2013 – No. 31.2

NEA News

In this issue:

OECD
BETTER POLICIES FOR BETTER LIVES

NEA
NUCLEAR ENERGY AGENCY

NEA News

Volume No. 31.2 2013

NEA News is published twice yearly in English and French by the OECD Nuclear Energy Agency. The opinions expressed herein are those of the contributors and do not necessarily reflect the views of the Organisation or of its member countries. The material in *NEA News* may be freely used provided the source is acknowledged. All correspondence should be addressed to:

The Editor, *NEA News*
OECD Nuclear Energy Agency
12, boulevard des Îles
92130 Issy-les-Moulineaux
France
Tel.: +33 (0)1 45 24 10 12
Fax: +33 (0)1 45 24 11 10

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 31 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 Russian Federation, 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.

For more information about the NEA, see:
www.oecd-nea.org

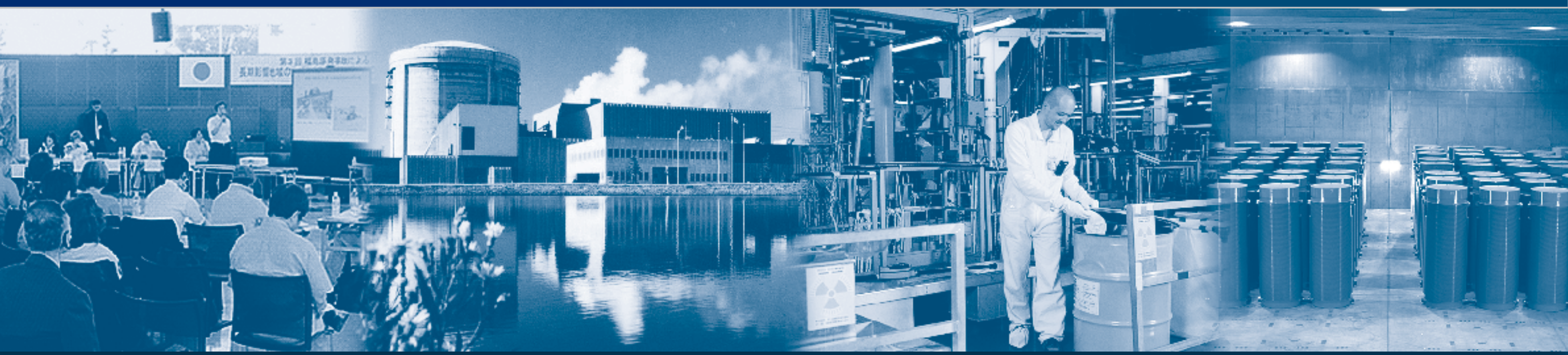
Editors:
Cynthia Gannon-Picot
Janice Griffiths

Design and layout:
Fabienne Vuillaume

Production assistant:
Andrée Pham Van

Cover page photo credits: The Fukushima Daiichi Initiative in Date City, Japan, 7-8 July 2012; Point Lepreau nuclear power plant, New Brunswick, Canada (AECL); A plant worker passes from the green to yellow zone in Saclay, France (A. Gonin, CEA); Gorleben transport cask interim storage facility, Gorleben, Germany (GNS – Gesellschaft für Nuklear Service mbH). Page 3 photo credit of Luis Echávarri (M. Lemelle, France).

Contents



Future energy needs, the NEA and nuclear power

How the world will meet growing energy needs in a safe, secure and affordable manner in the coming decades is a critical question facing governments, and there is no "one size fits all" ideal solution. Safe nuclear energy requires robust designs, competent operators with a strong safety culture and effective regulatory bodies. "Safe" for man and the environment can be seen not only as preventing accidents, but also mitigating climate change. International co-operation and the sharing of experience and best practice makes a positive contribution in this regard, and has recently led to the NEA publication on *The Fukushima Daiichi Nuclear Power Plant Accident: OECD/NEA Nuclear Safety Response and Lessons Learnt*.

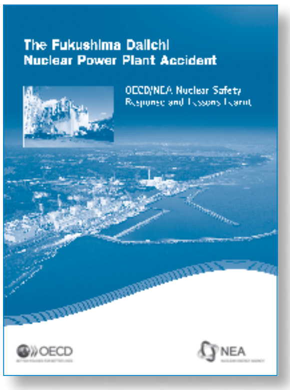
The first article of this edition of *NEA News* highlights the key messages and conclusions from this publication, and provides a brief overview of key NEA activities undertaken. In addition to heightening awareness about safety, the Fukushima Daiichi nuclear power plant accident also led to a revived interest in the establishment of a global nuclear liability regime. The recent Joint Statement by the United States and France emphasising the importance of nuclear generating countries moving towards a global nuclear liability regime provides impetus in this direction. The second article in this edition reviews overall progress towards such a global nuclear liability regime, which will also be the subject of the next NEA Steering Committee policy debate in April 2014.

The work towards safer and more economical nuclear technologies of the future being carried out within the framework of the Generation IV International Forum (GIF) is also described, as are a selection of other NEA activities and reports of interest. They address in particular the state of the art in radiological protection and the economics of the back end of the nuclear fuel cycle. Looking ahead, the Agency welcomes the recent signing of a Joint Declaration on Co-operation between the NEA and the China Atomic Energy Authority (CAEA), and looks forward to its practical implementation.

Finally, since this is my last editorial for *NEA News*, I would like to take this opportunity to express my appreciation to the many collaborators with whom I have worked over the past 17 years while at the head of the NEA. I would also like to extend my very best wishes to the next NEA Director-General and to the Agency as a whole in its future work.

Luis E. Echávarri
NEA Director-General

Responding to the Fukushima Daiichi nuclear accident



On 11 March 2011, Japan endured one of the worst combined natural disasters in its history when a massive earthquake struck its eastern coast and was followed by a tsunami which led to the loss of thousands of lives. These combined natural disasters were also at the origin of the Fukushima Daiichi nuclear power plant accident due to the prolonged loss of electric power supply and ultimate heat sink required for cooling. While the accident itself was not responsible for any casualties, it has affected the lives of tens of thousands of displaced Japanese citizens, resulted in very large economic costs and caused considerable environmental damage in the surrounding area.

The NEA member countries, standing technical committees and secretariat took prompt action following the Fukushima Daiichi nuclear power plant accident to review the safety of nuclear power reactors in operation. In parallel, they also extended offers of direct assistance to the Japanese authorities to help them face the various challenges presented by the accident and the evacuation of the population in the surrounding areas. In the months that followed, a significant amount of work has been undertaken by the NEA and its member and associate countries resulting in the launch of new activities, studies and projects, and more recently, the publication in September 2013 of the NEA report *The Fukushima Daiichi Nuclear Power Plant Accident: OECD/NEA Nuclear Safety Response and Lessons Learnt.*

The report outlines international efforts to strengthen nuclear regulation, safety, research and radiological protection in the post-Fukushima context. It also describes work on new reactors and legal frameworks, and highlights key messages and lessons learnt, notably as related to assurance of safety, shared responsibilities, human and organisational factors, defence-in-depth (DiD), stakeholder engagement, crisis communication and emergency preparedness. This article summarises the NEA response to the Fukushima Daiichi accident. Full details regarding the immediate response of NEA member countries are provided in the report.

It is clear that over two and half years after the accident, the Fukushima Daiichi accident is not a closed case. Efforts currently being made at the plant site and in the surrounding communities to remediate the situation, and work being carried out at the international level to draw lessons from the accident, will continue for many years and will require significant international co-operation. In this respect, the publication of the report marks an initial step in the post-Fukushima follow-up process.

Nuclear regulation

Ongoing and planned activities on regulatory matters, which are being overseen by the NEA Committee on Nuclear Regulatory Activities (CNRA), are described in the report. Activities of note include the formation of the Task Group on Accident Management (TGAM) to review accident management practices in light of the Fukushima Daiichi accident, and a joint workshop organised by the CNRA and the NEA Committee on the Safety of Nuclear Installations (CSNI) to discuss enhancements to DiD, as well as challenges related to DiD. This joint workshop, held on 5 June 2013, focused in part on the implementation of DiD – including strengthening the multiple barriers in place to protect the public and environment from the harmful effects of radiation and examining how to improve preparations for rare and extreme external hazards such as tsunamis.

The accident at the Fukushima Daiichi NPP has drawn greater attention to the regulation of nuclear site selection. Related activities are being co-ordinated by the NEA Working Group on the Regulation of New Reactors (WGRNR). The importance of crisis communication is also highlighted. Readers of the report will learn about the international workshop organised on this subject by the NEA in collaboration with the Spanish *Consejo de Seguridad Nuclear* (CSN) on 9-10 May 2012. Recommendations from that workshop have been gathered in a report entitled *Crisis Communication: Facing the Challenges*, and are today being incorporated into the actions of national regulatory organisations.

Nuclear safety

The report identifies a number of high priority activities on nuclear safety being carried out by the NEA and its member countries. They include a study

> **Key messages**
>
> - NEA member countries implemented focused safety reviews of their operating reactors and determined that they were safe to continue operation. Additional safety enhancements that will help to better cope with external events and severe accidents have been identified and are being implemented.
> - Nuclear safety professionals have a responsibility to hold each other accountable to effectively implement nuclear safety practices and concepts.
> - The primary responsibility for nuclear safety remains with the operators of the NPPs, and regulatory authorities have the responsibility to ensure that the public and the environment are protected.
> - There is no room for complacency in the implementation of nuclear safety practices and concepts.
> - The Fukushima Daiichi NPP accident identified significant human, organisational and cultural challenges, which include ensuring the independence, technical capability and transparency of the regulatory authority.
> - The fundamental concepts of defence-in-depth remain valid and continue to be shared by those in charge of nuclear safety.
> - Since an accident can never be completely ruled out, the necessary provisions for dealing with and managing a radiological emergency situation, onsite and offsite, must be planned, tested and regularly reviewed.
> - Ensuring safety is a national responsibility but poses a global concern due to potentially far-reaching accident consequences.
> - Complete experience feedback from the Fukushima Daiichi nuclear power plant accident will take many years.
> - A questioning and learning attitude is essential to continue improving the high level of safety standards and their effective implementation.
>
> Source: *The Fukushima Daiichi Nuclear Power Plant Accident: OECD/NEA Nuclear Safety Response and Lessons Learnt* (2013).

on human performance under extreme conditions. Readers will also learn about a task group established to review the robustness of electrical systems at nuclear power plants (ROBELSYS) and of new reports on hydrogen management and filtered containment venting. These reports are being co-ordinated by the NEA Working Group on Analysis and Management of Accidents (WGAMA).

Further nuclear safety-related activities include a status report on spent fuel accident and mitigation strategies, in light of the loss of cooling at the spent fuel pool of Fukushima Daiichi unit 4. The status report assesses the strengths and weaknesses of current accident analysis methods for developing prevention and mitigation strategies with different cooling mechanisms so as to identify additional research activities that might be needed to strengthen these strategies. A benchmark will be performed of software tools used to estimate fission product releases during accidents in nuclear power plants. A report identifying good practices and experiences in the area of risk analysis for natural external hazards will be produced. The MECOS project was launched to examine how seismic assessment of the consequences of seismic events on metallic components in nuclear power plants can be improved and can take particular account of plant ageing. For each activity or project, a comprehensive list of participating institutions is given in the report.

Joint research projects

The NEA has provided a platform for over 30 years to enable interested countries, on a cost-sharing basis, to pursue research or to share data concerning specific nuclear safety areas or issues that would otherwise be difficult to accomplish on a national basis. General information on ongoing joint research projects can be found on the NEA website, and information on the four initial, new joint projects that respond to research needs in light of the Fukushima Daiichi accident can be found in the report.

The first of these four projects, based on a proposal from Japan and initiated by the NEA, is a benchmark to use existing severe accident tools in order to reproduce the evolution of the accident at Fukushima Daiichi. It will also identify improvements that might strengthen these tools. This Benchmark Study of the Accident at the Fukushima Daiichi Nuclear Power Plant (BSAF) specifically concentrates on what took place within the first six days of the accident.

The additional three joint projects include the Hydrogen Mitigation Experiments for Reactor Safety (HYMERES), which aims to improve the knowledge of hydrogen behaviour within reactor systems and thus improve the quality of safety assessments of existing and new NPPs; the Primary Coolant Loop Test Facility (PKL) Project phase 3, which is based on an extension of the current experimental programme of the NEA joint project at the PKL test facility in Erlangen, Germany; and the Advanced Thermal-hydraulic Test Loop for Accident Simulation (ATLAS), which is operated by the Korea Atomic Energy Research Institute (KAERI) and can simulate the thermal-hydraulic behaviour of major systems and components in an APR1400 reactor under accident conditions. Both of the latter two projects will examine thermal hydraulic behaviour that might follow a serious accident in a pressurised water reactor system.

New reactors

The report also presents information on the Multinational Design Evaluation Programme (MDEP), a multinational forum for regulatory authorities who are, or will shortly be, undertaking the review of new nuclear power reactor designs. The NEA acts as Technical Secretariat for the MDEP, which undertakes a broad range of activities related to the multinational convergence of codes, standards, guides and safety goals, and which also carries out reviews of specific reactor designs such as the EPR, AP1000, APR1400, VVER and ABWR.

Radiological protection

The implications of the Fukushima Daiichi accident on radiological protection policy, regulation and application have been far-reaching, and the NEA and its member countries continue to devote significant resources to studying these effects and contributing to Japanese remediation efforts.

The wide-ranging activities conducted under the aegis of the NEA Committee on Radiation Protection and Public Health (CRPPH) are described in the report, notably those undertaken by the Expert Group on Radiological Protection Aspects of the Fukushima Accident (EGRPF), which was created by the NEA immediately after the accident. The EGRPF has conducted work on international trade in food and goods coming from contaminated areas in Japan, carried out a survey of emerging issues and lessons relating to recovery management and held the third Science and Values Workshop in Japan in November 2012, focusing on the theme of stakeholder involvement in radiological protection decision making.

The NEA Working Party on Nuclear Emergency Matters (WPNEM) has been equally active and has significantly adjusted its programme of work to identify and address emerging issues such as emergency management, emergency communications and the cost of nuclear accidents.

Fukushima Dialogue Initiative
Date City, Japan, 7-8 July 2012.

Also outlined in the report are the activities of the Information System on Occupational Exposure (ISOE) which mobilised members in the aftermath of the Fukushima Daiichi accident to collect and report their experience in the area of occupational exposure management in high radiation areas and for severe accident management.

The NEA was actively involved in the Fukushima Dialogue Initiative organised by the International Commission on Radiological Protection (ICRP). The series of local fora was designed to enable affected stakeholders to share their concerns, experience and actions.

Legal framework and liabilities

A number of targeted activities were undertaken by the NEA Nuclear Law Committee (NLC) in response to the Fukushima Daiichi accident. The NLC has been focusing in particular on the legal framework and implementation of Japan's compensation scheme for accident victims, and in view of the significant interest in this scheme, the NEA Secretariat, in co-operation with the Permanent Delegation of Japan to the OECD, prepared the publication entitled *Japan's Compensation System for Nuclear Damage: As Related to the TEPCO Fukushima Daiichi Nuclear Accident*. The publication gathers in one volume translations in English of major statutes, ordinances and guidelines issued in Japan for the establishment and implementation of the compensation scheme in response to the accident at the Fukushima Daiichi NPP. It also includes several commentaries by Japanese experts in the field of third party nuclear liability.

Key messages and conclusions

The Fukushima Daiichi Nuclear Power Plant Accident: OECD/NEA Nuclear Safety Response and Lessons Learnt report stresses key messages in a number of areas, as highlighted in the box on page 5. A selection of these key messages are further developed below.

The comprehensive safety reviews conducted at nuclear power plants in the post-Fukushima context carry an important safety message: that enhancements to nuclear power plants are aimed at making another Fukushima Daiichi-type accident (one due to multiple failures of safety systems) extremely unlikely in the future. The scope of comprehensive safety reviews conducted in NEA member countries following the Fukushima Daiichi accident were, however, broader than just the conditions experienced in Fukushima. In effect, the reviews involved confirming that existing design bases of nuclear power plants provided **assurance of safety** and better prepared power plant operators to respond to extreme initiating events. In addition, moving forward, it should be stressed that collectively, each individual working in the nuclear industry – operator, vendor, designer, constructor, technical safety expert and regulator – has a **shared responsibility** to hold each other accountable for the development and effective implementation of nuclear safety principles.

The barriers in place to protect people and the environment from the harmful effects of radiation, or DiD, constitute a foundation of these nuclear safety principles. The fundamental concept of DiD remains as valid after the accident as it did before, but going forward, regulatory authorities in each country should consider including within their guidance both prevention and mitigation measures at each level of DiD, and applying DiD to both the design phase and siting of the nuclear power plant.

It has also been recognised that **organisational factors**, including the independence, technical capability and transparency of the regulator in Japan, contributed to the Fukushima Daiichi accident and emergency response challenges encountered. Fukushima also showed that for the future planning and performance of measures to manage accidents, factors contributing to stress in **human performance** need to be considered.

The plans and countermeasures implemented in an emergency to protect the public from the harmful effects of radiation constitute the last barrier of defence-in-depth. Implementing protective measures, however, remains a challenge in the case of longer-term recovery and as those evacuated or sheltered after the Fukushima Daiichi accident wish to return to their normal lives. Such a transition requires considerable resources and effective **stakeholder engagement**.

Significant improvements are also needed in international **communication** and information exchange among national regulatory organisations and their crisis response centres. The Fukushima experience has clearly underlined the need to be able to communicate consistently and with plain language so that members of the public can understand their safety status.

With respect to **emergency preparedness** (and its international dimension), the differences between Japanese protection recommendations and those of foreign governments for their own citizens in Japan suggests that mechanisms to share technical information among governments should also be improved.

Specific conclusions from the accident-recovery process at Fukushima Daiichi could have an effect on the long-term recommendations for **research and development**. Significant information is being collected from the decontamination and recovery process, but this will take many years.

International co-operation should include not only short-term issues but also facilitate medium- and long-term actions to address lessons learnt and provide a forum for collecting, sharing and analysing data to develop consistent approaches that can be applied within national regulatory frameworks. The forum provided by the NEA facilitates such research and also allows peer regulators to actively encourage each other to remain vigilant in ensuring nuclear power plant safety.

Since a severe accident can never be completely ruled out, the response to radiological emergency situations, on and off the nuclear power plant site, must be planned, tested and regularly reviewed. In this respect, protection of the public and the environment from the harmful effects of radiation remains fundamental, and there should be no complacency in this regard. Further details of key messages and conclusions can be found in the report.

References

For access to the full NEA report *The Fukushima Daiichi Nuclear Power Plant Accident: OECD/NEA Nuclear Safety Response and Lessons Learnt,* see www.oecd-nea.org/pub/2013/7161-fukushima2013.pdf.

Japan's Compensation System for Nuclear Damage: As Related to the TEPCO Fukushima Daiichi Nuclear Accident is available at www.oecd-nea.org/law/fukushima/7089-fukushima-compensation-system-pp.pdf.

For general information on NEA ongoing joint research projects, see www.oecd-nea.org/jointproj/.

Progress towards a global nuclear liability regime

by S. Burns*

The Fukushima Daiichi nuclear power plant accident brought a renewed focus to the discussion of international nuclear liability regimes, and one that is not merely about the theoretical problems involved in the administration of a liability system to compensate damages resulting from a nuclear accident. Although the international conventions on third party nuclear liability are among the oldest international legal instruments bearing on the civilian use of nuclear power, progress towards broader adherence to the nuclear liability conventions has been uneven. This is particularly evident when compared with instruments such as the 1994 Convention on Nuclear Safety, which enjoys broad adherence among states involved in the generation of nuclear energy. While it may be true that nuclear generating states typically have liability legislation consistent with the principles of international regimes, greater harmonisation of law and practice, as well as better management of potential transboundary damages through greater participation in the international regimes, remains an important goal.

Background on existing international nuclear liability conventions

With the emergence of civilian nuclear power in the mid-1950s, the need for a special liability regime became more pressing in view of the perceived special and uncertain hazards of nuclear operations and the potentially far-reaching consequences of a nuclear accident that could cross national borders. The discussions that led to the adoption of nuclear liability regimes in the 1960s sought to balance the interests of potential victims of an accident and the interests of a nascent nuclear energy industry. These regimes would thus help to ensure adequate compensation for damage to persons and to property resulting from a nuclear accident and encourage the industry to assume full responsibility for safety without being exposed to an excessive liability burden.

In the late 1950s, the Organisation for European Economic Co-operation (today the OECD) brought legal experts together to explore the development of a regional instrument that would provide a uniform liability system for western European countries. These efforts led to the adoption in 1960 of the Paris Convention on Third Party Liability in the Field of Nuclear Energy. Of course, the 1960 Paris Convention, which entered into force in 1968, was only the first step towards the development of an international nuclear third party liability regime. After the adoption of the Paris Convention, the Brussels Convention Supplementary to the Paris Convention was adopted in 1963 (and entered into force in 1974) to provide additional funds that would compensate damage as a result of a nuclear incident where funds available under the Paris Convention proved to be insufficient. The Paris Convention and the Brussels Supplementary Convention were modified by protocols adopted in 1964 and 1982. The Vienna Convention on Civil Liability for Nuclear Damage was also adopted in 1963 under the auspices of the International Atomic Energy Agency (IAEA) and came into force in 1977. The Vienna Convention is, in general terms, open to all states; the Paris

Compensation under liability regimes

Regime	Amount available
Original Paris Convention (1960)	SDR 15 million [in 1990, the NEA Steering Committee for Nuclear Energy recommended an increase to SDR 150 million]
Existing Paris (1960) and Brussels Supplementary Convention (1963) regime	SDR 300 million
Original Vienna Convention (1963)	Minimum USD 5 million based on gold value at USD 35 per troy ounce on 29 April 1963, equivalent to about USD 176.79 million (based on price of gold on 2 December 2013)
Revised Paris Convention (2004) *[not yet in force]*	Minimum EUR 700 million
Revised Paris and Brussels Supplementary Convention regime (2004) *[not yet in force]*	Minimum EUR 1.5 billion
Revised Vienna Convention (1997)	Minimum SDR 300 million
Convention on Supplementary Compensation (1997) *[not yet in force]*	Minimum SDR 600 million

SDR 1 = USD 1.53 on 2 December 2013.

* *Mr. Stephen Burns (stephen.burns@oecd.org) is Head of the NEA Legal Affairs Section.*

Convention is open to OECD member countries and to any non-member with the consent of the contracting parties.

Just as the 1986 Chernobyl accident provided the catalyst for the adoption of the 1994 Convention on Nuclear Safety and other instruments that focused on emergency response and assistance, it also provided impetus to further improve the nuclear liability regimes. In 1988, the Joint Protocol Relating to the Application of the Vienna Convention and the Paris Convention was adopted under the joint auspices of the OECD/NEA and IAEA. The Joint Protocol, which came into force in 1992, provided a bridge between the two conventions and thereby broadened the geographic scope of the conventions' coverage. The goal was to extend the rights under one regime to victims of an accident in the territory of states party to the other, if both states were also contracting parties to the 1988 Joint Protocol.

In 1997, negotiations were also completed on two instruments under IAEA auspices: the Protocol to Amend the Vienna Convention on Civil Liability for Nuclear Damage (1997 Protocol to the Vienna Convention) and a new instrument, the Convention on Supplementary Compensation for Nuclear Damage (CSC). The CSC is open to states party to the Paris Convention or the Vienna Convention, in which case such states would abide by two conventions: either the Paris Convention or the Vienna Convention on the one hand, and the CSC on the other hand. The United States, however, has ratified only the CSC as it includes a "grandfather" clause that takes into account a particularity in the US Price Anderson Act on nuclear liability adopted in 1957, which provides for economic channelling of liability rather than the legal channelling provided under the Paris or Vienna regimes. Similar to the Brussels Supplementary Convention, the CSC provides a supplemental fund to be provided by its contracting parties so as to increase the amount of available compensation.

These developments were followed by negotiations concluded in 2004, when member states of the Paris Convention adopted revisions to modernise the Paris Convention and the Brussels Supplementary Convention. The revisions provide a considerable increase in the amount of compensation available to victims of a nuclear accident and expand the scope of application of the Paris Convention by broadening the range of compensation for damage as well as the geographical range. Of the modernised liability conventions, only the 1997 Protocol to the Vienna Convention has come into force.

Common principles reflected in the international nuclear liability conventions

All three conventions contain the same basic principles, which have largely been transposed into national legislation. Even for states that are not yet party to a convention but have nuclear liability legislation, the principles of the conventions are generally reflected in their national legislation. These principles include strict liability, exclusive liability (legal channelling), limitation on liability in amount, compulsory financial security, limitation of liability in time and unity of jurisdiction, as well as applicable law and non-discrimination.

Under conventions, states may also establish lower limits of liability for lower risk activities, depending on the nature of the nuclear installation (for example, research reactors) or the nuclear substances involved (such as during transportation).

Challenges in achieving a global nuclear liability regime

Despite the general consensus on liability principles and the steps to modernise the conventions and draw new states into the international regime, progress towards a more global regime has been uneven. For example, the 2004 protocols revising the Paris and Brussels Conventions have yet to enter into force. This delay is in part due to a 2004 EU Council Decision requiring European member states that are contracting parties to the Paris Convention to simultaneously deposit their instruments of ratification. The 1997 Protocol to the Vienna Convention, although in force, has only 11 contracting parties (and not all of them are nuclear power generating states). Although the United States has ratified the CSC, the convention has been ratified by only a few other states and has yet to enter into force for want of sufficient contracting parties totalling the required installed nuclear capacity.

More importantly, a number of states with significant nuclear energy capacity are not part of any regime: Canada, China, Japan, Korea and India (Canada and India have signed but not ratified the CSC). For the most part, these states have national legislation that generally conforms to the international norms, although India's legislation remains controversial because it is viewed by many as incompatible with the channelling principle under the international conventions. There are also potential new entrants into nuclear power generation that have not yet joined a convention. Overall, about 58% of reactors in operation or under construction worldwide are not currently subject to any regime in force.

The Japanese experience

Japan's experience in handling compensation issues in the wake of the Fukushima Daiichi nuclear power plant (NPP) accident has attracted a great deal of interest. Since 1961, Japan has had a national nuclear liability regime in force that reflects international principles. The Japanese government undertook extraordinary efforts to implement its national nuclear liability scheme in order to address the extensive demands to compensate damages attributable to the accident. The government moved purposefully to set up an independent committee of experts (the Dispute Reconciliation Committee for Nuclear Damage Compensation) as accorded under its legislation. This Committee adopted guidelines to determine the scope of the nuclear damage to be compensated. It also established the Nuclear Damage Compensation Facilitation Corporation, owned 50/50 by the state and Japanese nuclear operators, as part of the mechanism for providing governmental financial assistance under the applicable law to fund compensation when it exceeds the operator's financial security. Japan's experience has demonstrated the effectiveness of the basic principles in the international regime and the need to establish a clear and comprehensive legal framework in order to compensate victims of a nuclear accident. This framework must also allow the government and the operator to quickly adapt to the specific circumstances arising from an accident.

Recent developments

The IAEA Action Plan on Nuclear Safety, endorsed by the General Conference in September 2011, calls on member states to work towards establishing a global liability regime. Such a regime would address the concerns of all states that might be affected by an accident with a view to providing appropriate compensation for damages suffered. States are also encouraged to consider joining one of the international nuclear liability instruments. The International Expert Group on Nuclear Liability (INLEX) established in 2003 was tasked in the Action Plan with making recommendations in order to help achieve this goal.

In 2012, INLEX issued a set of recommendations to facilitate progress towards a global nuclear liability regime and encouraged nuclear and non-nuclear states to consider joining one or more of the relevant international instruments. It has also asked that states reflect these international principles in their national legislation in order to establish a more universal system and has endorsed progress towards the adoption of the modernised features of the regimes. These include setting higher minimum liability amounts and ensuring coverage of latent injuries, as well as taking steps to secure financial remuneration or provide compensation where an accident may exceed the capacity of the required financial security. Such steps can lead to greater harmonisation in the compensation regimes for victims of an accident. Moreover, states are urged to ensure that claims arising from a nuclear accident are dealt with in a single forum, in a prompt, equitable and non discriminatory manner with minimal litigation. The INLEX recommendations do not express a preference for one of the existing nuclear liability regimes, but they recognise that the Joint Protocol between the Vienna and Paris Conventions establishes treaty relations among states party to those regimes, while the CSC provides for treaty relations among states regardless of whether they are party to the Paris or Vienna Conventions.

Although it will take some time to achieve a global liability regime, there are signs of progress. Canada, for example, recently signed the CSC (5 December 2013) and intends to ratify the regime as part of its efforts to update its national legislation on nuclear liability. Potential new entrants into nuclear power generation (such as Saudi Arabia, Kazakhstan and the United Arab Emirates) are acceding to one or the other of the international regimes. The contracting parties to the Paris Convention that are affected by the 2004 EU Council Decision (i.e. 12 out of 16 contracting parties) are aiming to accomplish the necessary steps to allow the entry into force of the 2004 protocols in the near future.

In addition, the United States and France issued a Joint Statement on Liability for Nuclear Damage in August 2013 agreeing to "promote efforts to achieve a global nuclear liability regime based on treaty relations among France, the United States and other countries that might be affected by a nuclear accident", to "coordinate their actions in encouraging adherence to the enhanced international nuclear liability instruments" and to "urge countries to adopt national laws that incorporate the nuclear liability principles and recent enhancements to those principles", as well as certain best practices.

This joint statement is significant because it reflects a common stance on the importance of further progress in achieving a global regime from two major nuclear power generating states. Although "France views a system based on the revised Paris Convention (together with the revised Brussels Convention Supplementary to the Paris Convention), the revised Vienna Convention and the Joint Protocol as providing an appropriate basis for the compensation for nuclear damage", and "the United States views the CSC as the only existing nuclear liability instrument to which the United States can adhere", both countries acknowledge that "the CSC was designed to provide a basis for establishing a global nuclear liability regime by allowing adherence by countries that adhere to the Paris Convention or the Vienna Convention, including those countries that are linked by the Joint Protocol, and by countries with national laws that fully comply with the nuclear liability principles embodied in the Annex to the CSC." The joint statement underscores the commitment of the two countries to work towards a global liability regime, believing that "such actions by them and other countries will ensure adequate and equitable compensation for victims of nuclear damage arising from a nuclear accident, and will create the worldwide trust necessary for the development of nuclear energy and associated industrial activities."

Finally, the declaration issued by the G20 in September 2013 after its meeting in St. Petersburg encouraged "multilateral cooperation towards achieving a global nuclear liability regime."

Nuclear power generating countries

Status of ratification of international nuclear liability conventions (as of 2 December 2013)

Country	Plants: operating + under construction (UC)*	Conventions ratified	Country	Plants: operating + under construction (UC)*	Conventions ratified
Argentina	2 + 1 UC	VC; RVC; CSC	Mexico	2	VC
Armenia	1	VC	Netherlands	1	PC; BSC; JP; RPC; RBSC
Belarus	1 UC	VC, RVC	Pakistan	3 + 2 UC	
Belgium	7	PC; BSC; RPC; RBSC	Romania	2	VC; JP; RVC; CSC
Brazil	2 + 1 UC	VC	Russia	33 + 10 UC	VC
Bulgaria	2	VC; JP	Slovak Republic	4 + 2 UC	VC; JP
Canada	19	[signed CSC]	Slovenia	1	PC; BSC; JP; RPC; RBSC
China	18 + 30 UC		South Africa	2	
Czech Republic	6	VC; JP	Spain	8	PC; BSC; RPC; RBSC
Finland	4 + 1 UC	PC; BSC; JP; RPC; RBSC	Sweden	10	PC; BSC; JP; RPC; RBSC
France	58 + 1 UC	PC; BSC; RPC; RBSC	Switzerland**	5	PC; BSC; RPC; RBSC
Germany	9	PC; BSC; JP; RPC; RBSC	Chinese Taipei	6 + 2 UC	
Hungary	4	VC; JP	Ukraine	15 + 2 UC	VC; JP
India	21 + 6 UC	[signed CSC]	United Arab Emirates	2 UC	RVC; JP
Iran	1		United Kingdom	16	PC; BSC; RPC; RBSC
Japan	50 + 2 UC		United States	100 + 5 UC	CSC
Korea	23 + 5 UC				

PC: 1960 Paris Convention on Third Party Liability in the Field of Nuclear Energy
BSC: 1963 Brussels Convention Supplementary to the Paris Convention
RPC: 2004 Protocol to amend the Paris Convention (Revised Paris Convention – *not in force*).
RBSC: 2004 Protocol to amend the Brussels Supplementary Convention (*not in force*).
VC: 1963 Vienna Convention on Civil Liability for Nuclear Damage (Vienna Convention).
RVC: 1997 Protocol to Amend the Vienna Convention (Revised Vienna Convention).
JP: 1988 Joint Protocol Relating to the Application of the Vienna and Paris Conventions
CSC: 1997 Convention on Supplementary Compensation (*not in force*).

* *Source:* IAEA Power Reactor Information System (PRIS), www.iaea.org/pris/ (as of 2 December 2013).
** Switzerland deposited its instrument of ratification of the PC and BSC as amended by the 2004 Protocols; the conventions will only enter into force for Switzerland upon the entry into force of the 2004 Protocols.

The path to a global nuclear liability regime may not be an easy one, but even modest progress towards the adoption of internationally accepted principles in national legislation and further progress towards bringing the modernised regimes into force while enlarging their geographical scope through new accessions will have a salutary effect. Substantial nuclear generating capacity continues to operate worldwide and new nuclear power plant construction is underway in a number of countries. In this context, continued efforts to harmonise the international liability regimes and to broaden participation in them remain worthy objectives.

Further reading

For more information on the 1994 Convention on Nuclear Safety see www-ns.iaea.org/conventions/nuclear-safety.asp.

Texts of international conventions, in their original and modified forms, can be accessed through the NEA website at www.oecd-nea.org/law/legal-documents.html#agreements. Instruments under IAEA auspices can be accessed at http://ola.iaea.org/ola/treaties/multi.html.

For more information on the 2004 EU Council Decision see http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2004:097:0053:0054:EN:PDF.

The NEA report entitled *Japan's Compensation System for Nuclear Damage: As related to the TEPCO Fukushima Daiichi Nuclear Accident* (2012) is available at www.oecd-nea.org/law/fukushima/7089-fukushima-compensation-system-pp.pdf.

The IAEA Action Plan on Nuclear Safety (2011) is available at www-ns.iaea.org/actionplan/.

INLEX Recommendations (2012) are available at http://ola.iaea.org/ola/documents/ActionPlan.pdf.

The US-France Joint Statement on Liability for Nuclear Damage (2013) is available at http://energy.gov/sites/prod/files/2013/08/f2/Joint%20Statement%20Signed_0.pdf (English version); http://www.developpement-durable.gouv.fr/IMG/pdf/DECLARATION_FR_USA.pdf (French version).

The G20 Leaders' Declaration is available at www.g20.org/news/20130906/782776427.html.

State of the art in radiological protection science

by T. Lazo*

Scientific understanding of radiological protection issues continues to improve, and a number of new research developments have prompted renewed work at the NEA on the subject. This includes more in-depth examinations and an update of the NEA Committee on Radiation Protection and Public Health (CRPPH) publications on *Developments in Radiation Health Science and their Impact on Radiation Protection* (NEA, 1998) and *Scientific Issues and Emerging Challenges for Radiation Protection* (NEA, 2007). At the time, the 1998 report summarised what the most advanced science could reveal about radiological risks and addressed, in particular, risks at levels of exposure that people and workers experience routinely, below 100 mSv a year. It also presented the most up-to-date results in radiation biology, cell biology, radiation epidemiology, disease causality, and genetic effects, and concluded that much is known about radiological protection science but much remains unknown. This article looks at some of these issues, discusses advances in the state of the art of radiological protection science since the 1998 and 2007 publications, and reviews some future challenges and the way forward.

What is known about radiological protection science

It is assumed that the chief stochastic effect of ionising radiation at relatively low doses is its capacity to induce cancers. However, ionising radiation at the dose levels of interest to radiological protection (under 100 mSv) is considered to be a weak carcinogen. At doses in excess of 200 mSv, there is firm evidence of radiation-induced cancer risk in humans. In addition, no positive biological effects, such as the immune system developing a protective response after being exposed to acute doses of ionising radiation(a hormesis-like effect), have been observed in humans. While different tissues and organs can exhibit a wide range of sensitivity to radiation-induced cancers, at high doses exceeding 500 mGy, deterministic effects such as erythema, cataracts or infertility are known to occur.

It has been shown that radiation-induced, solid cancers have a long latency period, generally greater than ten years, whereas leukaemia and thyroid cancer in children can appear as soon as a few years after exposure. Various host factors (such as age at exposure, time since exposure, gender, genetic predisposition) and environmental factors (such as cigarette smoking or infectious agents) can also influence cancer risk at exposure levels where radiation effects have been observed. Cellular repair mechanisms are known to exist, but mis-repair and primary molecular and cellular events (residual DNA damage) can occur. The yield of this DNA damage sometimes depends linearly on absorbed energy, but many multi-step biological processes are known to be non-linear.

Epidemiological studies alone cannot provide definitive evidence of the existence or non-existence of carcinogenic effects due to either single low dose or continuing low dose-rate radiation. At the same time, the lack of epidemiological evidence for the existence of low dose and low dose-rate radiation-induced effects is not proof that such effects do not exist. Epidemiological studies have not detected any hereditary effects of radiation in humans with a statistically significant degree of confidence, but they have shown that the developing embryo/foetus is more sensitive to exposure to ionising radiation than children or adults.

Continuing uncertainties

The role of host factors – which could include age at exposure, time since exposure, gender, genetic predisposition and environmental factors such as smoking or ingesting infectious agents – as determinants of radiation risk remain unclear. Moreover, the shape of the dose-effect relationship (whether it be linear, quadratic or threshold) at low doses and dose rates for radiation carcinogenesis in humans is poorly understood. For the same absorbed dose, different types of radiation (alpha, beta, gamma, neutron) demonstrate different levels of risk of inducing biological effects (end-point damage), and the biological basis for this in humans at low doses and low dose rates continues to be a subject of debate in the scientific community.

* *Dr. Ted Lazo (edward.lazo@oecd.org) is Principal Administrator in the NEA Radiological Protection and Radioactive Waste Management Division.*

It should be said that the mechanism of carcinogenesis, whether induced by radiation or by other agents, is believed to be a multi-step process that cannot be fully understood. The origin of cancer is hypothesised to be the result of mutational events to critical genetic loci, and of other factors such as hormone status, age or immune function. The effects of radiation in the different steps of carcinogenesis are at present uncertain. Although damage to DNA is assumed to be a key step in radiation carcinogenesis, it is not known which critical lesions in DNA are responsible for gene or point mutations and chromosomal aberrations leading to cancer. Accordingly, the cause of an individual cancer cannot be specifically tied to a given initiating event, such as radiation exposure. For example, it is not clear how many tumourogenic cells are necessary to produce a cancer *in vivo* and why organs and tissues vary in radiosensitivity. In other words, there is a lack of understanding about sensitivity to radiation and whether it can be predicted from the spontaneous incidence of most cancers. No method currently exists to measure an individual's radiation sensitivity.

Although biological and chemical repair processes of radiation damage are known to occur in cells, the influence of repair processes on human radiogenic risk at low dose and low dose rate is also not fully understood. This contributes to the uncertainty in dose and dose-rate correction factors used to estimate radiogenic risk. In addition, there is no evidence to indicate whether an adaptive response, observed in single cells under certain conditions, influences radiogenic risks in humans or whether there are any positive biological health effects of low doses of radiation in humans (hormesis).

Emerging challenges and areas for further study

The 1998 report on radiological protection science successfully informed the NEA and the broader radiological protection community of the state of the art at that time, but work in the field continued to advance. On the occasion of the 50th anniversary of the creation of the CRPPH, an update of this latter report was published under the title *Scientific Issues and Emerging Challenges for Radiation Protection: Report of the Expert Group on the Implications of Radiation Protection Science* (NEA, 2007).

This report broadly confirmed the conclusions from the previous report, particularly in terms of what is known, but it offered new information as a result of important radiation and cell biology studies that had been performed since 1998. The new report addressed several areas of scientific research and their implications, including non-targeted and delayed effects, individual sensitivity, epidemiology and other challenges to the unified system of dose limitation. It also looked at several areas of radiological protection application that could present significant emerging challenges such as medical protection during medical exposure, radiological protection of the environment, challenges to the current paradigm, health impacts of accidents and malevolent radiological acts, and possible areas of new international collaborative research. As a result of the above work, the Committee drew several conclusions regarding emerging challenges, which are described below.

Non-targeted effects, adequacy of the dose concept

While the evidence is not yet conclusive, current and further radiation biological research, in areas such as non-targeted effects, adaptive response and dose response relationships, may lead to the formulation of a new radiation biology paradigm combining both classical (targeted or direct) and non-targeted (indirect) radiation effects. This paradigm could have significant implications in terms of how radiological risk is assessed. For example, a new scientific approach, or a significant modification to the current approach, to coherent, holistic risk assessment (for all types of radiation and all types of radiation exposure situations) may need to be developed. Such a change could also have a significant effect on current approaches to risk management.

Radiosensitivity

Major advances in cellular and molecular biology are providing a basis for building a more complete understanding of variations in radiosensitivity within populations. Today, elevated radiosensitivity to ionising radiation exposure is identifiable only for high levels of exposure. In the future, it is likely that individuals at increased risk of radiogenic cancer may be identified through simple, genetic screening. Such developments could have important implications for the current system of dose limitation and radiological protection, particularly for workers and for medical patients. These findings suggest, in particular, a need to define the radiosensitivity of individuals, a need to investigate whether protection would be better achieved through a single dose limit or dose limits customised to groups with differing radiosensitivity and a need to explore the ethical issues raised by genetic screening.

Epidemiology

Since radiation is only a weak carcinogen, large, long-term epidemiological studies are key elements in the assessment of risks. Funding of such studies should be sustainable over time so as to allow for the accurate and complete collection of relevant data. Examples of such studies include the Lifespan Study of Japanese a-bomb survivors, the study of nuclear workers, radon studies or studies of chronically exposed populations. Molecular epidemiology will be needed to address the issue of low-dose risks since classical epidemiology will clearly not solve this issue.

Medical exposure

Studies of the medical exposure of patients and medical workers have indicated that there has been a steady increase in doses. These increases support the need for better dose information, which would mean machines that are better equipped to measure and display patient exposures. It may also require the implementation of a new approach, perhaps regulatory, to ensure the optimisation of exposure. A regular interface between medical practices and other areas should be encouraged in order to make the best use of available knowledge and data.

Health impacts of an accident or wide-scale exposure

Maintaining public confidence is a critical issue when dealing with the consequences of a nuclear accident. People will likely seek information and guidance from healthcare providers, who will play a key role in determining how the general public will respond to the event. Information provided by organisations should not only address the consequences of high exposure but should also deal with the vast majority of people who will have experienced low or no exposure. A well-organised, effective medical response system needs to be in place and maintained in order to instil hope and confidence, reduce fear and anxiety, and support the continuity of basic community functions.

Radiological protection of the environment

The development of radiological protection principles for the environment is a new challenge and should not take place in isolation from other broader principles and related conceptual approaches that either exist or are under development. Such environmental principles will need to take into account existing legislative and regulatory approaches in order to have a practical utility.

The way forward

The NEA has continued to follow the status of radiological protection science, and given wide interest in the subject, is examining the current scientific understanding of the potential risks resulting from radiological exposure of less than 100 mSv. The Expert Group on Radiological Protection Science (EGRPS) was created in May 2013 to draft a report summarising the state of the art in radiological protection science, beginning with the analysis of the 2007 report by the Expert Group on the Implications of Radiological Protection Science, Scientific Issues and Emerging Challenges for Radiological Protection. To do this, the EGRPS will:

- survey relevant scientific materials, and assess the possible implications of short-term scientific results likely to emerge from ongoing studies;
- take into account ongoing work by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), the Multidisciplinary European Low Dose Initiative (MELODI), the United States Department of Energy (US DOE) low dose research and other relevant work;
- co-ordinate the development of the report with the Expert Group on Radiological Protection Aspects of the Fukushima Accident (EGRPF) in the context of its relevance to the management of Fukushima consequences.

The first meeting of the EGRPS took place on 12-13 September 2013, during which the basic structure of the report was agreed. Starting from the conclusions of the 2007 report, which the group felt were still broadly valid, the new work will include a discussion of the science of radiological protection, including risks of low dose and dose rates, non-cancer risks, individual sensitivity and social science aspects. It will also look at application aspects such as the system of radiological protection, impacts of nuclear accidents and malevolent acts, medical radiological protection issues, existing exposure situations, and environmental and radio-ecological radiology. This new report should be finalised by the end of 2014 and published after final approval in May 2015.

References

NEA (2007), *Scientific Issues and Emerging Challenges for Radiological Protection: Report of the Expert Group on the Implications of Radiological Protection Science*, OECD, Paris.

NEA (1998), *Developments in Radiation Health Science and their Impact on Radiation Protection*, OECD, Paris.

The economics of the back end of the nuclear fuel cycle

by M.E. Urso, A. Lokhov and R. Cameron*

Spent nuclear fuel and high-level waste from the fuel cycle of commercial nuclear power plants represent a small proportion of the radioactive waste produced globally by various industries (including medicine, agriculture and research), but they account for the greatest radioactivity content and longevity. While technologies are well developed and widely employed for the treatment and disposal of the much larger volumes of less radioactive low-level and short-lived intermediate-level waste, no final disposal facilities have yet been fully implemented for spent nuclear fuel (SNF) and high-level waste (HLW). A lack of experience in the construction and operation of deep geological repositories, combined with the extensive periods required for the implementation of back-end solutions, have thus contributed to growing uncertainties about the costs associated with managing SNF and HLW. The issue has become a central challenge for the nuclear industry and a matter of public concern and debate.

Many useful reports have been produced over the years, describing national waste management approaches or making suggestions on how to analyse disposal costs. Of particular note is the extensive work being carried out by the NEA Radioactive Waste Management Committee and its working parties. In recent years, a number of studies have also been undertaken in NEA member countries, examining the costs of the disposal of spent fuel and high-level waste. However, these national studies are linked to specific policy choices, practices and regulations, with the outcomes varying significantly across countries and thus not being directly comparable.

Since no recent comprehensive overview of the state of knowledge on the costs of back-end solutions across NEA countries was available, a new analysis was undertaken to gain a more in-depth understanding of economic issues and methodologies for the management of SNF and HLW from commercial power reactors. Based on this analysis, a report entitled *The Economics of the Back End of the Nuclear Fuel Cycle* was published in October 2013. Using official data supplied by national authorities, a descriptive overview was developed of general principles and frameworks for the long-term management of SNF, current national policies and practices, as well as available and prospective technology options, including:

- Direct disposal, where the fuel is used once and then regarded as waste for disposal.
- Partial recycling, where the spent fuel is reprocessed to recover unused uranium and plutonium for recycling in light water reactors (LWRs). Once irradiated, the recycled fuel bundles can be either stored (with the perspective of their reprocessing and recycling in future fast reactors – FRs) or disposed of after encapsulation.
- Advanced systems and fuel cycle concepts for the longer-term future, studied theoretically or on a pilot scale, with the dual objective of reducing the mass and radioactivity of waste destined to final disposal and optimising the use of natural resources.

In addition, a cost analysis of these options was conducted and estimates developed using a simplified economic model.

Both industrial fuel cycle options, direct disposal or partial recycling, as well as any prospective advanced option, will ultimately require the final disposal of HLW or SNF (treated as HLW in the once-through fuel cycle). There is general agreement that deep geological repositories (DGRs) offer the best solution in this regard. The major difference in the DGR needed for the different back-end options will be in relative size. Significant advances have occurred in several national programmes in the deployment of DGRs for HLW and SNF disposal. Conditions favouring progress include the maturity of the national industry, the long-term continuity in policy positions and a high degree of emphasis on community partnerships in the implementation of strategies. In some countries, stepwise approaches that foster partnerships with potential host communities have resulted in improved public acceptance.

Funding and costing

With expenditure spread over extended periods and much of these occurring long after power production and income from electricity generation have stopped, expenses for disposal constitute future financial liabilities. It is therefore important that

* *Dr. Maria-Elena Urso (mariaelena.urso@oecd.org) and Dr. Alexey Lokhov (alexey.lokhov@oecd.org) are administrators in the Nuclear Development Division. Dr. Ron Cameron (ron.cameron@oecd.org) is Head of the NEA Nuclear Development Division.*

the appropriate financial arrangements are established and that the accrual of adequate and available funds for the implementation of the selected back-end strategy is carefully pursued. Assessments of the costs for managing spent fuel and radioactive waste from the civil fuel cycle are essential to establish the size of these liabilities and guarantee their financing. Cost estimates for future facilities, including repositories, entail many uncertainties, which will only be reduced as experience is gained in implementing the necessary infrastructure. Naturally, cost uncertainties related to the full recycling option are greatest, since this strategy is furthest from commercialisation.

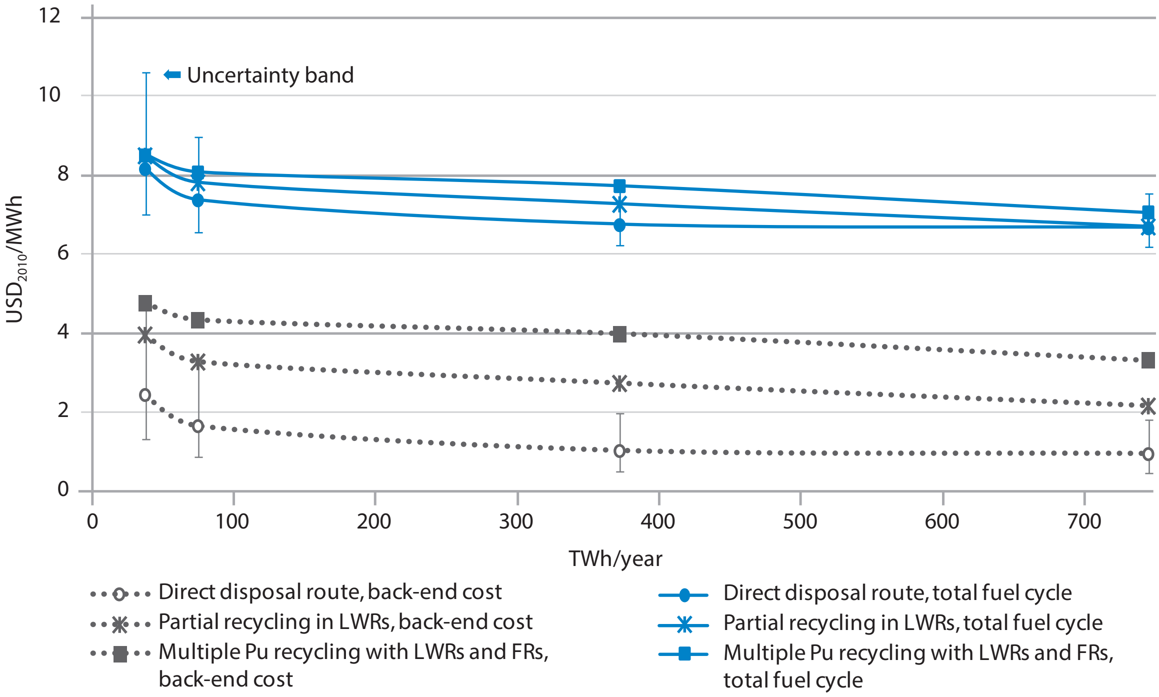
Most countries perform assessments of the costs for SNF/HLW management, encompassing the different stages of the back end (e.g. interim storage, encapsulation, transport), to define and verify the status of the financial provisions required to meet such costs. To verify continued fund sufficiency and to address changes, cost estimates and funding requirements are generally updated at regular intervals, taking into account new technical knowledge and actual fund developments. Furthermore, to secure the availability of funds, ring-fencing is required so that resources accrued are only used for the intended purpose. Segregation of funds is pursued by most but not all countries in their national legislations. Some funding systems also contain further inbuilt features to minimise risks; for instance, securities and guarantees may be requested from nuclear operators to protect against unforeseen developments.

Theoretical cost analysis for selected SNF management strategies

A direct quantitative comparison of SNF management costs in different countries was not considered feasible in the study, owing to differences across individual assessments. These variations are attributable to disparate factors, including types and quantities of SNF/HLW to be treated (as well as other radioactive waste, which sometimes is to be disposed of in the same DGR); specificities of national regulatory and legal frameworks; the different technologies involved; as well as the different itemisation and boundary conditions used in the cost estimates. Thus, rather than embarking on direct comparisons of national cost assessments, simulations of three generic, theoretical cases for idealised systems unrelated to any particular country were performed based on the cost information provided.

The analysis includes direct disposal of spent nuclear fuel, partial recycling in light water reactors and multiple plutonium recycling in a symbiotic configuration of light water and fast reactors. Calculations were performed for different discount rates to determine major cost drivers and, through sensitivity analyses, to highlight the impacts of key economic parameters as well as significant variations and uncertainties. Member countries provided essential input data on the capital, operation and maintenance costs of different back-end facilities. The main outputs include the total levelised fuel cycle cost and its composition, with a particular focus on the back-end components. It should be

Total fuel cycle and back-end levelised costs for different reactor fleets and strategies, 3% discount rate*



* Uncertainty bands are only plotted for the direct disposal case. Similar bands apply to the other options.

Source : *The Economics of the Back End of the Nuclear Fuel Cycle* (2013).

noted, however, that the assessment conducted cannot be simply transposed into a specific national context, as this would require a more detailed and adapted cost analysis. One example of the fuel cycle cost breakdown for the three different strategies is reported in the above figure for a fleet generating 75TWh/y at a 3% discount rate.

The results of this theoretical analysis show that costs calculated for the open fuel cycle option are lower than for the other idealised options assessed. Differences among the three options in the total fuel cycle component of the levelised costs of electricity are, however, within the uncertainty bands. For the recycling options, additional costs from reprocessing are partially offset by the savings on fuel costs at the front end. Differences are more noticeable if the back-end component of the fuel cycle cost is considered in isolation, since the offsetting effects are not taken into account.

It is important to note that, for all options assessed, the fuel cycle cost component associated with the management of SNF represents a relatively small fraction of the total levelised costs of electricity generation. However, these differences could translate into large absolute costs depending on the size of the nuclear programme and the period of electricity generation.

Sensitivity analyses show that in all three strategies, the total fuel cycle cost is most sensitive to the cost of fresh UOX fuel, which encompasses the price of natural uranium and enrichment services. Other influential factors are interim storage and deep geological repository costs in the direct disposal strategy (although a 50% increase in deep geological repository costs, which in absolute terms would be a large sum for larger nuclear power programmes, would give rise to only a few percentage points increase in the total fuel cycle costs), the cost of reprocessing in both recycling strategies and the fast reactor cost premium[1] for the multiple plutonium recycling option.

Advanced spent nuclear fuel options would be economically advantageous only if UOX fuel prices were significantly higher than current values and if fast reactor cost premiums were low.

In addition to economic considerations, the basis for any informed socio-political decisions in this area has to be broadened to a comprehensive evaluation of qualitative factors. Different qualitative factors that come into place in the selection of back-end strategies encompass political issues, like security of supply and non-proliferation; issues of an administrative, governmental infrastructural or social nature, like regulation, safety, public attitudes and transport; and more technical aspects, like environmental protection, retrievability, waste production and future technological developments.

The influence of these non-quantitative factors is also discussed in *The Economics of the Back End of the Nuclear Fuel Cycle*. Their relative importance is intricately linked to specific national contexts and may shift over time, with different factors potentially outweighing others in different countries.

On the basis of the analyses and information provided, it was concluded that while there may be reasons to extend the interim storage of SNF (a necessary step in the back end of any fuel cycle), these should not prevent governments from maintaining vigorous efforts towards the establishment of deep geological repositories, thereby addressing legitimate public expectations and fulfilling the "intergenerational equity" principle. In this process, and in the establishment and implementation of the SNF management strategy, public involvement is considered vital.

Governments should also continue to be vigilant in ensuring that the funding systems adopted are stable and robust and that the financial resources accrued will be adequate. Essential features are ring-fencing of funds and regular and frequent reviews to allow for the integration of newly accrued knowledge and developments, as well as swift consideration of shortfalls that may emerge.

For countries that are committed to the ongoing use or development of nuclear energy, comparisons of the costs of different strategies for managing the back end should be drawn on the basis of the full fuel cycle cost. For countries that are phasing out or have already exited nuclear power, a direct back-end cost comparison may be more appropriate. In all cases, assessments made for total or partial fuel cycle cost comparisons should be transparent about the assumptions and scope.

In any decision-making process on SNF management strategies, a multi-criteria approach should be adopted at the national level that extends quantitative economic considerations to include qualitative factors of important (or even determining) influence.

Given their potential for enhancing the long-term sustainability of nuclear power, R&D on advanced nuclear systems should be supported by governments, especially where issues of long-term fuel supply and reduction of waste volumes are particularly important. Further engineering and cost analyses would be valuable to reduce the uncertainties in the costs of their implementation.

International co-operation and sharing of experience for safe, reliable and economic implementation of back-end strategies should continue and be promoted, including the sharing of fuel cycle facilities and infrastructure, which would benefit in particular countries with small nuclear programmes.

Note

1. Fast reactors are expected to be more expensive than LWRs, and thus a special cost premium for their construction and operation is introduced. This extra cost is attributed to the back-end component since, in a multiple Pu recycling with LWRs and FRs strategy, the fast reactors are considered as a means for managing the SNF.

GIF's role in developing the nuclear technologies of the future

by J. Kelly, T. Dujardin and H. Paillère*

The development of early Generation I and Generation II nuclear technologies was often the result of either national research programmes, implemented by national industries, or technology transfers from pioneering companies in the United States such as Westinghouse, General Electric or Combustion Engineering. The development of Generation III reactors in the 1980s and 1990s benefitted from a higher degree of international collaboration among industrial partners, with for example the advanced boiling water reactor (ABWR) being developed by General Electric, Hitachi and Toshiba, or the European pressure reactor (EPR) developed by Framatome (now part of Areva) and Siemens. Projects undertaken by research organisations working together on topics such as severe accident management also contributed to these advancements. In the case of Generation IV technologies, an even higher degree of co-operation has been established among governments through the Generation IV International Forum (GIF).

GIF was set up in the early 2000s, at the initiative of the US Department of Energy. The role of GIF is to advance research and development in the design of nuclear energy systems of the future. These systems include fast neutron reactors cooled by sodium (SFR), lead (LFR) or helium gas (GFR); very-high-temperature gas-cooled reactors (VHTR); supercritical-water-cooled reactors (SCWR) and molten salt reactors (MSR). One of the more immediate benefits of this international collaboration is the sharing of research outcomes among the signatories of each system agreement as well as a more general exchange of information; but the conceptual designs under development also benefit from the discussions taking place among scientists and engineers from different backgrounds and experience.

Enhanced safety is one of the major design criteria for Generation IV reactors, made all the more important by the recent accident at the Fukushima Daiichi nuclear power plant. It is for this reason that GIF has set up a special task force to develop "safety design criteria" – in essence, design-independent safety requirements or options proposed by technology developers. GIF is now looking for feedback from regulatory bodies to discuss the applicability in future licensing activities of the first version of criteria developed for the sodium-cooled fast reactor technology. Improved economics is also a major area of interest to GIF, and a special working group was therefore set up very early to develop economic assessment methods and tools.

With a community of over 300 R&D managers from 8 countries (Canada, China, France, Japan, Korea, Russia, Switzerland and the United States) and the EU directly involved in GIF management activities – as well as at least ten times this number of engineers and scientists working on GIF-related R&D projects – the forum is well equipped to face the technical challenges involved in developing the next generation of reactors. However, technology development alone will not suffice in guaranteeing the success of the endeavour. Dr. John Kelly of the US Department of Energy and Mr. Yutaka Sagayama of the Japan Atomic Energy Agency (JAEA), the new Chair and former Chair respectively of the GIF governing body (the "Policy Group"), have both supported enhancing the level of collaboration within GIF and with other international organisations and initiatives as a key to the success of this endeavour.

GIF is also looking at working more closely with industry, through improved information exchange with the Senior Industrial Advisory Panel, and at communicating better with the public and particularly with younger generations. This will involve providing factual information on the goals and achievements of GIF and supplying educational material to assist researchers interested in Generation IV systems. Fulfilling these objectives will demonstrate to governments supporting the initiative that GIF has been successful in managing resources efficiently and making technical progress. This is a particularly important point since it is governments and industry that will be gathering the outcomes of GIF research activities and then engaging in more resource-intensive activities such as prototype development and testing.

* *Dr. John Kelly, Chair of the Generation IV International Forum, is Deputy Assistant Secretary for Nuclear Reactor Technologies at the US Department of Energy. Dr. Thierry Dujardin (thierry.dujardin@oecd.org) is NEA Acting Deputy Director-General and Deputy Director for Science and Development, and Dr. Henri Paillère (henri.paillere@oecd.org) is a nuclear energy analyst in the NEA Nuclear Development Division.*

System arrangements (SA) and Memoranda of Understanding (MoU)

System		Signatories
GFR (gas-cooled fast reactor)	SA	Euratom, France, Japan, Switzerland (2006)
SCWR (supercritical-water-cooled reactor)	SA	Canada, Euratom (2006), Japan (2007), Russia (2011)
SFR (sodium-cooled fast reactor)	SA	Euratom, France, Japan, Korea, United States (2006), China (2008), Russia (2010)
VHTR (very-high-temperature reactor)	SA	Euratom, France, Japan, Korea, Switzerland, United States (2006), China (2008)
LFR (lead-cooled fast reactor)	MoU	Euratom, Japan (2010), Russia (2011)
MSR (molten salt reactor)	MoU	Euratom, France (2010), Russia (2013)

Project arrangements (PA)

System	Status	Signatories
GFR Conceptual Design and Safety	Effective since December 2009	Euratom, France, Switzerland
SCWR Thermal-hydraulics and Safety	Effective since October 2009	Canada, Euratom, Japan
SCWR Materials and Chemistry	Effective since December 2010	Canada, Euratom, Japan
SFR Advanced Fuel	Effective since March 2007	Euratom, France, Japan, Korea, United States
SFR Global Actinide Cycle International Demonstration	Effective since September 2007	France, Japan, United States
SFR Component Design and BOP	Effective since October 2007	France, Japan, Korea, United States
SFR Safety and Operation	Effective since June 2009. New PA signed in November 2012 with 3 new partners: CIAE (China), JRC (Euratom) and Rosatom (Russia)	China, Euratom, France, Japan, Korea, Russia, United States
SFR System Integration and Assessment	Signature process ongoing	China, Euratom, France, Japan, Korea, Russia, United States
VHTR Materials	Effective since April 2010	Euratom, France, Japan, Korea, Switzerland, United States
VHTR Fuel and Fuel Cycle	Effective since January 2008	Euratom, France, Japan, Korea, United States
VHTR Hydrogen Production	Effective since March 2008	Canada, Euratom, France, Japan, Korea, United States

GIF is also in the process of updating its Technology Roadmap. The update of the 2002 version of the roadmap, to be published shortly, will integrate technical progress made to date and take into account national initiatives aimed at accelerating the demonstration phase of several technologies. In other words, a clearer view of the status of developments in Generation IV technologies will now be available in terms of viability (testing of basic concepts and resolution of technical show-stoppers) and performance (testing of processes and materials at the engineering scale). According to this updated roadmap, liquid metal-cooled fast neutron reactors such as the LFR and SFR should be ready for demonstration in the early 2020s. Industrial deployment of Generation IV reactors could start a decade later, depending on market conditions and vendor involvement to match the needs of utilities.

More than a decade after the establishment of GIF, the development of the next generation of nuclear technologies is making good progress within the unique collaborative framework that the forum offers. Contrary to previous generations of reactors, Generation IV systems will have made the most of international collaboration from the early stages of their design, and their future deployment will be a testimony to the success of the GIF initiative.

Three decades of enhancing confidence in thermodynamic calculations

by J. Perrone*

The Thermochemical Database (TDB) Project was initiated in 1984 as a joint activity of the NEA Data Bank and the NEA Radiological Protection and Radioactive Waste Management Division. The project was launched in response to a need that the radioactive waste management community had identified in NEA member countries to enhance confidence in thermodynamic calculations. The project's primary goal is to provide chemical thermodynamic constants that meet the quality requirements outlined in the safety assessment of underground radioactive waste repositories.

In order to assess the safety of a radioactive waste repository, it is essential to understand the geochemical behaviour of its components because the interaction of radionuclides with rock surfaces and coatings, or the formation of insoluble compounds, may greatly inhibit the migration of radionuclides into the environment. The modelling of processes affecting the behaviour of radionuclides in natural and engineered barrier systems is therefore an integral part of a radiological assessment methodology. Some basic information is acquired through speciation calculations using general, non-site-specific, chemical thermodynamic data. The value of the results of geochemical modelling as a predictive tool relies on the quality of the thermodynamic data used to calculate the chemical speciation.

To be useful in performance assessment work, a thermochemical database must not only contain data for all the elements of interest in radioactive waste disposal systems, but it should also treat all solids and aqueous species of the relevant elements, explain why and how the data were selected, document the sources of experimental data used and be internally consistent.

Although a number of thermodynamic data compilations and reviews were published in the mid-1980s, none of them fulfilled all these criteria or could be used reliably as a complete data source. The documentation on how and why a specific datum was selected was, in particular, often omitted.

It is also common to find specialised thermochemical databases intended for quite different purposes, such as general geochemical modelling under hydrothermal conditions and metallurgical or other simulations. As a result, most research groups supporting the performance assessment of radioactive waste disposal use their own databases for modelling purposes. However, these individual databases may lack internal consistency, and they often differ considerably, particularly in relation to data on actinides. It is thus not surprising that radionuclide speciation and maximum solubilities calculated by different groups, with different geochemical computer codes and data, under similar conditions, can differ by several orders of magnitude. These discrepancies have been attributed to shortcomings in the different databases, rather than the computer codes themselves.

During the period 1984-1998, a comprehensive, internally consistent and highly recognised, critically reviewed thermodynamic database was developed for five elements: uranium, americium, technetium, neptunium and plutonium. This first phase of the TDB Project set new standards for the critical review of chemical thermodynamic data through international co-operation. The framework and high scientific standards were appreciated by the radioactive waste disposal community because the objectives had been agreed based on the needs of various national programmes, and they were being pursued by teams of independent scientists from universities and research laboratories under the co-ordination of the OECD Nuclear Energy Agency.

A second phase that began in 1998 was designed to meet subsequent needs of radioactive waste management programmes by updating and applying the methodology to new elements. Since the start of Phase II, the TDB Project was organised as a semi-autonomous project under the guidance of a management board, with members representing 17 participating organisations from 13 NEA member countries.[1] The objectives of the project were set by the management board, taking into account the mobility, radioactivity, inventory and half-lives of the commonly occurring nuclides in radioactive waste, as well as the particular areas of interest of the participants. The NEA Data Bank co-ordinates the work of the review teams, ensures the publication of the review reports[2] and maintains the corresponding

* *Ms. Jane Perrone was, at the time of writing, Administrator in charge of the TDB Project (tdb@oecd-nea.org) in the NEA Data Bank.*

database. The project's core work is the identification and critical review of all published literature by teams of internationally recognised experts under a common set of published guidelines that detail the organisational and scientific aspects of the project.

The first step in the review procedure is the compilation of all data published in the scientific literature on the subject. TDB reviews only take into account primary experimental data and do not attempt to fill the gaps in the thermodynamic database by estimation. Instead, areas that merit further experimental investigation are indicated in the reports. The reports are reviewed independently by qualified experts (peer reviewers) to evaluate the judgments and assessments made by the primary reviewers, to verify the reports' assumptions, results and conclusions and to check whether an exhaustive consideration of the relevant literature has been undertaken. For each element, the dataset and the selection procedure are published under the authorship of the corresponding reviewers.

The outputs of NEA TDB reviews include not only a database of selected thermodynamic values, but also a detailed discussion of the key data sources, a presentation of the re-evaluations carried out by the reviewers and the complete set of auxiliary data used during the evaluation, as well as an exhaustive bibliography.

This documentation constitutes a true knowledge base. It allows the modellers to implement geochemical calculations on the basis of authoritative, up-to-date chemical information for systems involving a large variety of aqueous complexes and solids limiting solubility. It is also an excellent vector for knowledge transfer between two communities, for example between those developing new thermodynamic data – either by direct experimental work in the laboratory or participation in TDB review teams – and those modelling and analysing field data.

The TDB Project is currently in its fourth phase, with the fifth phase agreed upon by the participants for a period of four years beginning in January 2014. Eleven authoritative reviews have been published on the inorganic species of the actinides (uranium, neptunium, plutonium, americium and thorium) and of some elements of importance as activation or fission products (technetium, selenium, nickel, zirconium and tin), as well as compounds and complexes of these elements with selected organic ligands. The corresponding selected data are available for downloading from the NEA website. This series of publications also includes additional books with a different aim than that of the review books. These can either be a guide (*Modelling in Aquatic Chemistry*, 1994) or a state-of-the-art report (*Chemical Thermodynamics of Solid Solutions of Interest in Nuclear Waste Management*, 2007). A volume on the aqueous compounds and complexes of iron was published in December, and three additional reviews as well as two state-of-the-art reports are under preparation.

Some 60 internationally recognised scientists have been or are currently involved in this effort, which has thus far resulted in the critical review of more than 18 000 literature items – the oldest dating back to 1796 – stemming from the original work of more than 12 000 scientists.

Over its nearly thirty years of existence, the NEA TDB Project has developed a successful international collaborative framework wherein the need for critically reviewed chemical thermodynamics data for radioactive waste disposal has been met through the joint work of experts. Such work is held to the strict criteria of scientific quality and subject to review by peers ensuring scientific excellence. The NEA TDB database and associated reviews are available to the general public and have gained recognition both within and outside the radioactive waste management community. In the waste management community, these reviews are recognised as a reference source of thermodynamic data and as a guide for future research work. They also contribute to enhancing confidence in performance assessment exercises.

Notes

1. The participants in the TDB project include: NIRAS/ONDRAF (Belgium), NWMO (Canada), RAWRA (Czech Republic), POSIVA (Finland), ANDRA (France), CEA (France), KIT (Germany), KAERI (Korea), JAEA (Japan), ENRESA (Spain), SKB (Sweden), NAGRA (Switzerland), PSI (Switzerland), ENSI (Switzerland), NDA (United Kingdom), DOE-NE (United States) and DOE-EM (United States). To access the guidelines for the project, see www.oecd-nea.org/dbtdb/guidelines/.
2. For more information on thermochemical database (TDB) project publications, see www.oecd-nea.org/dbtdb/info/publications.

Improved nuclear data services based on JANIS

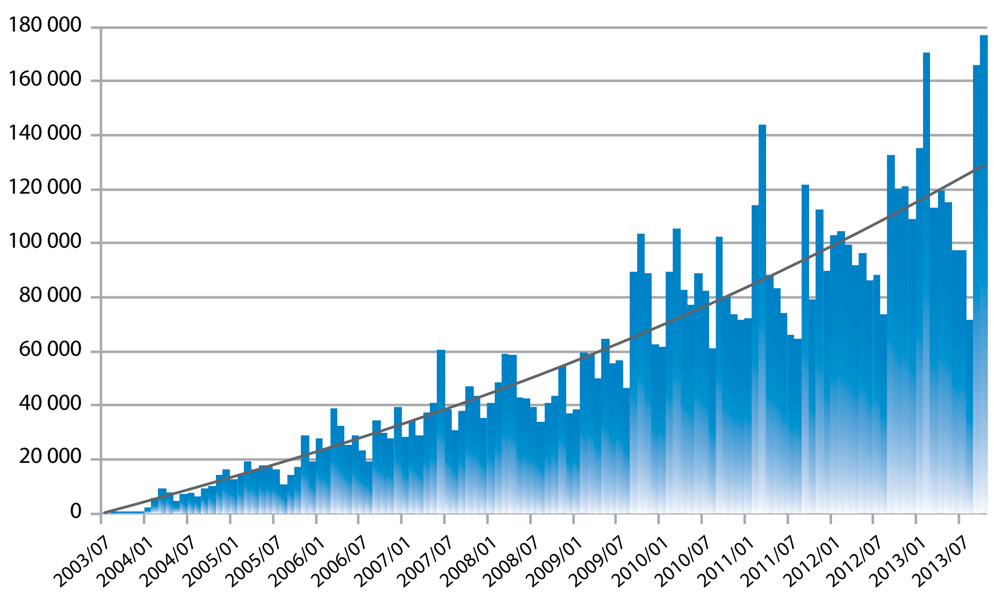
by E. Dupont, N. Soppera and M. Bossant*

Nuclear data and their associated uncertainties are key components of the basic nuclear tools used for the analysis and prediction of phenomena in the nuclear field. These data cover both the properties of radioactive nuclei and the description of nuclear reactions. The compilation and dissemination of nuclear data is overseen by the International Network of Nuclear Reaction Data Centres (NRDC). The large scope and detail of nuclear data libraries, and the diversity of applications and end-users has resulted in a need for convenient storage of data in standardised international formats, such as the Evaluated Nuclear Data Format (ENDF) for evaluated data and the Exchange Format (EXFOR) for experimental work. The NEA Data Bank, a member of the NRDC, maintains and develops large relational databases and user-friendly tools for accessing and manipulating nuclear data regardless of the storage format. The Java-based nuclear data information software (JANIS) was developed in order to facilitate remote access to the large nuclear databases hosted by the NEA Data Bank. JANIS has become a popular tool among scientists and students, and the number of users has increased steadily over the years. Figure 1 shows the evolution of access to the remote database, which is now queried more than 120 000 times per month. The latest developments of JANIS are described below, including the recent web extension, which is now the basis for the online nuclear data services of the Data Bank.

General features of JANIS

JANIS was designed to be a user-friendly software. The main program is a standalone application that allows direct access to remote and local databases, as well as to user data. The remote database is available on the NEA Data Bank server using Java Servlet technology. JANIS provides direct access to evaluated, experimental, and bibliographical data. The main standardised formats supported are ENDF-6 (and derived files), EXFOR, CINDA (bibliographic data) and NUBASE (basic properties of nuclei). In addition, user data provided in simple text format can be loaded via a versatile "text to data" interface. These data can be handled in a similar way as data from the main database. Various navigation tools are available to help the user identify the nuclei and data of interest. The main window of the standalone application is a "browser", which gives access to data through a chart of nuclides.

Figure 1: Number of requests per month to the remote database since 2003



* *Mr. Emmeric Dupont (emmeric.dupont@oecd.org), Mr. Nicolas Soppera (nicolas.soppera@oecd.org) and Mr. Manuel Bossant (manuel.bossant@oecd.org) work for the NEA Data Bank.*

Another way to access and compare data is to use the powerful search tools that query the databases. The data are displayed in a separate "renderer" window on different tabs depending on the quantity and the display mode chosen, for example plot, table, text, decay chain or colour maps (matrix). These data can be saved in various output formats. Tabulated data in particular can be saved in text format for the user's convenience. Various setting options also allow for the preparation of publication-ready plots in picture graphics format (PNG) or vector graphics formats (PostScript, PDF and Windows Metafile). And finally, all selected data, as well as plot, table and display settings, can be saved in a single XML file, which can later be reopened by JANIS on the same or any other computer.

Chart of nuclides

The main window of the standalone application displays a chart of all nuclides available in the selected database. This chart can also be used to display other information, such as spin-parity, half-lives, decay modes, or 2 200 m/s cross sections. Additional data are available by clicking on the chosen isotope.

Search tools

Various search tools allow the user to explore the contents of the three main databases. The results of the query can be refined and the selected data displayed according to the type of data.

- Evaluated data: search by library, incident particle, target, reaction, data type (cross section, spectra). More specific search tools are available to retrieve evaluated resonance parameters and radioactive decay lines.
- Experimental data: search by incident particle, energy, target, reaction, product, experimental facility, bibliographic reference.
- Bibliographic data: search by incident particle, energy, target, reaction, publication, work type (experimental, theoretical or evaluated).

Examples of basic nuclear data displayed with JANIS

JANIS gives the user access to various evaluated and experimental quantities. Data originating from the major evaluation files (ENDF/B, JEFF, JENDL, ROSFOND/BROND, TENDL) are displayed and most of them compared with experimental data from the EXFOR database. Some of the different data types available through JANIS include:

- radioactive decay data and basic nuclear structure information such as properties of nuclei (mass, spin-parity, half-life, decay modes), as well as discrete and continuous spectra of emitted particles;
- fission product yields including independent and cumulative yields for spontaneous and neutron-induced fission;
- cross sections that include integral or differential (with respect to energy) and double-differential (with respect to energy and angle) cross sections, along with resonance parameters;
- multiplicities of neutron and other emitted particles such as average fission neutron multiplicities (prompt, delayed), as well as average gamma multiplicity with respect to the incident energy;
- angular, energy or energy-angle distributions, which are normalised distributions of emitted particles in relation to their energy or angle;
- photon-production data such as specific production cross sections of a given gamma radiation in one or several reaction processes;
- nuclear data uncertainties and associated correlation matrices.

Examples of data manipulation with JANIS

The standalone application includes advanced functionalities for the comparison and computation of different kinds of data sets (see Figure 2). Functionalities may include group averaging of cross sections with different weighting flux (constant, Maxwell, reactor spectra and user-defined), basic

Figure 2: (left) **Calculation of the capture-to-fission cross-section ratio of ^{235}U, ^{238}U and ^{239}Pu using the equation editor –** (right) **^{238}U(n,f) cross-section from the online JANIS Book**

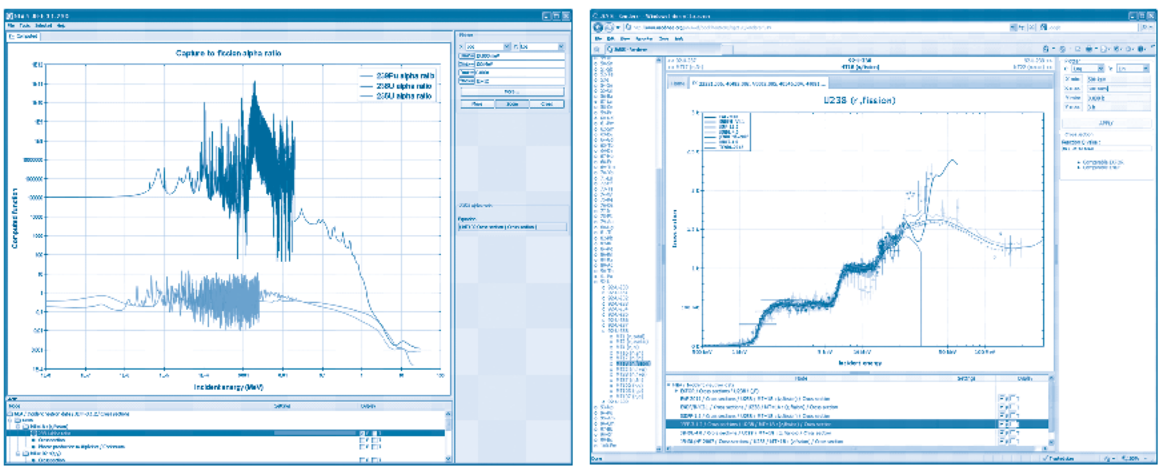
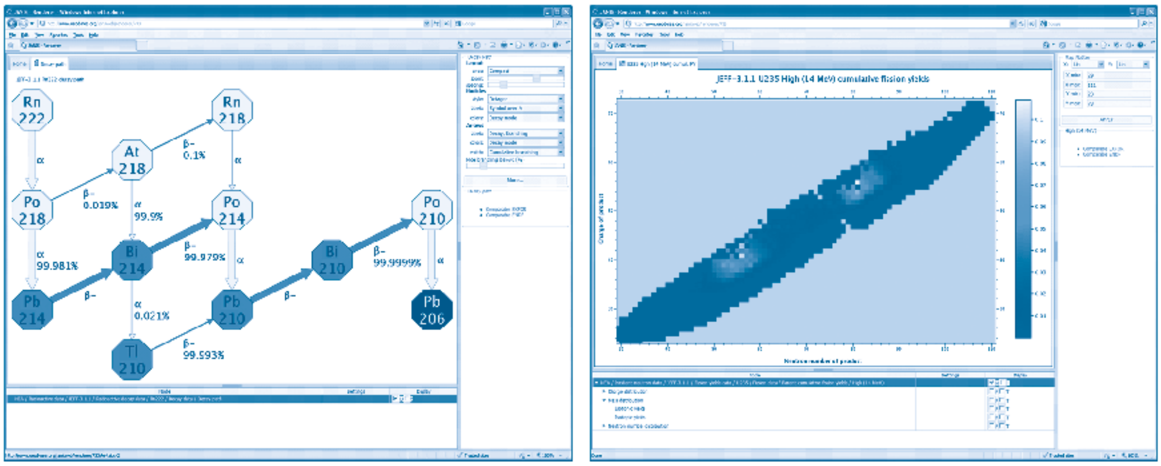


Figure 3: (left) **Compact representation of the ^{222}Rn decay chain in the (Z-N,Z) plan –** (right) **Cumulative fission product yields for the neutron-induced fission of ^{235}U at 14 MeV**



arithmetic operations (+, -, ´, /) on most pointwise or group-averaged evaluated data (cross sections, yields and distribution in energy and/or angle of the emitted particle), or comparisons of experimental and evaluated data. This tool allows comprehensive inter-comparison of evaluated data libraries for a given reaction quantity, as well as an automated comparison of experimental and evaluated data. In the latter case, the tool makes use of built-in computing capabilities to perform all the necessary operations in order to adapt the evaluated data to the experimental quantity compared (Maxwell average, ratio).

The results of these operations can be displayed, computed, compared and saved in various formats as easily as the original data sets.

JANIS Web

The JANIS Web extension only requires an Internet connection and a browser, without any software installation. The web version is not intended to replace the standalone version, but complements it by offering quick access to the most common features, such as direct access to the remote database; search interfaces to query the evaluated, experimental and bibliographic databases; and display of the data in various formats (plots, tables, text, decay chains, colour maps).

JANIS Web now provides the basis for the NEA Data Bank nuclear data online services. The search functionality allows the user to browse all databases, and the enhanced display interface facilitates the comparison of results.

JANIS Books

JANIS Books are a comprehensive compilation of cross-section curves related to experimental and evaluated data from a number of libraries, nuclear reactions and associated reaction products. These books are the result of the most recent developments of JANIS, which include built-in computing capabilities, automated comparison of experimental and evaluated data, and an XML-based file to save data and settings. JANIS Books are available for nuclear reactions induced by neutrons, photons and light-charged particles. The online books are based on JANIS Web in order to allow users to zoom in the plots, access complementary information and plot additional data (see Figure 3).

Outlook

JANIS has been developed to provide versatile and user-friendly access to both local and remote nuclear databases. The navigation, display and computing functionalities are appropriate for both beginners and experienced users. The development and recent integration of JANIS Web and JANIS Books into the online NEA Data Bank nuclear data services complements the standalone application by providing access to information without software installation.

More information is available on the NEA website at www.oecd-nea.org/janis. The authors of this article would like to acknowledge user feedback, which is essential in ensuring further improvements to JANIS.

Further reading

NEA (2012), "Contributions to the worldwide collection, compilation and dissemination of nuclear reaction data", *NEA News*, Volume 30, No. 2, OECD, Paris.

NEA (2001), "JANIS: new software for nuclear data services", *NEA News*, Volume 19, No. 2, OECD, Paris.

Knowledge management of neutronics integral experiments

by I. Hill, F. Michel-Sendis, N. Soppera and M. Bossant*

One of the main objectives of the NEA Nuclear Science Section is to support the preservation and dissemination of essential knowledge in the field of nuclear science. Within the Working Party on Nuclear Criticality Safety (WPNCS) and the Working Party on Scientific Issues of Reactor Systems (WPRS), large collections of integral benchmark experiments have been compiled and are available upon request. The NEA coordinates the evaluation and ensures the distribution of benchmark experiments in areas such as criticality safety (ICSBEP), reactor physics (IRPhEP), fuel performance (IFPE), radiation shielding (SINBAD), and Assay Data of Spent Nuclear Fuel (EGADSNF).

These experimental benchmarks represent a vast amount of information, with the ICSBEP handbook alone spanning more than 65 000 pages. Users of these databases face the challenge of efficiently identifying relevant information, as well as gaps in that information. To manage the data, the NEA Nuclear Science Section and Data Bank collaborate to create relational databases and corresponding user interfaces.

- **DICE:** Database for the International Handbook of Evaluated Criticality Safety Benchmark Experiments;
- **IDAT:** International Reactor Physics Handbook Evaluation Project Database and Analysis Tool;
- **SFCOMPO:** Spent Fuel Isotopic Composition Database.

An overview of the three databases available for knowledge management of neutronics integral experiments is shown in the figure below.

NEA relational databases

Database: DICE
Project: ICSBEP
Year database first released: 2001
Database availability: DVD, download, online

Database: IDAT
Project: IRPhEP
Year database first released: 2013
Database availability: DVD, download

NEA SFCOMPO

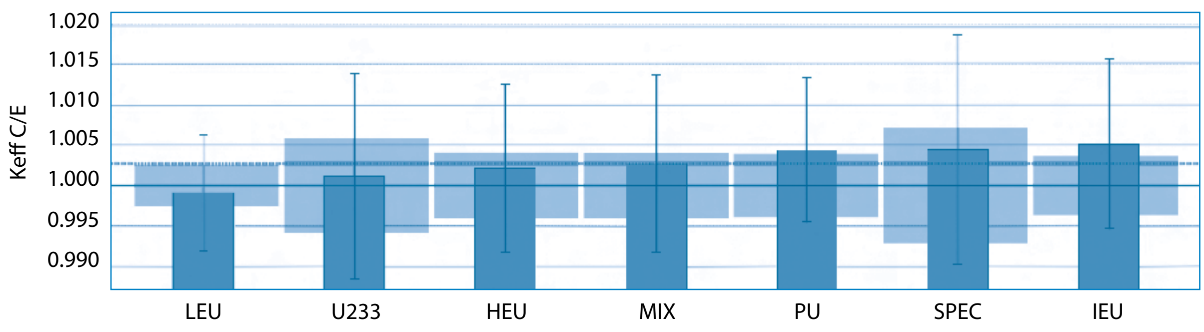
Database: WPNCS/EGADSNF
Project: WPNCS/EGADSNF
Year database first released: To be released in 2014
Database availability: Website and download (2014)

Non-comprehensive subset of searchable parameters

DICE	IDAT	SFCOMPO
Fissile material	Reactor name	Reactor name
Physical form	Reactor type	Reactor type
Spectrum	Measurement type	Coolant
Laboratory	Laboratory	Moderator
Fuel form	Fuel	Lattice type
Pu/U+Pu ratio	Spectral index	Lattice dimension
Moderator/coolant	Reactivity coefficient type	Rod pitch
Reflector material	Kinetics parameter	Rod diameter
Geometry	Reaction rate foil type	Fuel type
Benchmark keff	Benchmark keff	Enrichment
Energy of average neutron lethargy causing fission	Keff uncertainties	Burnup
3-group flux	3-group flux	Axial position
3-group keff sensitivities	3-group keff sensitivities	Isotope

** Mr. Ian Hill (ian.hill@oecd.org) works in the Nuclear Science Section. Dr. Franco Michel-Sendis (franco.michel-sendis@oecd.org), Mr. Nicolas Soppera (nicolas.soppera@oecd.org) and Mr. Manuel Bossant (manuel.bossant@oecd.org) work in the NEA Data Bank.*

DICE: Trending calculated over experimental keff data versus ICSBEP handbook volume data



At the highest level, each database acts as a tool with the same overall objectives: to efficiently search for relevant experimental data and to visualise trends across experimental data.

Released in 2001, DICE was the first of the database tools developed by the NEA Data Bank. The code was refined for over a decade, and subsequently leveraged to create the subsequent database tools. DICE was split into code that is common to each tool, providing a search feature (see the table for examples) and generic plotting/trending of numerical values. As a result, the three software packages have a similar look and feel.

Additionally, each database tool contains custom features built on top of the common layer. These custom features are adapted to accommodate user functionality requests, examples of which are described below.

DICE contains many classification fields that are necessary to efficiently explore the overall number of experimental configurations described. In 2013, DICE incorporated a search tool based on 3-group sensitivity data.

IDAT provides a graphical display of mesh tallies from different codes and allows the fluxes and reaction rates from two different models to be compared. Another custom feature automatically identifies similar benchmarks using parameters such as 3-group reaction rates and neutron balance data.

SFCOMPO provides a customised graphical display of the location of the analysed samples within the fuel assembly, provides reactor design data, displays graphs and tables of operational history information and isotopic measurements, provides links to bibliographical references of the original assay data reports, and, in the present development version, has incorporated advanced plotting capabilities.

Custom features proposed for one database have subsequently been deemed beneficial to another tool. DICE 2013, for example, incorporates a feature originally developed for IDAT, allowing trending of calculated versus experimental keff values, while at the same time visualising benchmark uncertainty. Each database has profited from cross-disciplinary feedback obtained from a wide range of experts.

Development is on-going with the databases at different stages of development. DICE was first released on CD-ROM in 2001 and, as of 2013, is also publically available as a web-start application. IDAT was released on DVD in 2013. SFCOMPO, initially transferred in 2001 to the NEA Data Bank from the Japan Atomic Energy Research Institute (JAERI) as a web application, is currently undergoing a complete upgrade and will be restructured into a java application called SFCOMPO 2.0. In this latter version, the number of reactors/samples will have tripled compared with the web page version.

All these database tools will continue to be refined, while providing users with the means to comb through the vast amount of experimental information collected within the Nuclear Science Section and Data Bank.

New publications

Economic and technical aspects of the nuclear fuel cycle

The Economics of the Back End of the Nuclear Fuel Cycle

NEA No. 7061. 188 pages.

The feasibility and costs of spent nuclear fuel management and the consequent disposal of ultimate waste continue to be the subject of public debate in many countries, with particular concern often expressed over the lack of progress in implementing final disposal. Uncertainties about back-end costs and the financial risks associated with management of the back end have also been singled out as possible deterrents to investment in new nuclear power plants. This report offers an appraisal of economic issues and methodologies for the management of spent nuclear fuel and high-level waste from commercial power reactors. It includes a review of different back-end options and current policies and practices, with a focus on the cost estimates for these options and the funding mechanisms in place or under consideration in OECD/NEA countries. A generic economic assessment of high-level estimates of back-end cost impacts on fuel cycle costs is undertaken for selected idealised scenarios, by means of a simple static model. Sensitivity analyses are conducted for the evaluation of uncertainties in major components and the identification of cost drivers. Since factors other than economics are an important part of the decision-making process, an analysis of the influence of key qualitative parameters in the selection of back-end strategies is also presented in this report.

Nuclear Energy Data 2013

Données sur l'énergie nucléaire 2013

NEA No. 7162. 92 pages.

Nuclear Energy Data is the OECD Nuclear Energy Agency's annual compilation of statistics and country reports documenting the status of nuclear power in the OECD area. Information provided by member country governments includes statistics on installed generating capacity, total electricity produced by all sources and by nuclear power, nuclear energy policies and fuel cycle developments, as well as projected generating capacity and electricity production to 2035, where available. Total electricity generation at nuclear power plants and the share of electricity production from nuclear power plants declined in 2012 as a result of operational issues at some facilities and suspended operation at all but two reactors in Japan. Nuclear safety was further strengthened in 2012 following safety reviews prompted by the Fukushima Daiichi nuclear power plant accident. Governments committed to maintaining nuclear power in the energy mix pursued initiatives to increase nuclear generating capacity. In Turkey, plans were finalised for the construction of the first four reactors for commercial electricity production. Further details on these and other developments are provided in the publication's numerous tables, graphs and country reports. This publication contains "StatlLinks". For each StatLink, the reader will find a URL which leads to the corresponding spreadsheet. These links work in the same way as an Internet link.

Nuclear safety and regulation

The Fukushima Daiichi Nuclear Power Plant Accident: OECD/NEA Nuclear Safety Response and Lessons Learnt

NEA No. 7161. 68 pages.

This report outlines the response of the OECD Nuclear Energy Agency (NEA) and its member countries to the March 2011 accident at TEPCO's Fukushima Daiichi nuclear power plant. All NEA members took early action to ensure and confirm the continued safety of their nuclear power plants and the protection of the public. Consistent with its objective of maintaining and further developing the scientific, technological and legal bases for safe nuclear energy, the NEA has assisted its member countries in their individual and collective responses to the accident. It has also provided direct assistance to the relevant authorities in Japan. These actions are summarised in the report along with lessons learnt thus far. Key messages are offered as a means to help strengthen the basis for nuclear safety and its implementation in all countries using nuclear power.

Radiological protection

Summary of the Fourth International Nuclear Emergency Exercise (INEX-4)

Exercise Conduct and Evaluation Questionnaires

NEA No. 7143. 48 pages.

The International Nuclear Emergency Exercise (INEX) series, organised under the OECD Nuclear Energy Agency (NEA) Working Party on Nuclear Emergency Matters (WPNEM), has proven successful in testing, investigating and improving national and international response arrangements for nuclear accidents and radiological emergencies. Early INEX exercises focused on the national and international aspects of early phase management of nuclear power plant emergencies. Starting with INEX-3 (2005-2006), the international community began looking at issues concerning longer-term consequence management. In 2008, the WPNEM started preparing the INEX-4 series, which was conducted in 2010-2011 and addressed consequence management and transition to recovery in response to malicious acts involving the release of radioactive materials in an urban setting. The goal of INEX-4 was to provide a basis for enhancing emergency management through the exchange of exercise experiences from participating countries and the identification of good practices and common issues. This summary report provides general outcomes based on country responses to the INEX-4 evaluation questionnaire and suggests areas of focus for future consideration.

Nuclear law

Nuclear Law Bulletin No. 91

Volume 2013/1

ISSN No. 0304-341X. 196 pages.

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 post-Fukushima Daiichi response: The role of the Convention on Nuclear Safety in strengthening the legal framework for nuclear safety”; “Adequate protection after the Fukushima Daiichi acccident: A constant in a world of change”; “Safer nuclear energy through a higher degree of internationalisation? International involvement versus national sovereignty”; and “Special report on the Second Annual Meeting of the Nuclear Law Association, ‘India’s nuclear energy sector: Business opportunities and legal challenges’, 2 March 2013, Mumbai, India”.

Nuclear science and the Data Bank

Chemical Thermodynamics of Iron

Volume 13a, Part 1

NEA No. 6355. 1 124 pages.

This volume is the 13th in the OECD Nuclear Energy Agency (NEA) «Chemical Thermodynamics» series. It is the first part of a critical review of the thermodynamic properties of iron, its solid compounds and aqueous complexes, initiated as part of the NEA Thermochemical Database Project Phase III (TDB III). The database system developed at the OECD/NEA Data Bank ensures consistency not only within the recommended data sets of iron, but also among all the data sets published in the series. This volume will be of particular interest to scientists carrying out performance assessments of deep geological disposal sites for radioactive waste.

International Handbook of Evaluated Criticality Safety Benchmark Experiments – ICSBEP

Version 2013

NEA No. 7166. DVD.

The Criticality Safety Benchmark Evaluation Project (CSBEP) was initiated in October of 1992 by the United States Department of Energy. The project quickly became an international effort as scientists from other interested countries became involved. The International Criticality Safety Benchmark Evaluation Project (ICSBEP) became an official activity of the Organisation for Economic Co-operation and Development (OECD) Nuclear Energy Agency (NEA) in 1995. This handbook contains criticality safety benchmark specifications that have been derived from experiments performed at various nuclear critical experiment facilities around the world. The benchmark specifications are intended for use by criticality safety engineers to validate calculational techniques used to establish minimum subcritical margins for operations with fissile material and to determine criticality alarm requirement and placement. Many of the specifications are also useful for nuclear data testing. Example calculations are presented; however, these calculations do not constitute a validation of the codes or cross section data. The evaluated criticality safety benchmark data are given in nine volumes. These volumes span nearly 66 000 pages and contain 558 evaluations with benchmark specifications for 4 798 critical, near critical or subcritical configurations, 24 criticality alarm placement/shielding configurations with multiple dose points for each and 200 configurations that have been categorised as fundamental physics measurements that are relevant to criticality safety applications. New to the Handbook are benchmark specifications for Critical, Bare, HEU(93.2)-Metal Sphere experiments referred to as ORSphere that were performed by a team of experimenters at Oak Ridge National Laboratory in the early 1970s. A photograph of this assembly is shown on the front cover.

Minor Actinide Burning in Thermal Reactors

A Report by the Working Party on Scientific Issues of Reactor Systems

NEA No. 6997. 82 pages.

This publication provides an introduction to minor actinide nuclear properties and discusses some of the arguments in favour of minor actinide recycling, as well as the potential role of thermal reactors in this regard. Various technical issues and challenges are examined from the fuel cycle, operations, fuel designs, core management and safety/dynamics responses to safety and economics. The focus of this report is on the general conclusions of recent research that could be applied to thermal reactors. Further research and development needs are also considered, with summaries of findings and recommendations for the direction of future R&D efforts.

Shielding Aspects of Accelerators, Targets and Irradiation Facilities – SATIF-11

Workshop Proceedings, Tsukuba, Japan, 11-13 September 2012

NEA No. 7157. 202 pages.

Particle accelerators have evolved over the last decades from simple devices to powerful machines, and are having an increasingly important impact on research, technology and daily life. Today they have a wide range of applications in many areas including material science and medical applications. In recent years, new technological and research applications have helped to define requirements while the number of accelerator facilities in operation, being commissioned, designed or planned has grown significantly. Their parameters, which include the beam energy, currents and intensities, and target composition, can vary widely, giving rise to new radiation shielding aspects and problems. Particle accelerators must be operated in safe ways to protect operators, the public and the environment. As the design and use of these facilities evolve, so must the analytical methods used in the safety analyses. These workshop proceedings review the state of the art in radiation shielding of accelerator facilities and irradiation targets. They also evaluate progress in the development of modelling methods used to assess the effectiveness of such shielding as part of safety analyses.

Status Report on Structural Materials for Advanced Nuclear Systems

NEA No. 6409. 107 pages.

Materials performance is critical to the safe and economic operation of any nuclear system. As the international community pursues the development of Generation IV reactor concepts and accelerator-driven transmutation systems, it will be increasingly necessary to develop advanced materials capable of tolerating the more challenging environments of these new systems. The international community supports numerous materials research programmes, with each country determining its individual focus on a case-by-case basis. In many instances, similar alloys of materials systems are being studied in several countries, providing the opportunity for collaborative and cross-cutting research that benefits different systems. This report is a snapshot of the current materials programmes supporting the development of advanced concepts. The descriptions of the research are grouped by concept, and national programmes are described within each concept. The report provides an overall sense of the importance of materials research worldwide and the opportunities for synergy among the countries represented in this overview.

Transition Towards a Sustainable Nuclear Fuel Cycle

NEA No. 7133. 68 pages.

Future fuel cycle characteristics, feasibility and acceptability will be crucial for the continued development of nuclear energy, especially in the post-Fukushima context. Fuel cycle choices have both long- and short-term impacts, and a holistic assessment of their characteristics, cost and associated safety issues is of paramount importance. This report seeks to associate quantified impacts with foreseeable nuclear energy development in different world regions. It gives initial results in terms of uranium resource availability, fuel cycle facility deployment and reactor types. In particular, the need to achieve short doubling times with future fast reactors is investigated and quantified. The report also provides guidelines for performing future studies to account for a wider range of hypotheses on energy demand growth, different hypotheses regarding uranium resource availability and different types of reactors to be deployed.

NEA

NUCLEAR ENERGY AGENCY

Visit our website at:

www.oecd-nea.org

You can also visit us on **Facebook** at:

www.facebook.com/OECDNuclearEnergyAgency

and

follow us on **Twitter** @OECD_NEA

OECD/NEA Publishing, 2 rue André-Pascal, 75775 PARIS CEDEX 16

PRINTED IN FRANCE

OECD Nuclear Energy Agency
12, boulevard des Îles
92130 Issy-les-Moulineaux, France
Tel.: +33 (0)1 45 24 10 15
nea@oecd-nea.org   www.oecd-nea.org

NEA No. 7169