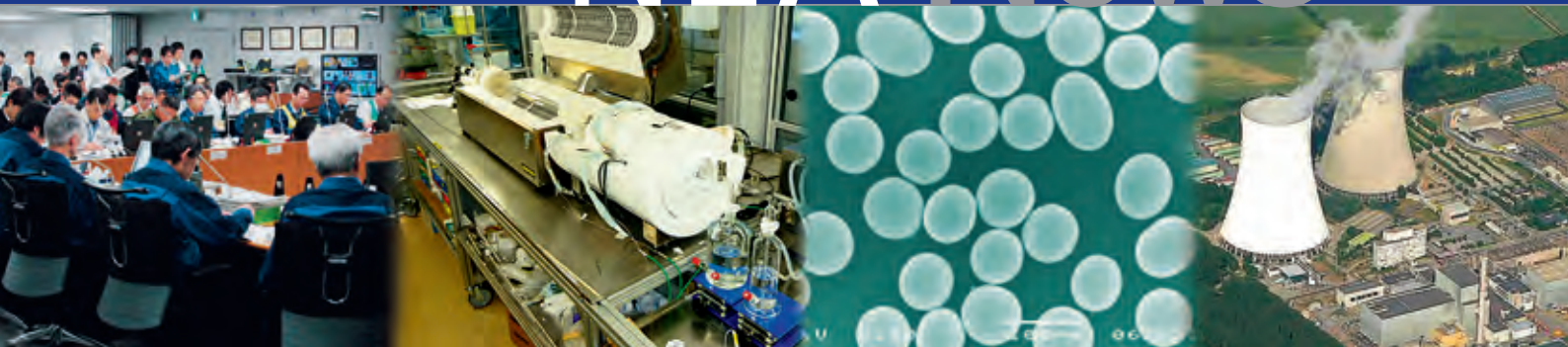


NEA News



In this issue:

The NEA integrated response to the Fukushima Daiichi nuclear accident

The economic costs of the nuclear phase-out in Germany

International joint projects on nuclear safety: 30 years of benefits

Good practice in effluent management for new nuclear build

and more...



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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 30 member countries: Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Luxembourg, Mexico, the Netherlands, Norway, Poland, Portugal, the Republic of Korea, the Slovak Republic, Slovenia, 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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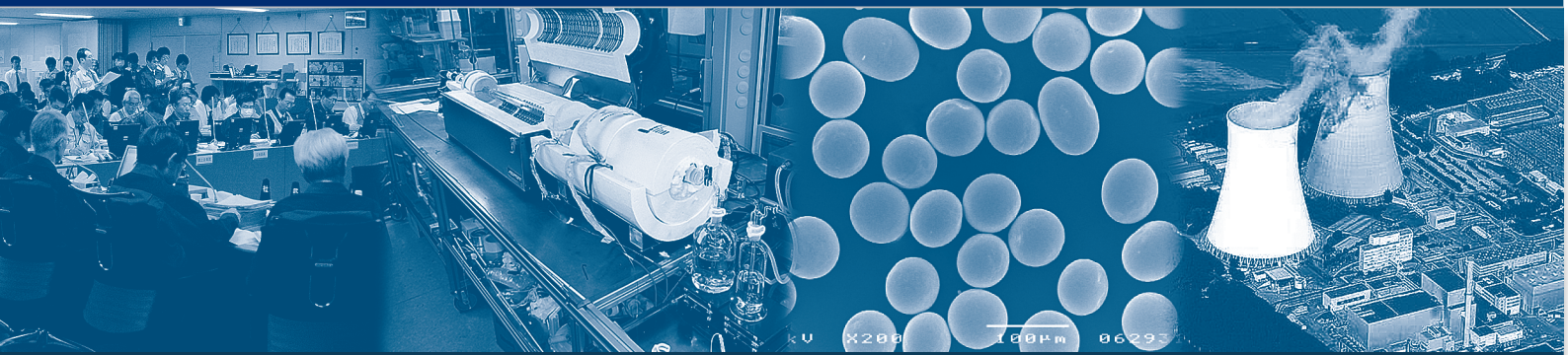
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Building the response to Fukushima



The safety of existing and future nuclear reactors worldwide is the Agency's top priority. Since the March 2011 accident at the Fukushima Daiichi nuclear power plant in Japan, the response of international organisations such as the NEA has focused firmly on the lessons to be learnt from the accident, and the effective and efficient exchange of information among member countries. For the NEA, an integrated response to the Fukushima Daiichi nuclear accident is essential if these lessons are to be implemented and global nuclear safety is to be strengthened further still.

Three NEA standing technical committees – the Committee on Nuclear Regulatory Activities (CNRA), the Committee on the Safety of Nuclear Installations (CSNI) and the Committee on Radiation Protection and Public Health (CRPPH) – are taking the lead in co-ordinating the NEA response to the March 2011 events. The Integrated NEA Fukushima Actions for Safety Enhancements (INFASE) programme will be addressing, among other issues, onsite and offsite accident management, crisis communications, regulatory infrastructure and decision making, the reassessment of defence-in-depth as well as certain nuclear safety methodologies, and radiological protection and public health. Under the overall co-ordination of the CNRA, the NEA response to the Fukushima Daiichi accident will ensure that highly important, urgent tasks produce draft results within one year. In this issue, readers will find a complete overview of the nine topical areas of the INFASE programme.

In terms of the consequences of the Fukushima Daiichi accident, it has had the effect of delaying the development of nuclear power programmes worldwide as the lessons from the accident are analysed and implemented. It has also had an impact on certain energy policies. Although most countries have reaffirmed their commitment to continue using nuclear power, a few have opted to phase out or not to reintroduce its use. Readers will find in this issue an article on the economic costs of the decision to phase out nuclear power in Germany, which was taken in the aftermath of the accident and involves the shutdown of all of the country's 17 reactors by 2022, before the end of their operational lifetimes.

Regarding the further strengthening of global nuclear safety post-Fukushima, an important step was taken on 23 May 2012 when the accession of the Russian Federation to the NEA and its Data Bank was formalised through an official exchange of letters at OECD headquarters in Paris. Russia has the fourth largest civilian nuclear programme in the world and its accession to the NEA – effective as from 1st January 2013 – will further improve international co-operation and ensure that the collective expertise of the NEA is enhanced.

As the Agency continues to move forward, the work being undertaken in response to the Fukushima Daiichi accident will yield positive results for the nuclear safety community and for the beneficiaries of nuclear power worldwide.

A handwritten signature in black ink, which appears to read 'Luis E. Echávarri'. The signature is fluid and cursive, written over a light background.

Luis E. Echávarri
NEA Director-General

The NEA integrated response to the Fukushima Daiichi nuclear accident

by G. Lamarre, T. Lazo, D. Jackson, J. Nakoski and H.B. Okyar*

The 11 March 2011 earthquake and massive tsunami that struck the eastern coast of Japan, and ultimately resulted in the core-melt accidents of Fukushima Daiichi units 1-3 and serious cooling problems in the spent fuel pool of unit 4, have left an enormous challenge for the Japanese authorities to address and remediate. For the international nuclear safety community, questions abound as to what lessons can be drawn from this tragic accident to enhance the safety of current and future nuclear power plants worldwide, and to improve emergency response arrangements and strategies on the national and international levels. In the immediate aftermath of the Fukushima Daiichi accident, NEA member and associated countries looked to the NEA to bring together experts to begin addressing some of the lessons emerging from the accident.

Integrated NEA process for post-Fukushima actions

To ensure that the NEA facilitated an effective and efficient exchange of information and response to the Fukushima Daiichi accident, in December 2011 a meeting was organised among the bureaus of the three principal standing technical committees with responsibilities in the areas of regulatory oversight, nuclear safety and radiation protection and public health: the Committee on Nuclear Regulatory Activities (CNRA), the Committee on the Safety of Nuclear Installations (CSNI) and the Committee on Radiation Protection and Public Health (CRPPH), to discuss how best to co-ordinate and co-operate in responding to the 11 March events. All three committees had begun to consider, and in some cases to initiate tasks to address, some of the lessons being learnt from the accident, and the meeting enabled agreement as to how an integrated response process would work. This would also facilitate communication of a clear and comprehensive NEA Fukushima Daiichi safety enhancement programme to all internal and external stakeholders.

The three committees agreed that the CNRA would assume overall co-ordination of the NEA integrated response and that the CNRA Senior-level Task Group on Impacts of the Fukushima Accident (STG-FUKU), which had been constituted in the immediate aftermath of the accident, would assume the role of programme oversight and co-ordinator. In addition, the CSNI extended the scope of its Programme

Review Group (PRG) to address cross-cutting activities related to the Fukushima accident. Further, the Expert Group on Radiological Protection Aspects of the Fukushima Accident (EGRPF) was established by the CRPPH as a focal point for co-operation with the committees mentioned above and among all relevant international organisations, in particular the International Atomic Energy Agency (IAEA) and the European Commission (EC), for radiological protection and emergency management issues. Direct support is also provided by the CRPPH Working Party on Nuclear Emergency Matters (WPNEM).

The three committees concluded that ongoing, approved work should largely continue unabated, but that all tasks should be considered to the extent possible through a multilateral lens, for example developing products that could answer questions in more than one of the safety fields.

Elements of the action plan

Based on the inputs of the three standing technical committees, their working parties and expert groups, an action list of key safety issues was prepared, responsibilities were agreed and cross-committee co-ordination mechanisms were confirmed. The table hereafter provides an overview of the Integrated NEA Fukushima Actions for Safety Enhancements (INFASE) programme as of May 2012.

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Topical areas

	Proposal	Status	CNRA	CRPPH	CSNI
1. Accident management and progression					
a. Transition: Development of programmes and procedures to address the transitional conduct of operations from normal to accident conditions, to severe accident conditions, and to the implementation of protective measures under the emergency preparedness plans. This includes onsite and offsite decision-making processes.	CNRA	P	L	S	S
b. Accident progression: Enhanced understanding of accident progression analyses methods and techniques.	CNRA	P	S	S	L
c. Human performance: Human and organisational performance issues under accident response conditions.	CNRA	P	S	S	L
d. Offsite: Improvement of offsite emergency preparedness by sharing knowledge on core-melt accident progression and source-term quantification to improve offsite emergency procedures and technical tools.	CRPPH	P	S	L	S
2. Crisis or emergency communications (primary information exchange between the CNRA and the CRPPH)					
a. Public: Communication with the public, media and other stakeholders.	CNRA	A	L	S	
b. Regulators: Communication with the regulators in other countries and with international organisations, such as the Inter-Agency Committee on Radiological and Nuclear Emergencies (IACRNE) and the International Atomic Energy Agency (IAEA).	CNRA	P	L	L	
c. Onsite-offsite: Crisis communications between onsite and offsite emergency response organisations.	CNRA	P	L	L	
3. Reassessment of defence-in-depth					
	CSNI	P	S		L
4. Evaluating the methodologies for defining and assessing initiating internal and external events, including coupled events, as well as methodologies defining the design-basis criteria					
	CSNI	P	S		L
5. Reassessment of operating experience and prior opportunities to identify or address conditions that could challenge nuclear safety					
a. Operating experience: Evaluation of operating experience for events that may be precursors to future events that could challenge the safety of nuclear power plants given the insights from Fukushima.	CNRA	A	L		S
b. Research: Review and gap analysis of safety research relevant to the analysis of the accident.	CSNI	A	S		L
6. Balancing deterministic and probabilistic approaches to regulatory decision making					
	CNRA	P	L		S
7. Regulatory infrastructure (non-cross committee)					
	CNRA	A	L		
8. Radiological protection (non-cross committee)					
	CRPPH	A		L	
9. Radiological protection aspects of decontamination and recovery (onsite and offsite, non-cross committee)					
	CRPPH	A		L	

P: planned, A: active, L: lead committee, S: supporting committee.

Onsite accident management

Regarding onsite accident management, the STG-FUKU recommended to the CNRA that an experts' meeting be held to better define the activities in this area that the NEA could support in addressing lessons learnt from the Fukushima Daiichi accident. The meeting was held on 20-22 March 2012 and included a pre-meeting survey to collect information on national approaches to onsite accident management. Responses were received from 12 countries; experts from 10 countries participated in the meeting.

During the meeting, the experts identified four broad areas (transitional procedures, onsite and offsite interactions, design and equipment, and human and organisational factors) under which ten proposals were developed and prioritised. Work that experts considered important to start immediately include issues related to the ability of people responding to the accident to handle beyond-design-basis situations and conditions; how and when to engage external help; approaches to decision making with guiding principles during emergency situations; and ensuring that instrumentation and equipment for addressing long-term aspects of onsite accident management are available. Other important issues that, for various reasons might be taken up at a later stage, include developing and maintaining the competencies of the people responding to beyond-design-basis events, and enhancements to onsite accident management procedures and guidance based on lessons being learnt from the accident.



TEPCO, Japan

Emergency Response Headquarters for the Fukushima accident (April 2011).

Reassessment of defence-in-depth

Following the issues and priorities outlined in its Concept Paper on Fukushima as well as the key priorities raised by the STG-FUKU, the CSNI and its work-

ing groups are currently considering tasks related to improving robustness and decreasing vulnerabilities of current and new reactor designs. Foremost in this area is further study of the means by which to improve a plant's ability to withstand the loss of basic safety functions such as residual heat removal, and coupled events such as the loss of power and the loss or degradation of critical instrumentation and control (I&C) systems. These vulnerabilities will be grouped into two broad categories. The first involves the loss of electrical systems, including how to better design electrical power generation and distribution systems within and outside the plant to maintain critical safety functions (core cooling, containment integrity, spent fuel cooling and confinement of radioactivity) and to effectively monitor them during prolonged loss of power events. The concept of better optimising current battery loads and sustaining critical power for extended periods of time is another key issue to be examined.

The second broad area concerns loss of ultimate heat sink, including a review of how safety functions for core cooling and spent fuel pool cooling can be maintained in the case of prolonged loss of heat sink. Design and other provisions to cope with loss of ultimate heat sink is a key aspect of increasing the defence-in-depth and robustness of plants. At its 6-7 June 2012 meeting, the CSNI further considered these two technical areas as well as discrete technical studies to address them.

Radiological protection and public health

With respect to radiological protection and public health issues, the CRPPH has been providing technical assistance to the Japanese authorities and international community via initiatives such as the Expert Group on Radiological Protection Aspects of the Fukushima Accident (EGRPFA), the assessment and sharing of national lessons learnt, the co-sponsorship of an International Symposium on Decontamination organised by the Japanese government in October 2011, and the co-sponsorship of the Fukushima Dialogue Initiative symposia being organised by the International Commission on Radiological Protection (ICRP).

In addition, the CRPPH agreed that it would be important to quickly collect the experience and lessons of its membership with regard to the evolution of national emergency response plans as a result of the Fukushima accident. A short list of framework areas has therefore been prepared to facilitate the identification of commonalities in national assessments, so that the committee may most effectively identify relevant areas for further CRPPH work. Below are the categories of issues identified for the collection of member country views and approaches with regard to their self-assessment of pre-Fukushima emergency response plans:

Relative to an accident in your own country:

- preparations for communications with other countries: preparations for translation, preparations to address overseas issues, preparations to advise other countries on decisions taken (or to be taken);
- preparedness and response plans for long-term releases: management of sheltering, of evacuated populations, of livestock and of civil protection (including medical support);
- preparedness and response plans for protection strategy optimisation (as in ICRP Publication 109): assessment of short-term countermeasure effects, projection of circumstances and exposure pathways over the longer term (i.e. up to one year), setting reference levels, establishing triggers, assessment and decision support tools;
- preparedness plans for recovery (as in ICRP Publication 111): radiation monitoring arrangements, introduction of health surveillance programmes, stakeholder involvement in emergency management planning, management of contaminated foodstuffs, mechanisms/processes for recovery planning.

Relative to an accident in another country:

- preparations for communication with other countries: understanding of facilities (such as type, location, surroundings, and citizens at or near the facility), approaches to collecting information (i.e. from the IAEA, the EC, the regulator or other institutions in the accident country);
- preparedness plans for assessment of overseas accidents: source-term assessment, access to local/regional meteorological data;
- preparedness plans for providing advice: to citizens in the accident country, to support embassy needs, to airlines and shipping companies, to national industry in the accident country, for importing food and goods from the accident country.

The initial results of the survey have been evaluated. However, in order to facilitate a more in-depth analysis, a new joint survey of the CRPPH and Working Party on Nuclear Emergency Management (WPNEM) members is being developed.

Safety research

One of the key areas of the integrated NEA response to the Fukushima Daiichi accident involves the review of past and ongoing safety research to determine whether there are gaps in research revealed by the accident that need to be addressed. The CSNI is currently considering a fundamental review of its past experimental work carried out as part of the OECD/NEA joint international research projects in order to apprise what has been done to date, to identify key technical gaps where safety research may be

required and to provide recommendations regarding priority safety research topics in the future. Results would then be presented to the member countries for their consideration.

Next steps

Based on the decisions taken by the CNRA, the CSNI and the CRPPH during the first half of 2012, certain high-importance and high-urgency tasks will be launched. Current tasks undertaken in response to the Fukushima Daiichi accident will continue as per their original schedule. The goal is to produce results in a timely manner for the benefit of the member countries and to provide them with information and data that will complement their work on Fukushima follow-up initiatives. The three committees have been clear in their expectations: that highly important, urgent tasks produce draft results within one year. Lower-importance and/or lower-urgency tasks are to be completed within a one- to three-year time period. The tasks which form part of the Integrated NEA Fukushima Actions for Safety Enhancements will be monitored and reported on through the NEA website and via the standing technical committee meetings on a regular basis.

The economic costs of the nuclear phase-out in Germany

by J.H. Keppler*

In the immediate aftermath of the March 2011 TEPCO Fukushima Daiichi nuclear power plant accident, the German federal government decided to temporarily halt the operation of the country's eight oldest energy-producing nuclear reactors. This was accompanied by a cabinet proposal to phase out all 17 of the country's nuclear reactors, which have a combined capacity of 20.5 GW, by 2022. On 31 July 2011 the proposal became law, and the temporary shutdown of the eight reactors was converted into a permanent shutdown by 6 August 2011. The nine remaining reactors are to be phased out progressively by 31 December 2022.

Shutting down reactors with an average lifetime of 33.5 years (compared to an industry standard of at least 40 years and in some countries, such as the United States, of 60 years) imposes significant costs on German power producers, electricity consumers and the German economy. This article estimates the direct costs linked to the shutdown of Germany's 17 nuclear power reactors before the end of their operational lifetimes. These are costs that are immediately passed on in the form of higher costs for electricity producers or higher prices for electricity consumers. This article does not consider any macroeconomic costs or impacts on total electricity output, inflation or unemployment, nor does it take into account any dynamic effects on Germany's industrial competence or any related impacts on future exports.

The direct costs of the shutdown take on three forms: a) the costs for constructing and operating replacement capacity on the supply side, b) higher electricity prices and a concomitant loss of consumer surplus on the demand side, and c) increased electricity imports. The costs for replacement capacity can be subdivided into additional investments costs, higher operating costs and higher costs for transport and distribution to the extent that replacement capacity is composed of decentralised renewables located far from final consumers. Higher electricity prices are due in the short term to a reduction of capacity margins (which means that equipment with higher operating costs will need to be employed), and in the long run due to an increase in the prices of gas, coal and carbon due to additional demand.

Methodological considerations

While the mechanisms determining the costs of a nuclear phase-out are well understood, their quan-

titative determination is difficult. The actual costs of the phase-out may well not be possible to determine with any accuracy, even if a number of important parameters can be determined. This is due to the fact that Germany had committed itself, even before the decision to phase out nuclear power, to an ambitious ecological restructuring of its energy sector (*Energiewende*) that includes the deployment of large amounts of renewable energy, in particular onshore and offshore wind power. Cost estimates of the phase-out of nuclear power depend largely on the relationship one postulates with the *Energiewende*.

On the one hand, most of the costs of the *Energiewende*, which also includes large-scale investment in heating and energy efficiency, have been committed independently of the phase-out of nuclear power. On the other hand, some of the capacity forthcoming under the *Energiewende*, which includes significant amounts of offshore wind power, will serve to substitute for nuclear capacity that is no longer available. In addition, Germany expects 12.9 GW of new fossil fuel capacity (of which 10.8 GW are coal-based) to come on line by 2015, which was committed to in the wake of the first phase-out decision, the *Atomkonsens*, of 14 June 2000 that had gained legal force on 22 April 2002. Much of the new coal and gas capacity was contracted to take advantage of the "free allowances" available for new entrants during the first two commitment periods (2005-2007 and 2008-2012) of the European Emission Trading Scheme (EU ETS).

A crucial element in determining the cost of the decision of the German government to phase out nuclear power is the baseline against which the costs of the electricity system resulting from the phase-out decision need to be assessed. This exercise takes the situation immediately preceding the phase-out decision in March 2011 as its baseline.

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In the months preceding the decision, the operators of Germany's nuclear reactors had obtained permission to prolong the lifetime of their plants by an additional 1 804 TWh beyond the amounts stipulated in an earlier phase-out decision of April 2002.

Since the government decision in March 2011 to phase out nuclear power in Germany, various experts have made a number of estimates of the cost implications of this decision. A widely cited study prepared by three research institutes in July 2011 for the German Federal Ministry of Economics was issued under the name *Energieszenarien 2011*. The model-based study estimates the net additional costs on the supply side due to variable costs increases at EUR 16.4 billion, and additional costs on the demand side of EUR 32 billion until 2030 due to increases in the electricity price.¹ While the total estimated costs of the phase-out of EUR 48 billion are not particularly far from the EUR 45.8 billion estimated in this study, the methodology and the calculations using endogenously estimated rather than empirical prices are quite different. Another model-based study from the Institute for the Rational Use of Energy at the University of Stuttgart estimates the energy-related costs of the phase-out in Germany at EUR 57 billion if a greenhouse gas reduction objective of 20% is maintained, and at EUR 74 billion if the objective is raised to 30%. The respective values for Europe as a whole would be on the order of EUR 81 billion and EUR 94 billion.²

As an international organisation, the NEA is committed to choosing a transparent and robust methodology applicable, in principle, to any one of its 30 member countries. Using large-scale macro-economic or even sector-specific models, whose assumptions necessarily could not be made apparent to readers, is not an option for a politically fraught issue such as the phase-out of nuclear power. This estimate is thus deliberately based exclusively on publicly available data that is treated according to transparent methodologies. The methodology adopted considers the costs of the phase-out as being composed of two key elements: a) the additional costs of building and operating dispatchable capacity with higher variable costs to substitute for nuclear plants with already amortised capital costs, and b) the losses to consumers due to higher electricity prices. The key assumption in both cases is that any missing capacity will need to be substituted at the long-term cost of producing electricity, for which the long-term forward contract for a year's worth of baseload electricity in the years 2013 to 2018 is a highly relevant indicator. All costs are assumed to accrue directly within the electricity sector. Neither second-round effects on industrial competitiveness nor multiplier effects on output, employment and inflation at the macroeconomic level are taken into account.

Measuring the costs of alternative electricity sources in terms of the market price for the forward delivery of baseload electricity is a transparent and

largely relevant measure. However, it poses two questions. First, are investments in the power market driven by market prices? For instance, 30 GW of wind capacity in Germany was financed exclusively by feed-in tariffs. Second, will prices during the four years beyond 2014 correspond to those currently quoted for the next three years? These are legitimate questions. However, treating them here would raise more questions than provide useful answers. Any assumption other than the one that forward prices reflect alternative costs of production would necessarily lead to further discussions about a) the extent to which more expensive renewable capacity was committed independently under the *Energiewende*, and b) in which direction long-term future prices would diverge from current forward prices. Contract prices are limited to 2012-2014 precisely because participants do not have any further information allowing them to trade for time frames further ahead, although the European Energy Exchange (EEX) in principle offers the possibility to quote contracts until 2017.

Thus, while the choice of electricity market prices to assess the opportunity costs of the nuclear phase-out is not flawless, it is by far the most acceptable measure. Any other choice, such as basing the opportunity costs of alternative production on cost assumptions of different technologies (as provided in the IEA/NEA *Projected Costs of Generating Electricity*) rather than wholesale prices would be far more speculative as it would forego any consideration of the dynamics that generate forward electricity prices on European wholesale markets. The price for one-year's worth of delivery for the years 2013-2015 stood at EUR 52/MWh in March 2011, and currently stands at EUR 51/MWh (April 2012). All cost data are in current, undiscounted euros.

It is furthermore assumed that costs for spent fuel disposal and decommissioning are not affected by the phase-out decision. While the phase-out decision might accelerate decommissioning schedules and thus increase financial costs by foregoing gains from discounting future expenditures, this article does not take such financial effects into account. In addition, there have been no announcements made to that effect.

Costs of replacing nuclear output with alternative means

This exercise takes a strict economic opportunity cost approach taking the legal situation prior to July 2011 as its baseline. Following the first German law on the phase-out of nuclear power of April 2002, the four nuclear power plant operators in Germany (E.ON, RWE, Vattenfall and EnBW) had the right to produce an additional 2 623 TWh starting from 1 January 2000. Of these 2 623 TWh, 981 TWh were still available on 1 January 2011, which corresponded to an average lifetime of 32 years for German reactors.

The 8 December 2010 change to the German Law on Atomic Power (*Atomgesetz*) allowed the extension of the operational life of German power plants by an additional 1 804 TWh with no fixed lifetime limitations. However, the individually allocated production volumes suggested average lifetime extensions of eight years for the six reactors that had begun commercial operations before 1980, and average lifetime extensions of 14 years for the 11 reactors that had begun commercial operations in 1980 or thereafter. Estimates based on the individually allotted production volumes suggest that the reactors connected to the grid in the late 1990s would have stayed in operation until the mid-2030s. The latest change to the *Atomgesetz* of July 2011 abrogated the previously granted lifetime extension of 1 804 TWh, and thus reduced the remaining lifetimes to the originally agreed production volumes, i.e. 981 TWh minus the volumes produced during the initial months of 2011. In addition, the law now specifies the final date of operation for each of the nine reactors still in operation after 6 August 2011.

The calculation of the costs therefore bases itself on a loss of production from nuclear power plants of 1 804 TWh. The cost of producing 1 804 TWh of baseload electricity with and without the 17 German nuclear power plants has also been compared. On one side of the equation, one needs to take into account the variable costs of the now shut-down nuclear plants whose considerable capital costs have already been amortised.³ On the other side, one needs to consider the full costs (including capital costs) of alternative means. There is no better indicator for the full costs of producing baseload electricity production than the one-year forward contract for baseload electricity, the widely traded “calendar”.

According to the IEA/NEA study on the *Projected Costs of Generating Electricity* (2010), the costs of producing this amount of electricity with nuclear power plants whose capital has been amortised would have been equal to the sum of fuel costs (including spent fuel disposal) and operating costs, or EUR 12/MWh or a total of EUR 21.65 billion. In addition, lifetime extensions would have required investments of EUR 500 million/reactor, which for 17 reactors would amount to EUR 8.5 billion. The total sum of producing 1 804 TWh under the original German lifetime extension scenario would thus have been EUR 30.15 billion.

This sum needs to be contrasted with the costs of producing 1 804 TWh of electricity by alternative means. These costs correspond to the cost of alternative production on the German electricity market, for which the price for the one-year forward baseload contract on the European Energy Exchange in Leipzig, Germany is a good indicator (see discussion above). Just before the phase-out decision, the price for this contract stood at EUR 52/MWh and the total cost of alternative production thus corresponded to a total of EUR 93.80 billion.⁴ The costs of the German

phase-out of nuclear power on the production side then correspond to the difference between producing 1 804 TWh with or without Germany's existing nuclear power plants or EUR 63.65 billion.

These would be the total welfare costs of the phase-out for the German economy under the assumption that supply and demand were in equilibrium on the electricity market before the phase-out decision. In other words, it assumes that all new capacity for substituting the 20.5 GW of nuclear power would need to be newly constructed. This first general approach, however, must be refined in light of the fact that in Germany, 12.9 GW of dispatchable capacity (of which 10.8 GW are coal-fired capacity) are currently under construction and could substitute up to 62% of the output from Germany's 20.5 GW of nuclear capacity. Much of this investment would have created over-capacity in the absence of a nuclear phase-out as it was driven primarily by the prospective value of future free carbon permits (see above). Hence, this capacity must be deducted from the costs of producing the output lost from the early retirement of Germany's nuclear power plants as it partly eliminates the need to build new plants to replace the phased-out reactors.

The availability of this “free” (in the sense of already paid for) capacity reduces the costs of production by alternative means by roughly 19%. This figure is arrived at by taking into account a) the share of capital costs of different German coal-fired power plants in total production costs, which according to the *Projected Costs* study varies between 20% and 41%, for a mean of 30%, and b) the share of roughly 62% for which the already committed investments of 12.9 GW in coal- and gas-fired capacity substitute for the 20.5 GW of nuclear capacity.⁵ The total costs of financing electricity production with alternatives to nuclear power would then decrease from EUR 93.80 billion to EUR 75.98 billion, and the cost of the phase-out on the supply side from EUR 63.65 billion to EUR 45.83 billion.

Distribution considerations

The amount of EUR 45.83 billion constitutes the welfare losses to German society due to generating electricity by alternative means to existing nuclear power plants. They would be borne primarily by the employees and shareholders of Germany's four nuclear utilities as well as by German society at large due to lower tax receipts. The total amount is independent of the specific tax arrangements, which would clearly affect the distribution, but not the sum, of these welfare losses. Examples are the nuclear fuel tax of EUR 2.3/MWh or the Promotional Contribution for Renewable Energies of EUR 9/MWh. From an economic rather than commercial point of view, these are transfer payments between different constituencies that have no impact on overall welfare changes, whose determination is the sole objective of this article.

Potential losses in consumer surplus

The costs of substituting the production lost due to the reduction of output from nuclear power plants by 1 804 TWh is not the only cost of the shutdown. There are also potential impacts on the demand side for electricity consumers. Before entering into the calculations themselves, it is worth considering the question of whether wholesale market prices or the end-use prices faced by final consumers are the relevant metric to assess costs on the demand side. Electricity end-use prices are complex constructions that include the cost of electricity on the wholesale market as well as the regulated tariffs for transport and distribution (including the cost of the feed-in tariffs for subsidised renewables) and VAT. Except for wholesale electricity prices, all the other elements are set by the regulator or the government and hence do not change with prices and do not affect consumer behaviour. In addition, end-use consumer prices are fixed according to long-term contracts (with some exceptions for very large industrial users), which are difficult to renegotiate immediately. Since wholesale prices are therefore the only element of end-use prices changing as a function of the nuclear phase-out and affecting consumer behaviour, it is on this basis that losses in consumer surplus must be assessed.⁶

Working with wholesale prices, Figure 1 shows how German wholesale prices for the 2013 one-year forward contract jumped from EUR 52/MWh to over EUR 60/MWh following the German government's March 2011 decision to shut down the country's eight oldest reactors and to phase out nuclear power. The price increase was due to the fact that the market assumes electricity price increases due to a rise in the variable costs of electricity produced by alternative technologies, mainly gas- and coal-fired plants. Market participants evidently assume that increased

demand for production from gas and coal plants will have knock-on effects on gas, coal and CO₂ prices that will translate into higher electricity prices. Price curves for one-year forward delivery in 2014 and 2015 have nearly identical shapes. There are currently only isolated trades for years beyond 2015. The 2013-15 electricity wholesale prices are likely to be the best predictor of prices beyond that period. Occasionally voiced concerns that long-run effects may be significantly higher are unfounded in the German context. If anything, the opposite is likely to happen as the 10.8 GW of coal-fired capacity mentioned above will become available. In addition, there will be downward pressure on prices due to the increasing influx of electricity from intermittent renewables such as wind and solar PV, which is remunerated through guaranteed feed-in tariffs and will thus run regardless of the price.

Prices have already declined since summer 2011 and stood at EUR 51.30/MWh in April 2012. In the present approach, it is impossible to assess whether the decline in wholesale prices from EUR 60/MWh to EUR 51/MWh is due to changes in the appreciation of the impact of the German nuclear phase-out in light of new fossil-fuel based capacity coming on stream, due to assumptions about lower economic growth or due to the influx of renewables. Lower gas prices (see Figure 2) are certainly part of the story, but are in turn due to a combination of endogenous (lower growth, less demand due to renewables) and exogenous factors (Qatari exports, declining US demand for imports, decreasing Chinese growth).

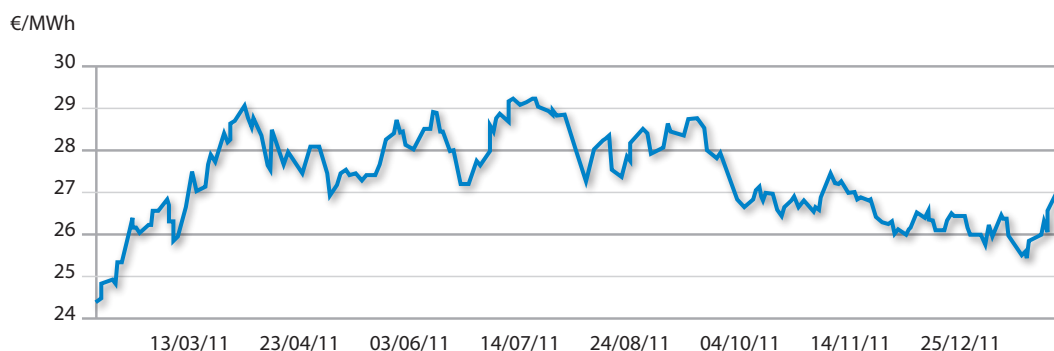
In this situation, it is very difficult to assess the impact of the exit from nuclear power on consumer welfare over the period concerned until the plants close. Among other reasons, it is because the answer to the question "What would have

Figure 1: Price for one-year forward delivery of baseload electricity in 2013



Source: www.eex.com/, price for the delivery of 1 MWh from 1 Jan. 2013 to 31 Dec. 2013.

Figure 2: Price for one-year forward delivery of natural gas



Source: www.eex.com/, price for the delivery of 1 MWh from 1 Jan. 2013 to 31 Dec. 2013.

happened if Germany had not exited nuclear power?” is unknown. While electricity prices have slightly decreased since the phase-out decision, it cannot be directly concluded that the decision has benefitted consumers. For example, it is possible that electricity prices could have been EUR 8 lower than what they are today and gas prices lower still without the phase-out. If forward electricity prices are lower due to the influx of intermittent renewables, then it is also likely that without further measures the German power market will be heading towards a capacity crunch. Without supplemental income streams, dispatchable capacity will no longer be able to support itself as load factors shrink due to the “compression effect” of the incoming renewables. This would, of course, lead to increased volatility with potentially high price spikes as conventional capacity is missing when intermittent renewables are absent. A first taste of such a situation was provided by the European cold wave in February 2012, when spot prices for peakload electricity on the French-German EPEX spot market reached at one point almost EUR 2 000/MWh on 9 February 2012 with a daily average of EUR 600.

Since the impact of the German phase-out decision on consumer welfare is thus nearly impossible to predict, there is merit in undertaking a methodological exercise of how to calculate losses in consumer surplus if the price impact of a particular decision was known. This article proceeds on the assumption that electricity prices are now EUR 8/MWh higher than what they would be if all of Germany’s nuclear energy power plants were still operating. Due to the uncertain nature of this assumption, however, the results were not included in the overall estimation of the costs of the German nuclear phase-out. Nevertheless, this calculation can be scaled if it is considered that lower or higher differences should apply.

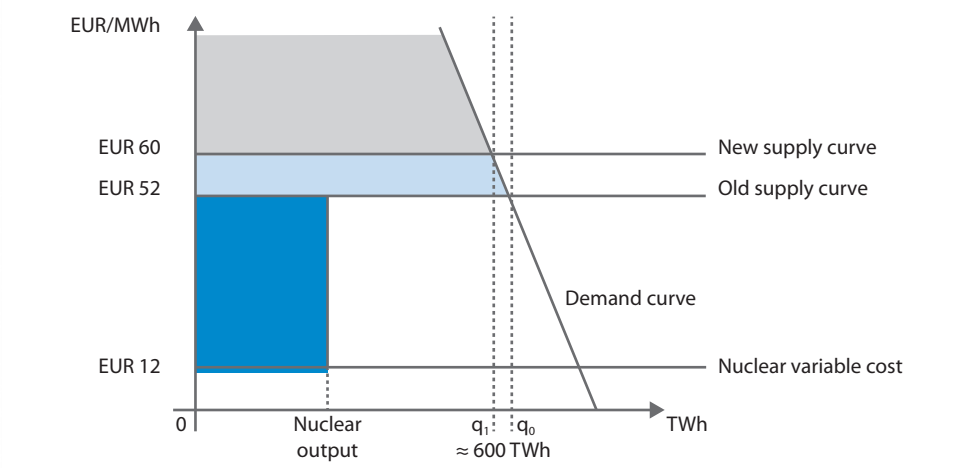
Calculating the welfare loss due to a price increase, one needs to consider the shape of the

demand and supply curves in the electricity market. Given the very high willingness to pay for the last unit of electricity, also referred to as the value of lost load (VOLL), which is artificially capped in the EEX at EUR 3 000/MWh, assuming price elasticities different from zero almost makes no impact when calculating a change from EUR 52 to EUR 60/MWh under the assumption of linear demand curves. Any other assumption would exceed the level of detail and sophistication for this article, which needs to be considered as a first estimate to obtain relevant orders of magnitude.

The situation is slightly more complicated for the supply curve. The price increase indicates that the supply curve of electricity is not infinitely elastic. However, in order to assess the welfare considerations, the question is whether the price increase benefits German producers through increased inframarginal rents or foreign importers of gas and coal.⁷ In the first case, these additional gains would need to be deducted from the total welfare impacts, in the second case not, since the gains would accrue outside of Germany. There are good reasons to believe that most of the virtual electricity price increase was due to an equivalent virtual increase in the price of fossil fuels. As shown in Figure 2, gas prices evolve roughly in parallel with the electricity price. Finer econometric analysis would have to confirm this conjecture and also determine the direction of the causality.

Figure 3 shows the different components of the welfare impacts. The loss due to increased production costs corresponds to the royal blue rectangle, which can also be interpreted as a loss of producer surplus (the difference between price and marginal cost). The loss of consumer surplus corresponds to the light blue trapezoid. The two sets of losses are independent and additional costs on the supply side due to higher resource costs cannot be netted out against losses in consumer surplus due to higher prices.

Figure 3: Supply and demand in the German electricity market



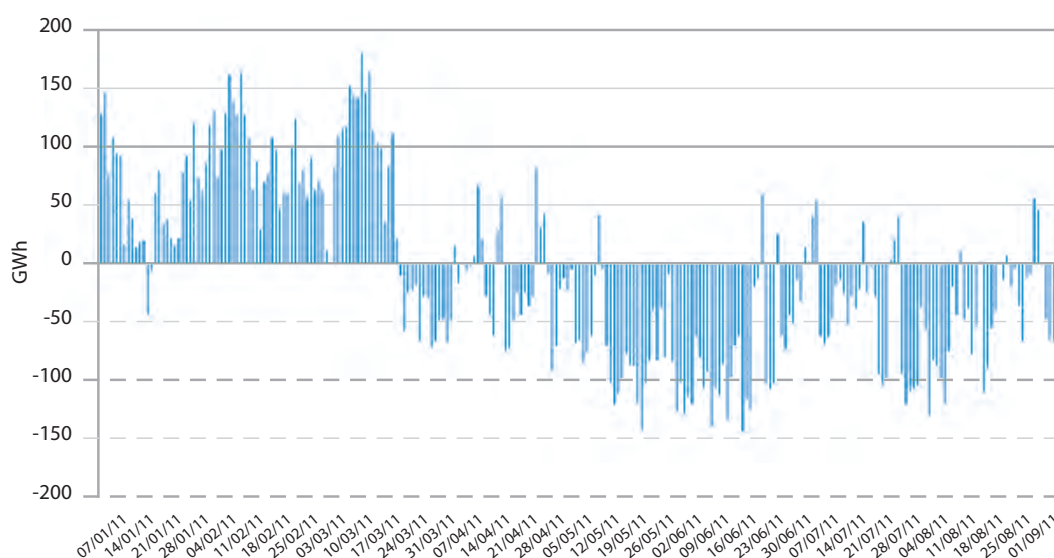
In 2010, Germany consumed slightly more than 600 TWh of electricity.⁸ Due to the inelasticity of demand in the relevant range this is unlikely to change much, and a price increase of EUR 8/MWh would reduce the economic utility of German power consumers by EUR 4.8 billion per year. A key question is for how many years this reduction in consumer surplus should be taken into account in the cost of a nuclear phase-out. A period of seven years seems appropriate assuming that keeping Germany's nuclear reactors in operation would have postponed the inevitable price increase by seven years. Of course, partial effects would have been felt for much longer as the last reactor would have gone off the grid only in the mid-2030s. However, its dampening impact would have been proportionately less and accounting for the full effect for seven

years thus seems to be the appropriate assumption. This establishes the total impact of higher electricity prices on the economic welfare of German electricity consumers at about EUR 33.60 billion.

Impact on Germany's trade balance

Figure 4 shows that Germany has become a net importer of electricity at a level of about 50 GWh/day compared to having been a net exporter at approximately 70 GWh/day before March 2011. With 360 trading days a year, this would amount to an impact on the German trade balance of EUR 2.5 billion per year. Net imports, however, cannot be equated to losses as the expenditure is matched by savings in production costs. In addition, the surplus of the overall German trade balance (about EUR 120 billion

Figure 4: Germany's net electricity trade in 2011



Source: Entso-e.

in 2010 alone) is only marginally affected. While the shift in the balance of electricity trade clearly shows the very real effects that Germany's decision to phase out nuclear power has on electricity markets, this particular impact on overall economic welfare is limited.

Conclusions

This estimation of the cost of Germany's nuclear phase-out has taken the situation immediately preceding March 2011 as its baseline. Under this assumption, it estimates the opportunity costs for lost output, which correspond to the cost of alternative electricity production, at EUR 45.8 billion. Under the admittedly highly uncertain assumption that electricity prices are now EUR 8/MWh higher than they would be in the absence of the phase-out, costs in terms of lost consumer surplus would be EUR 33.6 billion. This calculation depends linearly on the assumed price impact and can be scaled if it is considered that lower or higher differences should apply. The total costs of the *Energiewende* restructuring will be considerably higher still than the costs of the phase-out from nuclear power, and to the extent that its ambitious policy objectives become a reality, there will be an overlap between the cost figures (which will also change in the process as subsidised wind capacity instead of gas and coal substitute for nuclear) that is almost impossible to sort out. A number of alternative assumptions have been presented that readers can use to form their own opinion as a function of their interpretations of the German electricity sector.

smaller. On the other hand, the cost shares calculated in the *Projected Cost* study include a carbon price of USD 30, which is higher than the current EUR 10 per tonne of CO₂ under the EU ETS, so the share of capital costs (and the concomitant cost reduction) would be 2-3% higher. Given the necessarily approximate nature of these estimates, it does not seem sensible to include such refinements.

6. As far as demand elasticities in the electricity sector are concerned, they are in the short run very close to or at zero, both on the wholesale market and in the consumer sector. Long-term elasticities are greater but the literature is inconclusive on their precise level. Also in the long run, any price increase of less than EUR 5/MWh would be overwhelmed by other drivers of electricity demand such as the weather, industrial production, economic growth or energy efficiency improvements.
7. One may think of a coal producer, whose ability to generate carbon emission reductions has not changed, but who is now able to gain higher profits for a tonne of CO₂ abated due to higher prices in the carbon market. The use of more inefficient and thus higher-cost power plants would also generate additional profits for operators with the hitherto used more efficient plants.
8. See www.bmwi.de/BMWi/Navigation/Energie/Statistik-und-Prognosen/energiedaten.html for a wide array of statistical information on the German energy system.

Notes

1. The three institutes authoring the study were Prognos AG, Basel, EWI, Cologne and GWS, Osnabrück (see www.prognos.com/fileadmin/pdf/publikationsdatenbank/11_08_12_Energieszenarien_2011.pdf).
2. See "The post-Fukushima energy policy changes in Germany – An impact assessment", Alfred Voss, University of Stuttgart at www.modelisation-prospective.org/journee_chaire_2011.html.
3. Even for power plants not yet completely amortised, the assumption of zero capital costs holds since amortisation costs are due regardless of whether the plant produces or not. They are thus also due with the phase-out with reduced nuclear production. They therefore need to be taken into account in both calculations (the costs of producing 1 804 TWh including and excluding lifetime extensions) and the difference – the cost of the phase-out – would be unaffected.
4. The price for the one-year forward contract includes the *full* cost of electricity production, including capital costs.
5. In reality, the coal-fired power plants mentioned will be in operation for longer than the time needed to produce the foregone output from the nuclear power plants, so the *pro rata* cost reduction due to capital cost savings should be

International joint projects on nuclear safety: 30 years of benefits

by A. Thadani, V. Teschendorff and J. Gauvain*

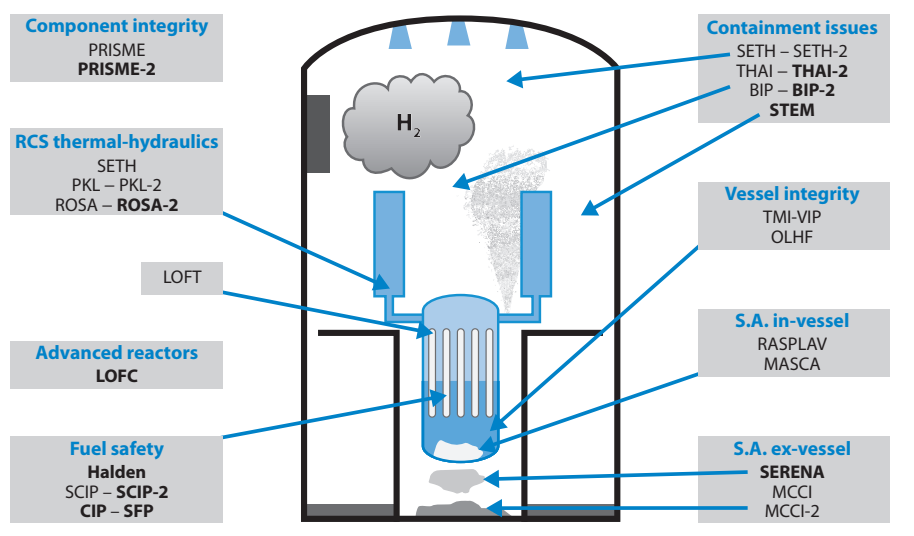
The NEA has an acknowledged role to assist its member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for a safe, environmentally friendly and economical use of nuclear energy. The NEA standing technical committees (STCs) are actively engaged in the generation of knowledge (for example through workshops, state-of-the-art reports, international standard problems and joint projects) and the exchanges among members of the committees and their working groups are excellent sources of tacit knowledge and communities of good practice. The NEA committees have generated significant technical and scientific information that is of value to the regulators and the developers of nuclear technology.

The activities of the NEA Committee on the Safety of Nuclear Installations (CSNI) and those of the international joint projects conducted under NEA auspices are responding to the challenges of power uprates, higher burn-up, new fuel element designs, new cladding materials and the development of models to analyse accidents, including severe acci-

dents, in view of their prevention and the limitation of their consequences. Thorough understanding of phenomena and failure mechanisms associated with accidents as well as common assessment of experimental data and computer code models strengthen the technical bases for safety decisions. One of the NEA's major achievements is the knowledge generated by these international joint projects. Such projects, primarily in the areas of nuclear safety and waste management, enable interested countries, on a cost-sharing basis, to pursue research or the sharing of data with respect to particular areas or issues.

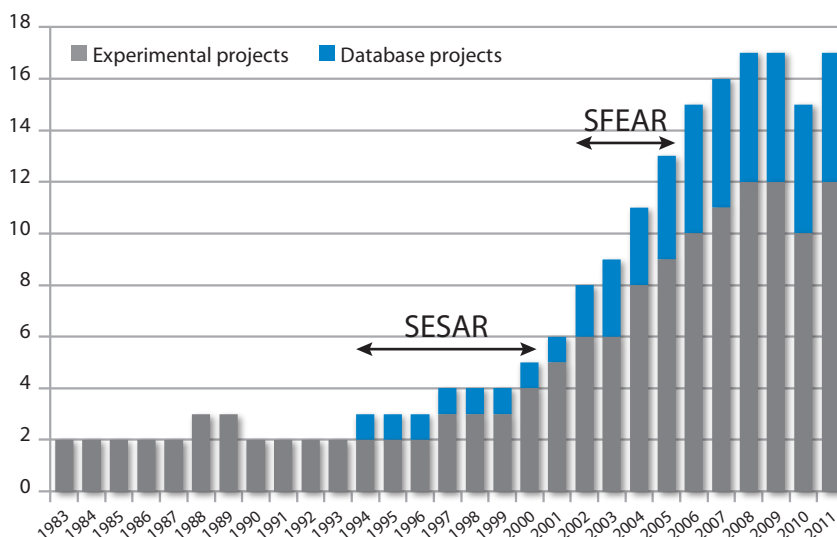
Since 1958, when the first project at the Halden reactor was established, more than 30 joint projects devoted to nuclear safety research have been conducted with wide participation of member countries. The projects described in this article are presented in terms of individual experimental programmes involving major facilities and thus contributing to the maintenance of indispensable safety research infrastructure and the expertise of the operating teams. The article summarises the achievements of the OECD/NEA joint projects on safety research that

Figure 1: OECD/NEA joint projects on nuclear safety



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Figure 2: Number of ongoing projects



were carried out over the last three decades with a specific focus on thermal-hydraulics, fuel behaviour and severe accidents. It shows that the resolution of specific safety issues in these areas has greatly profited from joint projects. It highlights the benefit of working together for maintaining unique experimental infrastructure, preserving skills and generating new knowledge.

Historical background and plans for safety and licensing support

The first three OECD/NEA joint undertakings required heavy funding through intergovernmental co-operation: the Halden Reactor Project created in June 1958 and still ongoing, the OECD Dragon Project created in April 1959 and run until 1976, and the Eurochemic Project established in July 1959 and completed in 1975. While in the 1960s international co-operation was intended for those large research programmes later covered by national industrial programmes, it appeared in turn in the early 1980s that national safety research programmes would be difficult to continue without external support. In this respect, following a proposal from the United States, the first OECD/NEA joint project fully dedicated to nuclear safety research – the Loss-of-fluid Test (LOFT) Project – was launched in spring 1983 with ten member countries. Since then, more than 30 safety joint projects have been set up, with an average duration of four years and an average participation of a dozen countries.

In 1992, a Senior Group of Experts on Safety Research (SESAR) was set up by the CSNI to review research being carried out and to identify future requirements and priorities. In its reports, concerns were raised about the member countries' ability to

maintain an adequate level of safety research, and one of the recommendations was "that the CSNI take a proactive role in organising and implementing co-operative projects". The impact of the SESAR and later the group on Support Facilities for Existing and Advanced Reactors (SFEAR) reports was significant, both on the number and on the contents of the joint projects. Figure 2 shows the increase in the number of projects following the SESAR recommendations.

Thermal-hydraulics

Thermal-hydraulic issues dominated safety and regulatory concerns from the early days of nuclear power plant operation. The focus shifted from large break, loss-of-coolant accidents (LOCA) to more frequent initiating events. The issues connected with LOCAs have mostly been resolved by analytical and experimental programmes, many of them in international co-operation. Validation matrices, international standard problems and results from OECD/NEA joint projects have substantially contributed to a consensus on the technical basis for closing typical thermal-hydraulic issues. The process of resolving recent issues like boron dilution and strainer clogging has greatly benefited from these projects.

The LOFT Project gave the participating countries access to a unique nuclear test facility and helped them resolve their national safety cases involving LOCAs. The SESAR Thermal-hydraulics (SETH) projects were successful in maintaining the PANDA, PKL and MISTRA test facilities. Mixing phenomena were investigated and data for computational fluid dynamics (CFD) code validation were provided. The *Primärkreislauf* (PKL) projects investigated natural circulation in a four-loop integral facility and largely supported the resolution of the boron dilution issue.

The Rig of Safety Assessment (ROSA) projects investigated complex thermal-hydraulic phenomena in a large-scale facility under full pressure and strengthened the database for system code validation. The PSB-VVER Project and the Bubbler Condenser Project significantly contributed to the resolution of VVER-specific safety issues in the cooling circuit and in the confinement. The Loss of Forced Coolant (LOFC) Project is investigating the loss of forced coolant in a high-temperature gas-cooled reactor (HTGR). The Fire Propagation in Elementary, Multi-room Scenarios (PRISME) Project investigated fire and smoke propagation in a complex arrangement of large rooms. Modelling the circulation and mixing of hot gases and their interaction with the structure will benefit from the data generated in this project.

Operating experience, lifetime management and lessons learnt from events may pose new questions which may also require safety research in the thermal-hydraulics area. Issues that may arise for new reactor designs are on the agenda of the pertinent CSNI working groups. Computer code modelling has advanced from conservative assumptions to a best-estimate approach, complemented by methods for quantifying uncertainties. Computational fluid dynamic codes are fast entering the nuclear industry. Development and validation for two-phase flows is in progress. The growing CFD applications for safety demonstration have to be accompanied by commonly accepted best practices. Thermal-hydraulics research has greatly advanced our understanding of phenomena that dominate transients and accidents and how to model them. OED/NEA joint projects have largely supported this achievement.

Fuel behaviour

Maintaining fuel and cladding integrity during transients and accidents is a fundamental safety concern. Therefore, failure mechanisms ought to be thoroughly investigated and understood. Power uprates, load following, longer cycles and higher discharge burn-up mean much more demanding fuel operating conditions. Care has to be taken that sufficient safety margins are maintained: fuel research and development is one of the areas that bring innovation to existing reactors, another specificity is the direct impact on plant performance which entails competition between fuel vendors.

OECD/NEA joint projects have addressed a variety of fuel issues of common interest, all of them of high safety significance. The Cabri reactor offers an almost unique opportunity for in-pile testing of high burn-up fuel under realistic pressurised water reactor (PWR) conditions. Hot cells are another important infrastructure for fuel safety research. The Studsvik Cladding Integrity Project (SCIP) has benefited from the facilities there and their associated analytical capabilities. The Paks incident was recognised as

an opportunity to gain insight into the behaviour of a large amount of real fuel under degraded cooling conditions, to observe beyond-design-basis phenomena and the capabilities of computer codes to predict them. The Sandia Fuel Project (SFP) acknowledges the fact that transients and accidents may challenge fuel integrity, not only in the reactor core but in the spent fuel pool as well. The Fukushima Daiichi accident was a lesson on this issue.

In summary, the activities of the CSNI Working Group on Fuel Safety and the OECD/NEA joint projects in the fuel area are responding to the challenges of power uprates, higher burn-up, new fuel element designs and new cladding materials. Thorough understanding of phenomena and failure mechanisms as well as common assessment of experimental data and computer code models strengthen the technical basis for a possible revision of acceptance criteria.

Severe accidents

Severe accidents have the potential to cause large releases of radioactive material and thus pose risk to public health and safety as well as the environment. The processes involved in the progression of severe accidents are very complex, requiring experimental data to support development of models to determine design and procedural requirements to prevent and/or mitigate the consequences of such accidents.

The CSNI has played a major role in organising and conducting joint projects in the area of severe accidents. These projects include the Three Mile Island Vessel Investigation Project (TMI-VIP), the RASPLAV Project and the follow-on Material Scaling projects MASCA-1 and 2 (assessment of RPV integrity under core melt conditions), the OECD Sandia Lower Head Failure (LHF) Project examining mechanical behaviour of the RPV lower head under pressurised severe accident conditions, the Melt Coolability and Concrete Interaction (MCCI) Project assessing ex-vessel molten core debris coolability, the Behaviour of Iodine Project (BIP), the Steam Explosion Resolution for Nuclear Applications (SERENA) Project assessing steam explosion risk after fuel-coolant interactions, the Thermal-hydraulics, Hydrogen, Aerosols, Iodine (THAI) Project on hydrogen and aerosols in the containment and the Source Term Evaluation and Mitigation (STEM) Project. These programmes and the CSNI activities on accident management have contributed to knowledge about severe accident phenomena, the resolution of many questions related to severe accidents and accident management measures (features and procedures) to terminate or mitigate the accident progression. However, it should be noted that the lessons to be learnt from the recent events at the Fukushima Daiichi nuclear power plant (e.g. in-vessel retention, accident management) would need to be studied carefully either to confirm earlier conclusions and/or to develop any new joint projects.

Working together

Experimental facilities and programmes have played an important role in safety research from the beginning and have contributed substantially to the resolution of various safety issues. These facilities were originally built to solve a specific safety-relevant issue and running the first experimental campaign was typically done by a national research programme. The most obvious benefit for both the country offering a programme and the countries joining is cost savings by pooling resources. Joint project proposals and the definition of experimental programmes should explicitly reference the technical goals that have been identified in the CSNI or the NEA Committee on Nuclear Regulatory Activities (CNRA) Operating Plans in response to the main challenges of their Joint Strategic Plan.

The initiative for a new project is normally taken by an organisation operating a facility which will in most cases become the Operating Agent (OA) if the proposal submitted to the CSNI leads to a joint project. Financing is established by sharing the cost among participants, with the host country typically bearing 50% of the actual programme cost. The NEA continues to support the project throughout its lifetime as a facilitator providing administrative and technical support. Progress of the project is usually monitored by a Management Board (MB) that may take decisions regarding the necessary adaptation of the research programme and the allocation of funds. The MB is supported by a Programme Review Group (PRG) providing technical advice.

Experimental programmes are usually established to provide data for resolving a specific safety issue. It has turned out that co-operation can even go a step further. The common recognition that the data is relevant for the scope of phenomena and safety topic under consideration is an additional value and a necessary step for building consensus.

It is common practice that analytical activities dealing with data prediction and interpretation, model development and computer code validation are performed by some or all project participants in parallel with those of the project. These analyses constitute a very valuable complement and an additional benefit of the OECD/NEA safety joint projects. The NEA platform brings together the world's leading experts who contribute to maintaining and improving expertise and tools in NEA member countries, to enhancing technical exchange among specialists, and to promote consensus building on approaches to resolve complex severe accident safety issues.

Conclusions

Joint projects have led to the conduct of safety-relevant programmes that would have never been carried out if the individual countries had to maintain and operate these large facilities on their own. In terms of resolving a safety issue "for good", joint

projects and experimental research form an often essential part of the solution, but of course seldom the final word.

The timescale of joint projects, including preparation, contract building, programme execution, data treatment and reporting, typically takes several years. Therefore, joint projects are mostly useful for dealing with mid-term or long-term issues. A new generation of experts is taking over and new countries are entering the nuclear arena. Joint projects have significant capabilities for knowledge transfer and for building expert capacity.

In view of the international nature of new reactor designs, it is important that the NEA be engaged early so that full benefit can be attained through international co-operation and through the use of expertise available within the CSNI in particular.

Reference

NEA (2012), *Main Benefits from 30 Years of Joint Projects in Nuclear Safety*, OECD/NEA, Paris.

Good practice in effluent management for new nuclear build

by R. Doty and T. Lazo*

The NEA Committee on Radiation Protection and Public Health (CRPPH) seeks to assist its member countries in regulating and applying the system of radiological protection by identifying and addressing important issues of common interest or international significance. Among the current areas being examined by the CRPPH is the evolution of the system of radiological protection as applied to protection of the environment and to construction of nuclear power reactors. A factor to be considered in addressing these issues is that activities involving any level of radiological risk are carefully scrutinised by the general public, and that the public expects its voice to be heard in processes authorising such activities.

Regarding power generation by new nuclear reactors, the CRPPH is interested in ensuring that effluent releases from such reactors are managed using good practices from existing facilities and are reduced as reasonably feasible by using processes such as optimisation and best available techniques. The CRPPH established an Expert Group on Best Available Techniques (EGBAT) to identify the relevant issues clearly and to begin to resolve them. After four years of preparatory work and the issuing of two summary reports on the status of effluent management, the EGBAT held an international workshop on 24-26 January 2012 as part of its plan to ensure that regulators, operators and reactor vendors could provide input for characterising available good practices in effluent management, ensuring appropriate monitoring and reporting of effluents, and identifying possible improvements in effluent management.

The workshop participants agreed that in regulating and operating the existing fleet of nuclear power reactors, performance is admirable in many respects (including effluent management during normal operations and refueling outages), but that each type of participant (regulator, operator and vendor) wants, expects and is expected to perform at a higher level. Further, the participants agreed that improving the ability to communicate accurately and in understandable language with legislators, the media and the general public is needed. Improvements are understood to be needed not just in risk communication, but also in ensuring that the science of radiological protection is advanced over time, using lessons learnt not only from designing, licensing and operating existent nuclear power reactors but also from thoughtful scientific research.

One open issue raised was that the metrics of “success” are not clear, which makes regulation, operation and communications difficult for all.

The workshop programme covered general effluent management issues, effluent management and “new build”, reporting and characterising good plant performance. During the presentations and discussions, a number of questions were raised with regard to how good practice should be understood and, to a certain extent, defined. To develop coherent responses to these questions in order to formulate a summary consolidating views on good practice, it was agreed that a short questionnaire should be sent to all participants. The main questions raised are presented below.

Effluent management issues

Questions in this area focus on issues relevant to designing and assessing approaches to effluent management. Many of the issues fall into one of three categories: 1) demonstrating and communicating appropriate protection of the public and the environment, 2) interpreting if there is a logical or reasonable endpoint to the processes of optimisation or the use of best available techniques, and if so, what guidance may be appropriate for establishing such an endpoint, and 3) searching for more effective means of effluent abatement.

Discharge abatement is based on a trade-off between costs and benefits, through reducing doses (application of optimisation via the as low as reasonably achievable “ALARA” principle), or through adoption of optimisation via the use of best available techniques (BAT) or their equivalent for reducing discharges. A general understanding of BAT recognises the importance of economic and social

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factors in deciding the technique (technology and practices) of choice, notably that technique deployment must be feasible.

Effluent management for new build

Issues in this area focus on aspects to be considered when evaluating the design and regulatory authorisation for the operation of a new nuclear power reactor. Several questions were raised regarding such evaluations, including how new reactor regulation should be managed with respect to existing reactor regulation, e.g. for tritium, for effluents from larger new reactors, with respect to the generation and management of solid radioactive waste, and with regard to benchmarking criteria.

In general, the designer and/or operator of a proposed facility will calculate estimated doses to members of the public surrounding the proposed facility, using applicable generic and available site-specific data on land use, population densities and other factors relevant to the calculation process. The designer and operator need to ensure that those estimated annual doses comply with the applicable dose limits. Additionally, in many countries, there are also either dose constraints, dose targets, or other applicable values which are to be met by those estimated doses forthcoming from the planning process.

Effluent measurement and reporting

These issues concern the details of effluent measurement and reporting, and workshop participants specifically sought out commonalities and differences in the national approaches to effluent management. Relevant questions raised include:

- How are effluent management priorities determined (e.g. with respect to dose or to total activity released, with respect to release rate and the effectiveness of abatement equipment efficiency, taking fuel integrity into account)?
- How is the concept of operating overhead regulated and applied?
- Should reporting continue for nuclides whose releases are historically very low (below detection limits) and have no dosimetric effect?
- What frequency of regulatory reporting should be established and how are release results and decisions communicated to the public?

Good plant performance

Related issues primarily concern characterising what attributes contribute to good plant performance as regards effluent management, and if there are plant conditions that assist in contributing to good performance. Technologies that have been effectively applied and management practices that have been found effective were discussed. According to several presentations at the workshop, improvements

in effluent management systems over the years have contributed to decreases in the levels of radioactive discharges from nuclear power plants. However, as available details are evaluated regarding selected (types of) nuclides, selected effluent pathways and selected reactor types, differences emerge in trends over time. Further evaluation of those trends may lead to helpful insights into reactor design and operations in order to enable continued decreases in release rates. Nevertheless, doses to members of the public remain low, both for groups of people living near nuclear power plants and the broader population.

Associated questions include:

- How can one balance risk transfers from the public to the workers resulting from new effluent management approaches?
- How are/should risks and benefits of effluent management approaches be evaluated?
- What metrics can be used to delineate “success” in terms of good effluent management practice?

Moving forward

A wave of new construction of nuclear power plants is anticipated to occur in various countries and regions of the world. The general tendency to move away from a “dilute and disperse” towards a “concentrate and contain” approach to radioactive waste management means that the level of discharges from these plants will be a key factor in their broad acceptability and important for their regulation and operation.

Increased consolidation of reactor vendors, and the consequent implication that nearly identical plants will be widely deployed, means that some level of harmonisation in terms of the best reasonably achievable discharge performance is desirable, both to avoid repetition of work and because the increasing similarity of reactor designs may lead to increased expectations of comparable performances.

While the workshop raised a number of questions, it also resulted in a plan to develop a final product: a short report on what regulators, operators and vendors consider to be “good practices” in terms of effluent management for the licensing and operation of new nuclear power plants. The plan expressed at the workshop, and agreed by the CRPPH at its March 2012 meeting, was to develop a questionnaire to elicit additional information from participants (and selected other affected parties), so that a final report of the workshop and thereby of the EGBAT can be prepared. Two suggestions for the EGBAT final report were that it should include a detailed description of the purposes of effluent monitoring and, to the extent feasible, available guidance on achievement of “success” in effluent management. It is hoped that the workshop’s final report will be completed and approved by the CRPPH for publication in the latter half of 2012.

Innovative fuels and structural materials for advanced nuclear energy systems

by Y.J. Choi, K.O. Pasamehmetoglu and T.R. Allen*

Advanced nuclear energy systems such as Generation IV reactors benefit from various innovative design features to enhance the performance of the nuclear reactors. The development of new nuclear fuels and structural materials is one of most important steps to accomplish the successful deployment of advanced nuclear energy systems. Under the guidance of the NEA Nuclear Science Committee, the Working Party on Scientific Issues of the Fuel Cycle has therefore been closely monitoring R&D programmes in these areas. Two of its expert groups have carried out reviews of the latest developments.

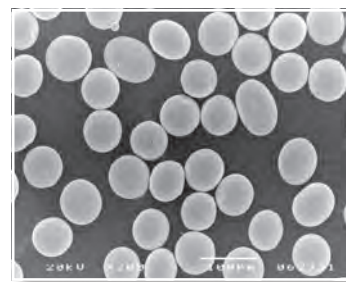
Innovative fuels refer to fuels containing minor actinides (MAs), notably neptunium, americium and curium, as opposed to standard fuels, such as uranium or uranium-plutonium fuels, currently being used. Fuels bearing MAs are also favourable for transmutation. The fuel types that have been considered in detail are oxide, metallic-nitride and dispersion fuels as well as special mechanical forms, e.g. particle, vibropac and sphere-pac fuels. An assessment was made of the fabrication processes and irradiation performance of the fuels along with the available fundamental properties and characterisation activities. The state-of-the art knowledge for each fuel type was also compared to a technology readiness level (TRL) scale from 1 to 9, where 9 corresponds to fully mature and largely commercialised technologies.

The most important issue for innovative structural materials is to select and to characterise structural materials that can be implemented in advanced nuclear fuel cycles under extreme conditions such as high temperature, high dose rates, corrosive chemical environments and long service lifetimes. Hence, key steps include identifying system requirements for advanced reactors, advanced materials being studied to meet the system requirements and the level of readiness of each of the materials. A comparative study was conducted based on the R&D status of

structural materials for each advanced reactor concept, following the framework of the Generation IV International Forum with separate areas of focus for gas-cooled reactors, liquid-metal-cooled reactors, water-cooled reactors and sodium-cooled reactors. Accelerator-driven systems cooled by lead or lead-bismuth eutectic alloys were also considered.

Innovative fuels

Two metal fuels were studied: uranium-plutonium-zirconium (U-Pu-Zr) alloys to be used in a fast reactor core and non-fertile (uranium-free) or low-fertile alloys to be used in accelerator-driven transmutation systems or as fuel in transuranic (TRU) burner reactors. The U-Pu-Zr fuel alloys usually contain up to 8 wt% of MAs and mixtures of rare earth (lanthanide). The non-fertile or low-fertile TRU-Zr fuel alloys contain higher fractions of zirconium (30-60 wt%) while U-Pu-Zr alloys usually contain less (10-20 wt% Zr). From the MA transmutation point of view, metal-fuelled fast reactors have an effective transmutation rate of MAs due to the high-energy neutron spectrum. Simultaneous recovery of MAs with plutonium in the electro-metallurgical process also facilitates MA recycling for substantial MA transmutation in a fast reactor fuel cycle system. For metal fuel fabrication, electro-metallurgical processes and injection casting can be used. The fuel-cladding compatibility issue, e.g. fuel-cladding chemical interaction (FCCI), is one of the most important from the standpoint of fuel lifetime and safety, but information in this area remains very limited. Further study of the alloy characteristics is necessary to better understand fuel performance.



Microscopic image of U 10 wt% Zr powder.

For oxide fuel, two scenarios were considered: homogenous fuel with 1-5 wt% MAs (i.e. minor actinide bearing fuel – MABF), and heterogeneous fuel with 10-20 wt% MAs inside a UO_2 support (i.e. minor actinide bearing blanket – MABB). The main challenges associated with homogeneous fuel development are improving fuel driver performances and MA transmutation efficiency. Recently, R&D programmes have shown that the maturity of the

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homogenous fuel is sufficient to plan future needs. Demonstration on the scale of a fuel pin bundle (in capsules) or on that of an assembly is still necessary. In the heterogeneous (MABB) concept, the MAs are diluted in the UO₂ matrix at a peripheral position in the sodium-cooled fast reactor (SFR). This core batch will allow higher MA content with little impact on the reactor operating parameters and core safety. Current R&D status is at an early stage of design and preliminary tests. More experimental programmes should be developed to improve composition design, fuel element dimensions, fabrication technology, properties and behaviour laws as well as validation of the fuel performances.

Nitride fuel has long been studied since it has a high melting temperature compared to oxide fuel. Its thermal conductivity is also comparable to that of metal fuels. This part of the review focused on uranium mono-nitride (UN). The nitrides also support a hard spectrum as required for efficient actinide fission. Both UN and PuN show good compatibility with the actinide nitrides. Two fabrication technologies are being developed: carbothermic reduction of oxides partitioned by an aqueous process and nitridation-distillation of actinide metals recovered in a liquid cadmium cathode through a pyrochemical process. Greater understanding of the fundamental properties as well as irradiation tests of both fertile and non-fertile compositions are still needed.

Inert matrix fuels (IMF) focus on Pu and MA transmutation, replacing the fertile material (²³⁸U) with a neutronically inert matrix. The matrix dilutes the transuranium material to reach acceptable power levels and fuel operating temperatures. For the fuel or target design the yttrium-stabilised zirconia (YSZ) in the form of a single ceramic (CER) was selected, and ceramic-ceramic (CERCER) and ceramic-metal (CERMET) configurations were studied in order to ease an adjustment of the properties. Dispersion of the (mixed) actinide oxide in a second material with a higher thermal conductivity is a

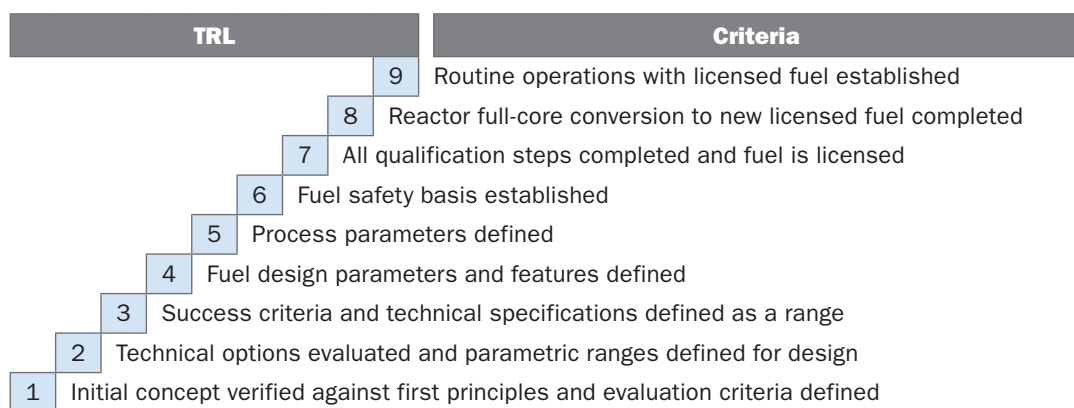
convenient means to increase the overall thermal conductivity of the sample.

The concept of particle nuclear fuel involves compacting the combustible material into the rod in the form of microscopic pieces or combustible material particles (in the µm to mm size range). In order to obtain acceptably high fuel densities, typically several particle-sized fractions are filled under vibration into the pin, such as vibropac and sphere-pac fuel. Vibropac fuel is fabricated from particles collected from the electrode of a pyrochemical process. Sphere-pac fuel involves compacting the spherical particles derived from a formation process of nitrate solutions during an aqueous reprocessing.

The technology readiness level (TRL) for the innovative fuels were developed and evaluated to quantify the maturity of a given technology relative to its full-scale deployment. However, it is noted that the TRL only provides a relative measure of technological maturity compared to the end objective of large-scale deployment. Technical risk was not considered in the TRL evaluation. It has been observed that the fabrication processes of such fuels are limited to laboratory-scale studies (~10⁻³ kg of transuranics). Irradiation testing is limited to small samples or rodlets. Large-scale irradiation testing (few full-length rods or subassembly scale) do not exist. A review of the current situation has concluded the following:

- Oxides and metallic transuranic-bearing fuels are the most mature, roughly corresponding to TRL 4.
- There are some laboratory-scale data for fabrication and characterisation of nitride fuels but successful irradiation testing to desired burn-ups is lacking. Large-scale fabrication of nitrides using a mature sintering process is also challenging because of americium-nitride volatility. It has been estimated that the TRL for TRU-bearing nitride fuels is around 3.
- Dispersion fuels (especially those with an inert matrix) have received recent attention. While successful fabrication processes at the

Technology readiness level (TRL) completion criteria



laboratory-scale have been demonstrated, the assessment of irradiation performance is pending the post-irradiation examination of recent irradiation tests. The TRL level has been estimated at between 3 and 4.

- There is currently a very limited set of studies with special fuel forms (vibropac and/or spherepac) that include transuranics (except for limited data with neptunium).

Innovative structural materials

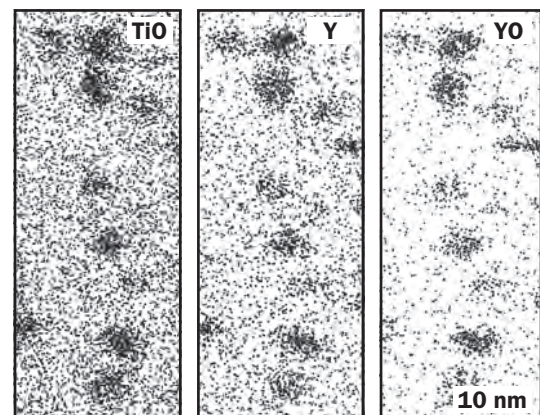
The Generation IV International Forum (GIF) has selected six advanced reactor concepts that promise to offer improved nuclear reactor performance in terms of safety, proliferation resistance, economic performance, better use of natural resources and waste minimisation. For all six concepts, improvements in material performance will be critical to the ultimate success of the reactor concept. The analysis indicates that many materials, or material classes, are common across the concepts so there are many opportunities for cross-cutting research programmes that will ultimately benefit several concepts.

Both for austenitic steels and ferritic-martensitic steels, a number of improved alloy compositions have been developed and are being developed further still. Nevertheless, the physical metallurgy reasoning which guides alloy development is far from obvious, and would merit some attention at a fundamental level. It would appear that there are limited efforts on improving nickel-based alloys, despite the fact that even modest improvements in high-temperature strength would be clearly beneficial. Within each of these alloy classes, it is very likely that there may not be a single, universal alloy suitable for all kinds of applications. Specific alloy development may well be required for the optimised design of specific components. Furthermore, although world resources for most alloying elements exist, the quality of the minerals used may be different, leading to different levels and types of impurities. Extra care will have to be taken regarding the definition and analysis of alloy compositions.

A number of reactor projects rely to a considerable extent on the promise of higher performance (stress, creep, temperature, even corrosion resistance) of oxide dispersion strengthened (ODS) steels. However, in order for these to be actually used in reactor components, very substantial further research efforts will be required at all levels, from applied research (fabrication, shaping, welding) to more fundamental research (physical metallurgy, microstructural stability, irradiation effects). The amount of effort required to progress from fundamental understanding to mastering robust manufacturing processes, including forming and assembling, should not be underestimated. Concerted international research with clear go/no-go steps would be helpful.

The carbon/carbon (C/C) and silicon/carbon (SiC/SiC) composites have been extensively studied

and are used for other (aerospace) applications, but it is not necessarily given that they can be readily transposed to nuclear reactors without substantial further research, notably for fuel rod cladding. Much less work has been done on titanium-silicon ternary carbide (Ti_3SiC_2) ceramics, and the knowledge base remains somewhat limited. Unfortunately, the graphite grades used in the past no longer exist so studies are ongoing to qualify modern graphite grades, as the properties change with input materials and processing conditions.



Atom probe tomography image of oxide clusters in an ODS steel irradiated in the Advanced Test Reactor at the Idaho National Laboratory.

The major technical challenges that appear across countries in the development of innovative materials include:

- developing structural steels of ceramic composites that can serve for transporting very high-temperature gases;
- qualifying modern graphite materials for nuclear uses;
- optimising oxide dispersion strengthened (ODS) steels as a high-temperature cladding and duct material for fast reactor systems, including radiation resistance and corrosion resistance;
- developing higher strength steels for sodium piping that would allow for lower overall plant costs while maintaining adequate safety;
- understanding dissolution, oxidation and embrittlement of steels exposed to lead alloys as well as development of protective coatings;
- developing materials that can withstand dissolution in high-temperature fluoride salts.

NEA follow-up and further reading

The two reviews – on innovative fuels and on innovative structural materials for advanced nuclear energy systems – are scheduled to be published in 2012 as NEA reports. To receive notification of their availability, sign up for the NEA's free monthly news bulletin at www.oecd-nea.org/bulletin.

Radiological characterisation for decommissioning

by S. Thierfeldt*

In April 2012, the OECD Nuclear Energy Agency (NEA), in co-operation with Studsvik Nuclear AB, the Swedish Radiation Safety Authority (SSM), the Swedish Nuclear Fuel and Waste Management Company (SKB) and AB SVAFO, held a Workshop on Radiological Characterisation in Decommissioning at Studsvik, in Sweden. During three days, a wide range of presentations, posters, discussions and site visits brought together over 120 participants from 23 countries and 4 international organisations.



The Studsvik site where the workshop was held.

Why radiological characterisation now?

Many decommissioning projects of all types of nuclear installations have progressed substantially and/or have been completed to brown field or green field conditions. It was therefore timely to bring together experts in a workshop and to evaluate the information on radiological characterisation gained from these numerous projects. The information will be particularly valuable for the large number of decommissioning projects about to start in the near future.

Moreover, the importance of this topic is reflected in the April 2011 decision by the NEA Working Party on Decommissioning and Dismantling (WPDD) to convene a Task Group on Radiological Characterisation for Decommissioning (RCD). This task group compiled the current status of radiological characterisation in NEA member countries and also participated in the organisation of the workshop.

The work of the task group has thus far shown that the objectives and methods for radiological characterisation differ for systems, structures and

components (metal), buildings and building rubble (concrete structures), and sites (land).

- **Characterisation of materials and systems:** Radiological characterisation is mainly based on surface measurement methods and samples taken from the materials to determine the contamination and induced radioactivity of the metal. Radiological characterisation provides the basis for estimating the material quantities for treatment as radioactive waste or for clearance, for determining the necessary extent of decontamination, for choosing the most suitable segmenting techniques and for planning radiological protection measures.
- **Characterisation of rooms and buildings:** Unlike for metals, radiological characterisation of building surfaces aims to determine not only the lateral distribution, but also the penetration depth of contamination. In addition, induced radioactivity around the reactor core can be very deep. Therefore, characterisation also relies on drilling cores that are analysed slice by slice. When systems, metallic structures and components of a nuclear facility have been removed, the results of the characterisation of rooms and buildings form the basis for determining which areas need to be decontaminated to which depth and how much of the resulting rubble will need to be treated as radioactive waste.
- **Characterisation of land and groundwater:** Characterisation of the land surrounding a nuclear installation may pose a problem if leakages of radioactive liquids have occurred during the operational phase of the facility. If there is reason to believe that contamination has not merely spread on the surface of the land (like on roads or other sealed surfaces), then the determination of the depth and the lateral spread of the underground contamination may require substantial effort. There are examples of sites of nuclear installations where soil had to be removed down to depths of several metres over large areas in order to locate and remove the contamination.

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However, radiological characterisation requires more than just measurement methods. Many countries have recognised the importance of providing support and recommendations on efficient characterisation strategies. The widely used *Multi-Agency Radiation Survey and Site Investigation Manual* (MARSSIM), the *Multi-Agency Radiation Survey and Assessment of Materials and Equipment Manual* (MARSAME) and the *Environmental Radiation Survey and Site Execution Manual* (EURSSEM) are available, describing sampling and measurement methods, evaluation procedures, quality assurance and other relevant issues. Furthermore, the acquired data need to be stored, managed, retrieved and evaluated using versatile databases. In recent years, software for statistical evaluation of the data and for visualisation of the measurement results have been developed to perfection and are widely used. In particular, robust statistical analysis of the data enables the reduction of the number of samples and measurements without losing significance of the results.

The relevance of radiological characterisation

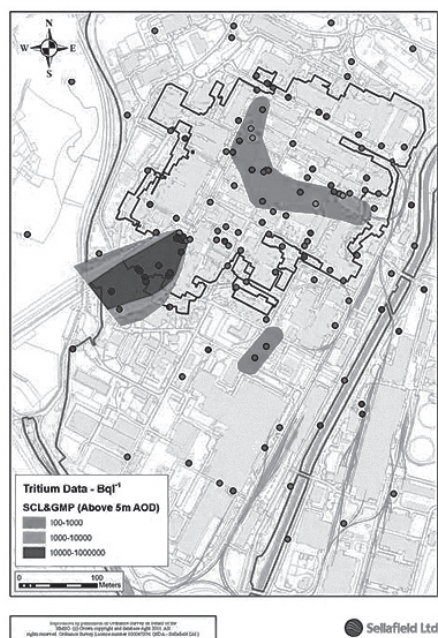
Radiological characterisation is at the heart of each decommissioning project. It is relevant for all phases of decommissioning and should be started as early as possible. Radiological characterisation is relevant for establishing and refining the decommissioning plan, for radiological protection, for planning waste

management and clearance, for cost estimates and for many other aspects of decommissioning projects.

Measurement techniques and sampling strategies are available for all types of facilities and for all types of contamination or induced radioactivity. However, it is also clear that many approaches used in the past leave room for improvement, for example through a more stringent application of statistical measurement and evaluation techniques, a better understanding of the data quality objectives or better visualisation of the measurement results. It is also necessary to develop ways to better integrate the characterisation of radiological and hazardous contamination (such as polychlorinated biphenyls – PCB – widely used in decontamination coatings, asbestos and polycyclic aromatic hydrocarbons) and to decrease the costs of characterisation by using innovative measurement and data evaluation techniques.

Results of the workshop

The NEA Workshop on Radiological Characterisation for Decommissioning addressed the topics described through many interesting presentations, posters and discussions. The results of this workshop will be valuable for all those involved in decommissioning planning and implementation. Therefore, publication of the workshop proceedings as an NEA document is foreseen in the second half of 2012. In the interim, supporting workshop materials are available at www.oecd-nea.org/rwm/wpdd/rcd-workshop/.



Characterisation of a complex nuclear site with a long operating history for soil and groundwater contamination – a huge task (from the presentation “The Sellafield Contaminated Land and Groundwater Management Project: Characterisation of a Complex Nuclear Facility” by Julian Cruickshank).

Over two decades of information exchange on partitioning and transmutation

by Y.J. Choi*

Partitioning and transmutation (P&T) is considered as a means of reducing the burden on geological disposal. As plutonium and the minor actinides are mainly responsible for the long-term radiotoxicity, when these nuclides are removed from the waste (partitioning) and then fissioned (transmutation), the remaining waste loses most of its long-term radiotoxicity. The radiotoxic inventory can be reduced by up to a factor of 10 if all the plutonium is recycled and fissioned. Reduction factors higher than 100 can be obtained if, in addition, the minor actinides (MAs) are burned. Moreover, in principle the P&T strategy allows a combined reduction of the radionuclide masses to be stored, their associated residual heat, and, as a potential result, the volume and the cost of the repository. Recent developments indicate the need for embedding P&T strategies into advanced fuel cycles considering both waste management and economic issues. Non-proliferation resistance of the overall fuel cycle, including the final repository, is also potentially enhanced by the same partitioning and transmutation strategies, in particular if the plutonium is not separated from the transuranics (TRU).

In this context, since 1990, the NEA has been organising a biennial Information Exchange Meeting on Actinide and Fission Product Partitioning and Transmutation (IEMPT) to provide experts a forum for presenting and discussing scientific and strategic issues associated with P&T technology. The meetings have been held in Mito (Japan) in 1990, at Argonne (USA) in 1992, in Cadarache (France) in 1994, in Mito (Japan) in 1996, in Mol (Belgium) in 1998, in Madrid (Spain) in 2000, in Jeju (Korea) in 2002, in Las Vegas (USA) in 2004, in Nimes (France) in 2006, in Mito (Japan) in 2008 and in San Francisco (USA) in 2010.

Until the year 2000, the scope of the meetings mainly focused on the physics and chemistry of P&T and the number of papers presented was less than 60. The number of papers increased dramatically when the scope of the meeting was extended to cover nuclear fuel cycle issues, system design and fuels and materials as well as related policies and strategies. In 2008, more than 140 papers were presented either in oral or poster sessions. The shift in the scope of the meetings also reflects the trends in world nuclear R&D issues such as progress on generation IV systems design and enhancement of fuels and material development. The meetings typically include a special session on the current status of national programmes on P&T or specific issues to

be discussed. In 2008, a special session on fuel cycle strategies and transition scenarios was organised.

The 12th IEMPT meeting will be held in Prague, Czech Republic on 24-27 September 2012, hosted by the Radioactive Waste Repository Authority (RAWRA) and co-sponsored by the European Commission (EC) and the International Atomic Energy Agency (IAEA). The meeting will cover scientific as well as strategic/policy developments in the field of P&T such as: fuel cycle strategies and transition scenarios; radioactive waste forms; the impact of P&T on geological disposal; radioactive waste management strategies (including secondary wastes); transmutation fuels and targets; pyro and aqueous separation processes; materials, spallation targets and coolants; transmutation physics, experiments and nuclear data; transmutation systems' design, performance and safety; handling and transportation of transmutation fuels; and the economics of P&T.

More information about the 12th meeting and the call for papers are available at www.oecd-nea.org/pt/iempt12/. The proceedings of the previous meetings are available at www.oecd-nea.org/pt.



Participants at the October 2008 Information Exchange Meeting on Actinide and Fission Product Partitioning and Transmutation held in Mito, Japan.

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New publications

General interest

NEA Annual Report – 2011

978-92-64-99179-8. 56 pages. Free: paper or web.

Economic and technical aspects of the nuclear fuel cycle

Nuclear Education and Training: From Concern to Capability

978-92-64-17637-9. 200 pages. Price: € 60, US\$ 84, £ 54, ¥ 7 800.

The OECD Nuclear Energy Agency (NEA) first published in 2000 *Nuclear Education and Training: Cause for Concern?*, which highlighted significant issues in the availability of human resources for the nuclear industry. Ten years on, *Nuclear Education and Training: From Concern to Capability* considers what has changed in that time and finds that, while some countries have taken positive actions, in a number of others human resources could soon be facing serious challenges in coping with existing and potential new nuclear facilities. This is exacerbated by the increasing rate of retirement as the workforce ages. This report provides a qualitative characterisation of human resource needs and appraises instruments and programmes in nuclear education and training initiated by various stakeholders in different countries. In this context, it also examines the current and future uses of nuclear research facilities for education and training purposes. Regarding the nuclear training component of workforce competence, it outlines a job taxonomy which could be a basis for addressing the needs of workers across this sector. It presents the taxonomy as a way of enhancing mutual recognition and increasing consistency of education and training for both developed and developing countries.

The Role of Nuclear Energy in a Low-carbon Energy Future

978-92-64-99189-7. Free: web only.

This report assesses the role that nuclear energy can play in supporting the transition to a low-carbon energy system. It begins by considering the greenhouse gas emissions from the full nuclear fuel cycle, reviewing recent studies on indirect emissions and assessing the impact that nuclear power could make in reducing greenhouse gas emissions. The report provides estimates of the construction rates that would be needed to meet the projected expansion of nuclear power foreseen by many energy scenarios published by international organisations. It then assesses the economic, technical, societal and institutional challenges represented by such an expansion to identify the most significant barriers. The capacity of nuclear power plants to operate in an electricity system with a large share of renewables, and the impact of smart grid technologies are also examined. Finally, long-term prospects for nuclear energy are discussed in terms of development of new reactor and fuel cycle technologies, non-electric applications and new operational and regulatory constraints that could arise as a consequence of climate change.

Trends towards Sustainability in the Nuclear Fuel Cycle

978-92-64-16810-7. 184 pages. Price: € 50, US\$ 70, £ 45, ¥ 6 500.

Interest in expanding nuclear power to cope with rising demand for energy and potential climate change places increased attention on the nuclear fuel cycle and whether significant moves are being taken towards ensuring sustainability over the long term. Future nuclear power programme decisions will be increasingly based on strategic considerations involving the complete nuclear fuel cycle, as illustrated by the international joint projects for generation IV reactors. Currently, 90% of installed reactors worldwide operate on a once-through nuclear fuel cycle using uranium-oxide fuel. While closing the fuel cycle has been a general aim for several decades, progress towards that goal has been slow. This report reviews developments in the fuel cycle over the past ten years, potential developments over the next decade and the outlook for the longer term. It analyses technological developments and government actions (both nationally and internationally) related to the fuel cycle, and examines these within a set of sustainability parameters in order to identify trends and to make recommendations for further actions.

Nuclear safety and regulation

Computational Fluid Dynamics (CFD) for Nuclear Reactor Safety Applications

Workshop Proceedings, CFD4NRS-3, Bethesda, Maryland, USA, 14-16 September 2010

CD. Free on request.

CSNI Technical Opinion Papers No. 14

Nuclear Licensee Organisational Structures, Resources and Competencies: Determining their Suitability

978-92-64-99175-0. 16 pages. Free: paper or web.

The way in which nuclear licensees' organisations are structured and resourced clearly has a potential impact on nuclear safety. As experience has continually demonstrated, operating organisations with a strong training programme for personnel, adequate resourcing and overall effective leadership and management perform more effectively in times of crisis than those lacking in one or more of these areas. In parallel, the nuclear industry is developing new resource deployment strategies which are making increased use of contractors and leading to changes in organisational structure, which in turn create challenges for the continued safe operation of nuclear facilities. This technical opinion paper represents the consensus among human and organisational factor specialists in NEA member and associated countries on the methods, approaches and good practices to be followed in designing an organisation with a strong safety focus while meeting business needs. It also considers some of the attributes that an organisation which is effectively managing its resources and capabilities might demonstrate.

Main Benefits from 30 Years of Joint Projects in Nuclear Safety

978-92-64-99171-2. 132 pages. Free: paper or web.

One of the major achievements of the OECD Nuclear Energy Agency (NEA) is the knowledge it has helped to generate through the organisation of joint international research projects. Such projects, primarily in the areas of nuclear safety and radioactive waste management, enable interested countries, on a cost-sharing basis, to pursue research or the sharing of data with respect to particular areas or issues. Over the years, more than 30 joint projects have been conducted with wide participation of member countries. The purpose of this report is to describe the achievements of the OECD/NEA joint projects on nuclear safety research that have been carried out over the past three decades, with a particular focus on thermal-hydraulics, fuel behaviour and severe accidents. It shows that the resolution of specific safety issues in these areas has greatly benefited from the joint projects' activities and results. It also highlights the added value of international co-operation for maintaining unique experimental infrastructure, preserving skills and generating new knowledge.

Radioactive waste management

International Structure for Decommissioning Costing (ISDC) of Nuclear Installations

978-92-64-99173-6. 192 pages. Free: paper or web.

Cost estimation for the decommissioning of nuclear facilities can vary considerably in format, content and practice both within and across countries. These differences may have legitimate reasons but make the process of reviewing estimates complicated and the estimates themselves difficult to defend. Hence, the joint initiative of the OECD Nuclear Energy Agency (NEA), the International Atomic Energy Agency (IAEA) and the European Commission (EC) was undertaken to propose a standard itemisation of decommissioning costs either directly for the production of cost estimates or for mapping estimates onto a standard, common structure for purposes of comparison. This report updates the earlier itemisation published in 1999 and takes into account experience accumulated thus far. The revised cost itemisation structure has sought to ensure that all costs within the planned scope of a decommissioning project may be reflected. The report also provides general guidance on developing a decommissioning cost estimate, including detailed advice on using the structure.

Methods for Safety Assessment of Geological Disposal Facilities for Radioactive Waste

Outcomes of the NEA MeSA Initiative

978-92-64-99190-3. Free: web only.

Safety assessment is an interdisciplinary approach that focuses on the scientific understanding and performance assessment of safety functions as well as the hazards associated with a geological disposal facility. It forms a central part of the safety case, and the results of the safety assessments provide evidence to support decision making. The goals of the NEA project on "Methods for Safety Assessment for Geological Disposal Facilities for Radioactive Waste" (MeSA) were to examine and document methods used in safety assessment for radioactive waste disposal facilities, to generate collective views based on the methods' similarities and differences, and to identify future work. The project reviewed a number of approaches used by various national and international organisations. Following the

comprehensive review, a generic safety case with a safety assessment flowchart was developed and is presented herein. The elaboration of the safety concept, the use of safety functions, the implication of uncertainties and the formulation of scenarios are also discussed.

Reversibility of Decisions and Retrievability of Radioactive Waste

Considerations for National Geological Disposal Programmes

978-92-64-99169-9. 28 pages. Free: paper or web.

The most widely adopted solution for the definitive management of high-level radioactive waste involves its emplacement in deep geological repositories whose safety should not depend on the active presence of man. In this context, national programmes are considering whether and how to incorporate the concepts of reversibility of decisions and retrievability of waste, including to what extent retrieval can or should be facilitated at the design stage of a repository, and if so over what timescales. This brochure delivers the key findings and observations of the OECD Nuclear Energy Agency (NEA) project on reversibility and retrievability conducted from 2007 to 2011 with the participation of 15 countries and 2 international organisations. It outlines the activities undertaken and points to further resources. While focused on deep geological disposal, the pragmatic and precise information provided may also be pertinent to sub-surface disposal and to decision-making processes more generally. This brochure, and related project documents, will be of interest to technical and policy professionals and civil society stakeholders concerned with radioactive waste disposal.

Thermodynamic Sorption Modelling in Support of Radioactive Waste Disposal Safety Cases

NEA Sorption Project Phase III

978-92-64-17781-9. 152 pages. Price: € 46, US\$ 64, £ 41, ¥ 5 900.

A central safety function of radioactive waste disposal repositories is the prevention or sufficient retardation of radionuclide migration to the biosphere. Performance assessment exercises in various countries, and for a range of disposal scenarios, have demonstrated that one of the most important processes providing this safety function is the sorption of radionuclides along potential migration paths beyond the engineered barriers. Thermodynamic sorption models (TSMs) are key for improving confidence in assumptions made about such radionuclide sorption when preparing a repository's safety case. This report presents guidelines for TSM development as well as their application in repository performance assessments. They will be of particular interest to the sorption modelling community and radionuclide migration modellers in developing safety cases for radioactive waste disposal.

Nuclear law

Nuclear Law Bulletin No. 88

Volume 2011/2 (December 2011)

0304-341X. 210 pages. 2012 subscription (two issues per year): € 121, US\$ 161, £ 96, ¥ 16 000.

The *Nuclear Law Bulletin* is a unique international publication for both professionals and academics in the field of nuclear law. It provides subscribers with authoritative and comprehensive information on nuclear law developments. Published twice a year in both English and French, it features topical articles written by renowned legal experts, covers legislative developments worldwide and reports on relevant case law, bilateral and international agreements as well as regulatory activities of international organisations. Feature articles in this issue include "The status of radioactive waste repository development in the United States", "The Radioactive Waste Directive: a necessary step in the management of spent fuel and radioactive waste in the European Union", "The continuing role of item-specific agreements in the IAEA safeguards system" and "Fukushima: liability and compensation".

Nuclear science and the Data Bank

Actinide and Fission Product Partitioning and Transmutation

Eleventh Information Exchange Meeting, San Francisco, California, USA, 1-4 November 2010

978-92-64-99174-3. 404 pages. Free: paper or web.

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