in the physical and engineering models, but also and more significantly in our ability to predict and influence the behaviour, needs and aspirations of future populations many generations removed from us. In addition, and especially taking current trends towards reversibility and stepwise decision making into account, it is increasingly recognised that the impacts of the present generation's actions on the distant future are likely to be modified by the actions of our more immediate successors.

Current thinking about these ethical obligations is evolving, and such ethical considerations are another factor contributing to differences in national criteria for long-term protection. This is particularly evident when comparing the approaches in different countries to the question of time limits or cut-offs to the application of regulatory criteria, and/or to the use of criteria which depend on the timescale.

Conclusions

Since the granting of a licence for definitive disposal of long-lived waste and closure of a repository involves the ultimate absence of the element of active control, the design objective is passive safety without the requirement for further intervention. This represents a fundamental difference between the regulation of present-day activities and the regulation of disposal. This fundamental difference is reflected to a greater or lesser extent in the regulatory processes and criteria adopted in each country.

The LTSC working group is continuing its investigations on this subject and, at the time of writing, was preparing to hold a workshop at the end of November in Paris. In addition to making the work done to date more widely and better known, it is hoped that points of agreement and points for further discussion will be identified during this workshop, so that a road map for future work may be proposed in support of regulators and policy makers who are currently charged with developing regulatory acceptance criteria for proposed repositories. ■

Note

1. See www.nea.fr/html/rwm/reports/2005/nea6041-regulatory-function.pdf.

News briefs

Legislative update: France

Act on nuclear transparency and safety

A new comprehensive nuclear legislative framework on nuclear transparency and safety ("the TSN Act") was adopted in France on 13 June 2006, finally concluding almost a decade of intense legislative drafting in this field. The existing legal framework in France was disparate and consisted essentially of regulations, rendering nuclear law particularly complex and fragmentary in nature. The primary purpose of the adoption of the TSN Act was therefore to provide more coherence in this field, and to address the perceived democratic deficit by allowing parliamentary debate on nuclear issues which raise many economic, social and environmental questions.

In addition to establishing a legislative framework for nuclear activities, the objectives of the TSN Act are to establish important definitions at legislative level (e.g. nuclear security, nuclear safety, protection against ionising radiation, nuclear transparency); to lay down the main principles governing nuclear activities (principles of prevention, polluter pays and participation, as well as radiological protection principles); to organise nuclear information; to review the administrative framework for basic civilian nuclear installations; and to clarify and strengthen the control system and sanctions applicable.

Nuclear transparency is defined as "all the provisions taken to guarantee the public's right to reliable and accessible information about nuclear safety". Section 18 of the Act provides that the government is responsible for informing the public about monitoring procedures and results with regard to nuclear safety and radiological protection. The Act contains provisions on the right of access to nuclear information and on the reorganisation of information bodies. The High Committee for Nuclear Safety Transparency is to replace the Higher Nuclear Safety and Information Council, and shall be responsible for helping to inform the public about nuclear activities and issuing reforms intended to improve nuclear safety and radiological protection. The status of local information commissions (CLIs) is enhanced by the TSN Act and their role is confirmed. CLIs have a general monitoring, information and consultation mission with regard to nuclear safety, radiological protection and the impact of nuclear activities on persons and the environment.

Title IV of the TSN Act enshrines the existing regulations governing the design, operation and shut-down of nuclear facilities. The licensing procedure for the creation of a basic nuclear installation is amended as a result of the division of competence between the state and the Nuclear Safety Authority (ASN). Licences will henceforth be issued by decree once the ASN has given its opinion, and will determine solely the characteristics and perimeter of the installation as well as the deadline for commissioning. Requirements relating to the design, construction and operation of the facility, water abstraction and maximum release levels will therefore no longer be specified in the decree authorising the facility's creation, but in a decision issued by the ASN and subject to the approval of discharge levels. The regulatory regime is modelled on the requirements applicable to ICPE installations (installations classified for environmental protection purposes). Similarly, dispute resolution and inspection in relation to basic nuclear installations are now subject to the same regime as that which applies to ICPE installations.

The independent administrative authority established under Article 4 of the Act, the French Nuclear Safety Authority *(Autorité de sûreté nucléaire – ASN)*, replaces the Directorate-General of Nuclear Safety and Radiological Protection and now shares, with the ministers responsible for nuclear safety and radiological protection, regulatory and inspection powers in the area of nuclear safety, radiological protection and public information.

This legislation also contains (in Article 55) the amendments to the provisions of the 1968 Nuclear Liability Act, which will become applicable upon entry into force of the 2004 Protocols to Amend the Paris and Brussels Conventions.

Act concerning the sustainable management of radioactive materials and waste

Adopted on 28 June 2006, the Act concerning the sustainable management of radioactive materials and waste prolongs and consolidates the structure established by the well-known "Bataille Act" of 1991, which set out a vast research programme on the possible solutions for managing long-lived, high-level radioactive waste in France. The 2006 Act confirms the continuity and the complementarity of the three axes already selected by the Bataille Act: partitioning and transmutation of long-lived radioactive elements; reversible waste disposal in a deep geological formation; and storage.

Research into the partitioning and transmutation of long-lived radioactive elements is to be conducted in conjunction with studies and investigations into the new generation of nuclear reactors and those concerning accelerator-driven reactors dedicated to the transmutation of waste; a pilot facility is to be commissioned before end 2020. As regards reversible waste disposal in a deep geological formation, licensing is to take place before 2015, and operations at the storage facility should commence in 2025.

The 2006 Act also establishes a national radioactive material and waste management plan, which shall "take stock of existing modes for managing radioactive materials and waste, list the foreseeable requirements of storage or disposal facilities, detail the required capacities of such facilities together with corresponding storage times and, in the case of radioactive waste for which no final management mode exists, determine the objectives to be achieved". A decree shall specify the requirements of this national plan, to be established and updated every three years.

The Act provides for the establishment of a dedicated fund at ANDRA, the National Radioactive Waste Management Agency, in order to finance investigations and studies relating to the storage and deep geological disposal of radioactive waste. This fund shall be subsidised from an additional research tax on major nuclear installations (INB). A second fund is also established at ANDRA for the construction, operation, maintenance and shut-down of storage and disposal facilities for high-level and long-lived waste. ■

Multinational Design Evaluation Programme (MDEP) Stage 2

The NEA has been selected to perform the technical secretariat functions for Stage 2 of the Multinational Design Evaluation Programme (MDEP). The MDEP was set up to share the resources and knowledge accumulated by national nuclear regulatory authorities during their assessment of new reactor designs, with the aim of improving both the efficiency and the effectiveness of the process. Although its multinational dimension is part of its strength, a key concept of the MDEP is that national regulators will retain sovereign authority over all licensing and regulatory decisions.

The initiative was first proposed in July 2005, by the Chairman of the US Nuclear Regulatory Commission, as a Multinational Design Approval Programme. He stated that, "The maturity of the nuclear power technical and regulatory bodies today provides us with an opportunity to enhance safety and security. I believe that the experienced nuclear safety regulators of the world should take this opportunity to share their nuclear safety and technical knowledge, and to participate in the development of better technical frameworks for addressing the safety and security of the anticipated new generations of nuclear reactors."

Following a series of informal discussions among head regulators across the world, consensus was reached on a three-stage process to enhance co-operation among regulators facing the licensing of new reactors in the near future. The three stages are:

- Stage 1 – Enhanced multilateral co-operation within existing regulatory frameworks;
- Stage 2 – Multinational convergence of codes, standards and safety goals;
- Stage 3 – Implementation of MDEP Stage 2 products to facilitate the licensing of new reactors, including those being developed by the Generation IV International Forum (GIF).

In Stage 1, which began in 2005, nuclear regulators are using the technical data gathered during the certification of a reactor design in one country for its certification in another, thereby avoiding unnecessary duplication of work. The nuclear regulatory authorities of France and Finland are currently working with their American counterparts on the licensing of the European or evolutionary pressurised water reactor (EPR) design.

The Policy Group of MDEP Stage 2 met in September 2006 at NEA Headquarters and adopted its Terms of Reference (ToR). Mr. André-Claude Lacoste, Director-General of the French Nuclear Safety Authority, was elected Chairman of the Policy Group, the US Nuclear Regulatory Commission was selected to chair the Steering Technical Committee. The heads of the regulatory authorities of the ten participating countries[1] also agreed that the NEA should perform the technical secretariat functions for MDEP Stage 2.

The main objective of Stage 2 is to identify common regulatory practices and regulations that enhance the safety of new nuclear reactor designs. Ultimately this is expected to lead to a convergence of codes, standards and safety goals in the participating countries. To this end, two pilot projects have been launched. The first will investigate the licensing basis for new nuclear reactor designs, the scope of design safety reviews and overall safety goals. The second will examine regulatory oversight of components manufactured for nuclear reactors. Stage 2 has the ambitious goal to provide initial results within a year on sectors such as digital instrumentation and control, civil accident requirements and emergency core cooling system requirements.

The expected results of MDEP Stage 2 will be to:

- Allow knowledge transfer through the exchange of information on regulatory practices used by the participating countries in their design reviews, covering *inter alia* technical evaluations, codes, standards and safety goals, inspection practices, licensing requirements, safety research and operating experience.
- Identify similarities and differences in regulatory practices and obtain insights in order to better understand the technical basis for the differences.
- Seek and achieve convergence on reference regulatory practices in order to facilitate more efficient and effective design reviews, if reasonably practicable.
- Implement the results on specific designs for new reactors.
- Further stakeholder understanding of regulatory practices on an international basis.

In accomplishing the above, it is anticipated that Stage 2 outcomes would constitute very useful input for upgrading IAEA Safety Standards.

Two key elements of NEA support will be to establish an effective communication plan and to ensure adequate interactions with other international initiatives. As part of this task, the NEA Secretariat will prepare a proposal to facilitate the exchange of information on the project, both internally and externally. Adequate interaction with other stakeholders, especially with industry, was considered to be important by the participating countries and will be addressed in the forthcoming meetings of the pilot projects and Policy Group. ■

Note

1. There are currently ten participating countries in the MDEP, including seven NEA members(*): Canada*, China, Finland*, France*, Japan*, the Republic of Korea*, the Russian Federation, South Africa, the United Kingdom* and the United States*. The International Atomic Energy Agency (IAEA) will take part in the work of MDEP Stage 2.

NEA joint projects

NEA joint projects and information exchange programmes enable interested countries, on a cost-sharing basis, to pursue research or the sharing of data with respect to particular areas or issues in the nuclear energy field. The

Project	Participants	Budget
Cabri Water Loop Project Contact: carlo.vitanza@oecd.org Current mandate: 2000-2010	Czech Republic, Finland, France, Germany, Hungary, Korea, Slovak Republic, Spain, Sweden, Switzerland, United Kingdom, United States	≈US$ 77.5 million (total)
COMPSIS Project Contact: pekka.pyy@oecd.org Current mandate: January 2005-December 2007	Chinese Taipei, Finland, Germany, Hungary, Japan, Korea, Slovak Republic, Sweden, Switzerland, United States	€ 100 000 /year
Co-operative Programme on Decommissioning (CPD) Contact: torsten.eng@oecd.org Current mandate: January 2004-January 2009	Belgium, Canada, Chinese Taipei, France, Germany, Italy, Japan, Korea, Slovak Republic, Spain, Sweden, United Kingdom	≈€ 44 000 /year
Fire Incidents Records Exchange (FIRE) Project Contact: jean.gauvain@oecd.org Current mandate: January 2006-December 2008	Canada, Czech Republic, Finland, France, Germany, Japan, Netherlands, Spain, Sweden, Switzerland, United States	≈€ 91 300 /year
Halden Reactor Project Contacts: pekka.pyy@oecd.org carlo.vitanza@oecd.org Halden contact: Fridtjov.owre@hrp.no Current mandate: January 2006-December 2008	Belgium, Bulgaria, Czech Republic, Denmark, Finland, France, Germany, Hungary, Japan, Korea, Norway, Russia, Slovak Republic, Spain, Sweden, Switzerland, United Kingdom, United States	≈US$ 20 million /year
Information System on Occupational Exposure (ISOE Programme) Contact: brian.ahier@oecd.fr Current mandate: 2002-2007	Armenia, Belgium, Brazil, Bulgaria, Canada, China, Czech Republic, Finland, France, Germany, Hungary, Italy, Japan, Korea, Lithuania, Mexico, Netherlands, Pakistan, Romania, Russia, Slovak Republic, Slovenia, South Africa, Spain, Sweden, Switzerland, Ukraine, United Kingdom, United States	≈€ 370 000 /year
International Common-cause Data Exchange (ICDE) Project Contact: pekka.pyy@oecd.org Current mandate: April 2005-March 2008	Canada, Finland, France, Germany, Japan, Korea, Spain, Sweden, Switzerland, United Kingdom, United States	≈€ 140 000 /year

projects are carried out under the auspices, and with the support, of the NEA. All NEA joint projects currently under way are listed below.

Objectives
• Extend the database for high burn-up fuel performance in reactivity-induced accident (RIA) conditions. • Perform relevant tests under coolant conditions representative of pressurised water reactors (PWRs).
• Define a format and collect software and hardware fault experience in computer-based, safety-critical NPP systems in a structured, quality-assured and consistent database. • Collect and analyse COMPSIS events over a long period so as to better understand such events, their causes and their prevention. • Generate insights into the root causes of and contributors to COMPSIS events, which can then be used to derive approaches or mechanisms for their prevention or for mitigating their consequences. • Establish a mechanism for efficient feedback of experience gained in connection with COMPSIS events, including the development of defences against their occurrence, such as diagnostics, tests and inspections. • Record event attributes and dominant contributors so that a basis for national risk analysis for computerised systems is established.
• Exchange scientific and technical information amongst decommissioning projects on nuclear facilities.
• Collect fire event experience (by international exchange) in the appropriate format and in a quality-assured and consistent database. • Collect and analyse fire events data over the long-term with the aim to better understand such events, their causes and their prevention. • Generate qualitative insights into the root causes of fire events which can then be used to derive approaches or mechanisms for their prevention or for mitigating their consequences. • Establish a mechanism for the efficient feedback of experience gained in connection with fire including the development of defences against their occurrence, such as indicators for risk-based inspections. • Record characteristics of fire events in order to facilitate fire risk analysis, including quantification of fire frequencies.
Generate key information for safety and licensing assessments and aim at providing: • extended fuel utilisation: basic data on how the fuel performs, both at normal operation and transient conditions, with emphasis on extended fuel utilisation in commercial reactors; • degradation of core materials: knowledge of plant materials behaviour under the combined deteriorating effects of water chemistry and nuclear environment, also relevant for plant lifetime assessments; • man-machine systems: advances in computerised surveillance systems, virtual reality, digital information, human factors and man-machine interaction in support of upgraded control rooms.
• Collect and analyse occupational exposure data and experience from all participants to form the ISOE databases. • Provide broad and regularly updated information on methods to improve the protection of workers and on occupational exposure in nuclear power plants. • Provide a mechanism for dissemination of information on these issues, including evaluation and analysis of the data assembled and experience exchanged, as a contribution to the optimisation of radiation protection.
• Provide a framework for multinational co-operation. • Collect and analyse common-cause failure (CCF) events over the long term so as to better understand such events, their causes and their prevention. • Generate qualitative insights into the root causes of CCF events which can then be used to derive approaches or mechanisms for their prevention or for mitigating their consequences. • Establish a mechanism for the efficient feedback of experience gained in connection with CCF phenomena, including the development of defences against their occurrence, such as indicators for risk-based inspections. • Generate quantitative insights and record event attributes to facilitate the quantification of CCF frequencies in member countries. • Use the ICDE data to estimate CCF parameters.

Project	Participants	Budget
MASCA-2 (Material Scaling) Project Contact: jean.gauvain@oecd.org Current mandate: 2003-2006	Belgium, Canada, Czech Republic, Finland, France, Germany, Hungary, Japan, Korea, Russia, Slovak Republic, Spain, Sweden, Switzerland, United States	≈US$ 1 million /year
Melt Coolability and Concrete Interaction (MCCI) Project Contact: carlo.vitanza@oecd.org Current mandate: April 2006-June 2009	Belgium, Czech Republic, Finland, France, Germany, Hungary, Japan, Korea, Norway, Spain, Sweden, Switzerland, United States	≈US$ 1.2 million /year
Piping Failure Data Exchange (OPDE) Project Contact: alejandro.huerta@oecd.org Current mandate: July 2005-July 2008	Belgium, Canada, Czech Republic, Finland, France, Germany, Japan, Korea, Spain, Sweden, Switzerland, United States	≈US$72 000 /year
PKL-2 Project Contact: jean.gauvain@oecd.org Current mandate: January 2004-December 2006	Belgium, Czech Republic, Finland, France, Germany, Hungary, Italy, Japan, Korea, Spain, Sweden, Switzerland, United Kingdom, United States	US$ 1.2 million /year
PRISME Project Contact: carlo.vitanza@oecd.org Current mandate: January 2006-December 2010	Belgium, Canada, Finland, France, Germany, Japan, Korea, Netherlands, Spain, Sweden	€ 7 million (total)
PSB-VVER Project Contact: jean.gauvain@oecd.org Current mandate: February 2003-June 2007	Czech Republic, Finland, France, Germany, Italy, Russia, United States	US$ 0.4 million /year
Rig of Safety Assessment (ROSA) Project Contact: carlo.vitanza@oecd.org Current mandate: April 2005-December 2009	Belgium, Czech Republic, Finland, France, Germany, Hungary, Japan, Korea, Spain, Sweden, Switzerland, United Kingdom, United States	US$ 1 million /year
SETH (SESAR Thermal-hydraulics) Project Contact: jean.gauvain@oecd.org Current mandate: April 2001-December 2006	Belgium, Czech Republic, Finland, France, Germany, Hungary, Italy, Japan, Korea, Spain, Sweden, Switzerland, Turkey, United Kingdom, United States	US$ 0.9 million /year
Studsvik Cladding Integrity Project (SCIP) Contact: carlo.vitanza@oecd.org Current mandate: July 2004-June 2009	Czech Republic, Finland, France, Germany, Japan, Korea, Spain, Sweden, Switzerland, United Kingdom, United States	US$ 1.8 million /year
Thermochemical Database (TDB) Project Contact: federico.mompean@oecd.org Current mandate: February 2003-February 2007	Belgium, Canada, Czech Republic, Finland, France, Germany, Japan, Spain, Sweden, Switzerland, United Kingdom, United States	≈€ 0.4 million /year

Objectives
● Provide experimental information on the phase equilibrium for different corium mixture compositions that can occur in water reactors. ● Generate data on relevant physical properties of mixtures and alloys that are important for the development of qualified mechanistic models.
● Provide experimental data on melt coolability and concrete interaction (MCCI) severe accident phenomena. ● Resolve two important accident management issues: – the verification that molten debris that has spread on the base of the containment can be stabilised and cooled by water flooding from the top; – the two-dimensional, long-term interaction of the molten mass with the concrete structure of the containment, as the kinetics of such interaction is essential for assessing the consequences of a severe accident.
● Collect and analyse piping failure event data to promote a better understanding of underlying causes, impact on operations and safety, and prevention. ● Generate qualitative insights into the root causes of piping failure events. ● Establish a mechanism for efficient feedback of experience gained in connection with piping failure phenomena, including the development of defence against their occurrence. ● Collect information on piping reliability attributes and influence factors to facilitate estimation of piping failure frequencies, when so decided by the Project Review Group.
● Investigate pressurised water reactor (PWR) safety issues by means of thermal-hydraulic experiments to be conducted at the *Primärkreislauf-Versuchsanlage* (primary coolant loop test facility) in Germany. ● One category of tests focuses on boron-dilution issues. ● A second type of test addresses potential accident conditions during shutdown (mid-loop operation).
● Answer questions concerning smoke and heat propagation inside a plant, by means of experiments tailored for code validation purposes.
● Provide the unique experimental data needed for the validation of thermal-hydraulic codes and to support refinements to safety assessment tools for VVER-1000 reactors.
● Provide an integral and separate-effect experimental database to validate code predictive capability and accuracy of models. In particular, phenomena coupled with multi-dimensional mixing, stratification, parallel flows, oscillatory flows and non-condensable gas flows are to be studied. ● Clarify the predictability of codes currently used for thermal-hydraulic safety analyses as well as of advanced codes presently under development, thus creating a group among OECD member countries who share the need to maintain or improve technical competence in thermal-hydraulics for nuclear reactor safety evaluations.
● Carry out thermal-hydraulic experiments in support of accident management at facilities identified by the NEA Committee on the Safety of Nuclear Installations (CSNI), such as those requiring international collaboration to sponsor their continued operation. ● The first part of the programme addressing primary loop accidents has been completed. ● The second part addressing data for computerised fluid dynamics (CFD) code validation for containment applications is under way.
● Assess material properties and determine conditions that can lead to fuel failures. ● Improve the general understanding of cladding reliability at high burn-up through advanced studies of phenomena and processes that can impair fuel integrity during operation in power plants and during handling or storage. ● Achieve results of general applicability (i.e. not restricted to a particular fuel design, fabrication specification or operating condition).
Produce a database that: ● contains data for all the elements of interest in radioactive waste disposal systems; ● documents why and how the data were selected; ● gives recommendations based on original experimental data, rather than on compilations and estimates; ● documents the sources of experimental data used; ● is internally consistent; ● treats all solids and aqueous species of the elements of interest for nuclear waste storage performance assessment calculations.

New publications

Economic and technical aspects of the nuclear fuel cycle

Forty Years of Uranium Resources, Production and Demand in Perspective – The "Red Book" Retrospective

ISBN 92-64-02806-4 *Price: € 90, US$ 121, £ 64, ¥ 12 500.*

The Red Book Retrospective was undertaken to collect, collate, analyse and publish all of the key information collected in the 20 editions of the Red Book published between 1965 and 2004. Additionally, every effort has been made to fill in gaps in the record to provide the most complete and exhaustive information possible. As a result, the Red Book Retrospective gives a full historical profile of the world uranium industry in the areas of exploration, resources, production, reactor-related requirements, inventories and price. It provides in-depth information relating to the histories of the major uranium-producing countries including Australia, Canada, France, Germany (including the former German Democratic Republic), the Russian Federation (including the former Union of Soviet Socialist Republics) and the United States. For the first time, for example, a comprehensive look at annual and cumulative production and demand of uranium since the inception of the atomic age is possible. Besides reporting and documenting the historical data, expert analyses provide fresh insights into important aspects of the industry including: the cost of discovery, resources to production ratios and the time to reach production after discovery, among others. Taken together, the Red Book Retrospective provides the most complete record of the uranium industry publicly available, dating from the birth of civilian nuclear energy through to the dawn of the 21st century.

Nuclear Power Plant Life Management and Longer-term Operation

ISBN 92-64-02924-9 *Price: € 30, US$ 40, £ 21, ¥ 4 100.*

This book, prepared by NEA member country experts, contains data and analyses relevant to nuclear power plant life management and the plants' extended, longer-term operation (LTO). It addresses technical, economic and environmental aspects and provides insights into the benefits and challenges of plant life management and LTO.

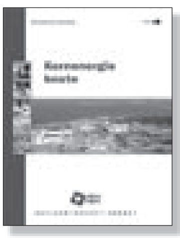
It will be of interest to policy makers and senior managers in the nuclear power sector and governmental bodies involved in nuclear power programme design and management. The data and information on current trends in nuclear power plant life management will be useful to researchers and analysts working in the field of nuclear energy system assessment.

Now available!

Kernenergie heute

Originalfassungen veröffentlicht unter dem Titel: Nuclear Energy Today

ISBN 92-64-02653-3 *Preis: € 25, US$ 32, £ 16, ¥ 3 200.*



Energie ist der Motor der Weltwirtschaft und mit der Expansion der führenden Volkswirtschaften und dem Wachstum der Entwicklungsländer steigt der Weltenergiebedarf stetig an. Die Befriedigung dieser Nachfrage bei gleichzeitigem Schutz der Umwelt und der natürlichen Ressourcen stellt eine der großen Aufgaben unserer Zeit dar. In weiten Teilen der Gesellschaft wird darüber debattiert, wie die Energieversorgung der Zukunft gesichert werden kann und ob der Kernenergie dabei eine Rolle zukommen sollte. Kernenergie ist eine komplexe Technologie, die wichtige Fragen aufwirft und seit ihren Anfängen von Kontroversen überschattet ist. Sie birgt jedoch zugleich große potenzielle Vorteile.

Nuclear safety and regulation

Learning from Nuclear Regulatory Self-assessment

International Peer Review of the CSN Report on Lessons Learnt from the Essential Service Water System Degradation Event at the Vandellós Nuclear Power Plant

ISBN 92-64-02310-0 *Free: paper or web.*

Nuclear regulatory self-assessment together with the benchmarking of regulatory practices against those of other countries operating nuclear power plants are key elements in maintaining a high level of nuclear safety. In that light, the Spanish *Consejo de Seguridad Nuclear* (CSN) formally asked the OECD Nuclear Energy Agency (NEA) to establish an international peer review team to assess the CSN report on the lessons learnt as a result of the 2004 Vandellós II event involving essential service water system degradation.

The International Review Team considers the CSN report prepared in follow-up to the Vandellós event to be a commendable effort in regulatory self-assessment. The report, complemented by this international peer review, should enable the CSN to take appropriate action to ensure that its regulatory supervision is in line with best international practice.

Radioactive waste management

Decommissioning Funding: Ethics, Implementation, Uncertainties

A Status Report

ISBN 92-64-02312-7 *Free: paper or web.*

This status report is based on a review of recent literature and materials presented at NEA meetings in 2003 and 2004, and particularly at a topical session organised in November 2004 on funding issues associated with the decommissioning of nuclear power facilities. The report also draws on the experience of the NEA Working Party on Decommissioning and Dismantling (WPDD).

This report offers, in a concise form, an overview of relevant considerations on decommissioning funding mechanisms with regard to ethics, implementation and uncertainties. Underlying ethical principles found in international agreements are identified, and factors influencing the accumulation and management of funds for decommissioning nuclear facilities are discussed together with the main sources of uncertainties of funding systems.

Releasing the Sites of Nuclear Installations

A Status Report

ISBN 92-64-02307-0 *Free: paper or web.*

Releasing the site of a nuclear installation from radiological control is usually one of the last steps of decommissioning. To date, site release has been practised in a limited number of cases only as most decommissioning projects have not yet advanced to a state where the release of the site is imminent or because the site will continue to be used for nuclear activities. Therefore, for a number of decommissioning projects where planning for site release will soon start, this status report provides useful considerations based on NEA member country experience and expert advice.

In addition to describing the basic considerations which must be taken into account when deciding on the release of a site, the status report provides guidance on establishing release criteria. The report also addresses site release implementation, measurement techniques and underground contamination. It will be of particular interest to regulators, implementers, R&D experts and policy makers dealing with decommissioning and dismantling issues.

Radioactivity Measurements at Regulatory Release Levels

ISBN 92-64-02319-4 *Free: paper or web.*

The release of radioactive materials from regulatory control is subject to release limits which are often based on published recommendations of international organisations, which aim to minimise radiological risks. The application of the recommendations has thus led to limits being set at very low activity levels. Adequate methods of measurement must be available to demonstrate or verify that the activity levels are lower than the recommended values. Measurements would also have to be made under practical industrial conditions, where various constraints could significantly influence the results. Hence, the costs of activity measurements at extremely low levels on large quantities of equipment with complex geometries could be prohibitively high. The NEA Co-operative Programme on Decommissioning (CPD) established a special Task Group to study these issues in an analytical and structured manner. This report describes the group's findings regarding the objectives and methodology for radiological characterisation and the equipment used for measurements. The report also contains case studies from NEA member countries and a critical discussion of different methods and techniques.

Roles of Storage in the Management of Long-lived Radioactive Waste (The)

Practices and Potentialities in OECD Countries

ISBN 92-64-02315-1 *Free: paper or web.*

This report examines the roles that storage plays, or might play, in radioactive waste management in OECD/NEA member countries. A better understanding of these roles provides valuable input to current debates on the end-points of long-lived radioactive waste management. The report focuses on spent nuclear fuel, high-level waste from reprocessing and other long-lived, solid radioactive wastes.

Safety of Geological Disposal of High-level and Long-lived Radioactive Waste in France

An International Peer Review of the "Dossier 2005 Argile" Concerning Disposal of the Callovo-Oxfordian Formation

ISBN 92-64-02299-6 *Free: paper or web.*

A major activity of the OECD Nuclear Energy Agency (NEA) in the field of radioactive waste management is the organisation of international peer reviews of national studies and projects. The peer reviews help national programmes assess accomplished work. The general comments expressed in the reviews are also of potential interest to other member countries. The present review was carried out to inform the French Government whether the "Dossier 2005 Argile" prepared by the National Agency for the Management of Radioactive Waste (Andra) was consistent with international practices and whether future research needs were properly identified.

Selecting Strategies for the Decommissioning of Nuclear Facilities

A Status Report

ISBN 92-64-02305-4 *Free: paper or web.*

This status report is based on the viewpoints and materials presented at a seminar held in Tarragona, Spain on 1-4 September 2003 as well as the experience of the NEA Working Party on Decommissioning and Dismantling (WPDD). It identifies, reviews and analyses factors influencing decommissioning strategies and addresses the challenges associated with balancing these factors in the process of strategy selection. It gives recognition to the fact that, in addition to technical characteristics, there are many other factors that influence the selection of a decommissioning strategy and that cannot be quantified, such as policy, regulatory and socio-economic factors and aspects that reach far into the future. Uncertainties associated with such factors are a challenge to those who have to take decisions on a decommissioning strategy. Potentially interested groups of readers are regulators, implementers, R&D experts and policy makers dealing with decommissioning and dismantling issues as well as politicians, decision makers and the general public.

Nuclear law

Indemnification of Damage in the Event of a Nuclear Accident

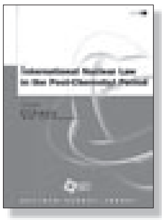
Workshop Proceedings, Bratislava, Slovak Republic, 18-20 May 2005

ISBN 92-64-02625-8 *Price: € 40, US$ 54, £ 28, ¥ 5 500.*

The Second International Workshop on the Indemnification of Nuclear Damage was held in Bratislava, Slovak Republic, from 18 to 20 May 2005. The workshop was co-organised by the OECD Nuclear Energy Agency and the Nuclear Regulatory Authority of the Slovak Republic. It attracted wide participation from national nuclear authorities, regulators, operators of nuclear installations, nuclear insurers and international organisations. The purpose of the workshop was to assess the third party liability and compensation mechanisms that would be implemented by participating countries in the event of a nuclear accident taking place within or near their borders. These proceedings contain the papers presented at the workshop, as well as reports on the discussion sessions held.

International Nuclear Law in the Post-Chernobyl Period

ISBN 92-64-02293-7 *Free: paper or web.*



The accident at the Chernobyl nuclear power plant in 1986 heightened awareness of the need to improve the international legal framework governing the safe and peaceful uses of nuclear energy. Numerous legal instruments have subsequently been adopted. This compendium examines the developments which have taken place in international nuclear law since 1986. It reproduces a number of articles which have been published in the OECD/NEA *Nuclear Law Bulletin*, accompanied by some previously unpublished works. The principal legal instruments examined in this publication govern early notification and assistance in the event of a nuclear accident, nuclear safety, the safety of radioactive waste and spent fuel, and nuclear liability and compensation.

Nuclear Law Bulletin No. 77

ISSN 0304-341X *Price: € 92, US$ 111, £ 60, ¥ 12 200.*

Considered to be the standard reference work for both professionals and academics in the field of nuclear law, the *Nuclear Law Bulletin* is a unique international publication providing its subscribers with up-to-date information on all major developments falling within the domain of nuclear law. Published twice a year in both English and French, it covers legislative developments in almost 60 countries around the world as well as reporting on relevant jurisprudence and administrative decisions, international agreements and regulatory activities of international organisations.

Nuclear science and the Data Bank

International Evaluation Co-operation

Vol. 7: Nuclear Data Standards

ISBN 92-64-02313-5. Free: paper or web.

Vol. 20: Covariance Matrix Evaluation and Processing in the Resolved/ Unresolved Resonance Regions

ISBN 92-64-02302-0. Free: paper or web.

Vol. 22: Nuclear Data for Improved LEU-LWR Reactivity Predictions

ISBN 92-64-02317-8. Free: paper or web.

JEFF-3.1 Nuclear Data Library – JEFF Report 21

ISBN 92-64-02314-3. Free: paper or web.

Nuclear Production of Hydrogen

Third Information Exchange Meeting, Oarai, Japan, 5-7 October 2005

ISBN 92-64-02629-0 *Price: € 80, US$ 108, £ 57, ¥ 11 100.*

Hydrogen has the potential to play an important role as a sustainable and environmentally acceptable energy carrier in the 21st century. Since natural sources of pure hydrogen are extremely limited, it is necessary to develop technologies to produce large quantities of hydrogen economically. The currently dominant technology for producing hydrogen is based on reforming fossil fuels, a process which releases greenhouse gases. Hydrogen produced by water cracking, using heat and surplus electricity from nuclear power plants, requires no fossil fuels and results in lower greenhouse gas emissions. This report presents the state of the art in the nuclear production of hydrogen and describes its associated scientific and technical challenges.

Perspectives on Nuclear Data for the Next Decade

Workshop Proceedings, Bruyères-le-Châtel, France, 26-28 September 2005

ISBN 92-64-02857-9 *Price: € 70, US$ 94, £ 50, ¥ 9 700.*

With a declining number of nuclear data evaluators in the world and an increasing demand for high quality data, there is a risk that evaluators will concentrate on producing new nuclear data to the detriment of developing new models and methods for evaluating existing data. In this context, it is essential to identify the basic physics issues that are going to be important for future nuclear data evaluation processes. At the same time, demand for new types of data, which will be needed in emerging nuclear applications, could warrant new evaluation techniques that are presently only used in the context of fundamental research and not in nuclear data production. These proceedings present the main findings of the workshop, which explored innovative approaches to nuclear data evaluation with the aim of opening new perspectives, building new research programmes and investigating prospects for international collaboration.

Source Convergence in Criticality Safety Analysis

Phase I: Results for Four Test Problems

ISBN 92-64-02304-6 *Free: paper or web.*

The NEA Working Party on Nuclear Criticality Safety established an Expert Group on Source Convergence in Criticality Safety Analysis to explore the problems of slow convergence and statistical fluctuations that can combine to produce unreliable source distributions and fission rates as well as underestimates of k_{eff} and its uncertainty. Aimed at fostering improved robustness of criticality safety analyses with respect to source convergence, the group's first task was to assemble four test problems that represent cases previously encountered in criticality safety analyses. The problems include a reactor fuel storage array, a spent fuel pin array, an aqueous processing system and an array of small fissile components. The results of the four test problems are described.

Speciation, Techniques and Facilities for Radioactive Materials at Synchrotron Light Sources

Workshop Proceedings, Berkeley, California, United States, 14-16 September 2004

ISBN 92-64-02311-9 *Free: paper or web.*

This NEA workshop is the third in a series devoted to the application of synchrotron accelerator-based techniques to radionuclide and actinide sciences. As synchrotron radiation is particularly well-suited for obtaining information about the molecular structure of radionuclides and actinide species, it is useful for understanding and predicting the behaviour of these hazardous elements in the environment. Application areas include risk assessment of nuclear waste storage, remediation of contaminated sites, development of effective separation technologies and radiopharmaceutical chemistry. These proceedings contain all of the abstracts and some of the full papers presented at the workshop. In addition to presenting the latest experimental and theoretical results, the workshop also provided opportunities for knowledge transfer between established experts in the field and young scientists.

Very High Burn-ups in Light Water Reactors

ISBN 92-64-02303-8 *Free: paper or web.*

This publication investigates the limitations and potential benefits of very high fuel burn-up (60-100 GWd/t) in light water reactors. It covers technical aspects, such as fuel fabrication, thermal-hydraulic design limits and fuel performance, as well as economic aspects. The report provides several recommendations regarding scientific and technological areas in which further development is required to achieve these very high burn-ups.

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