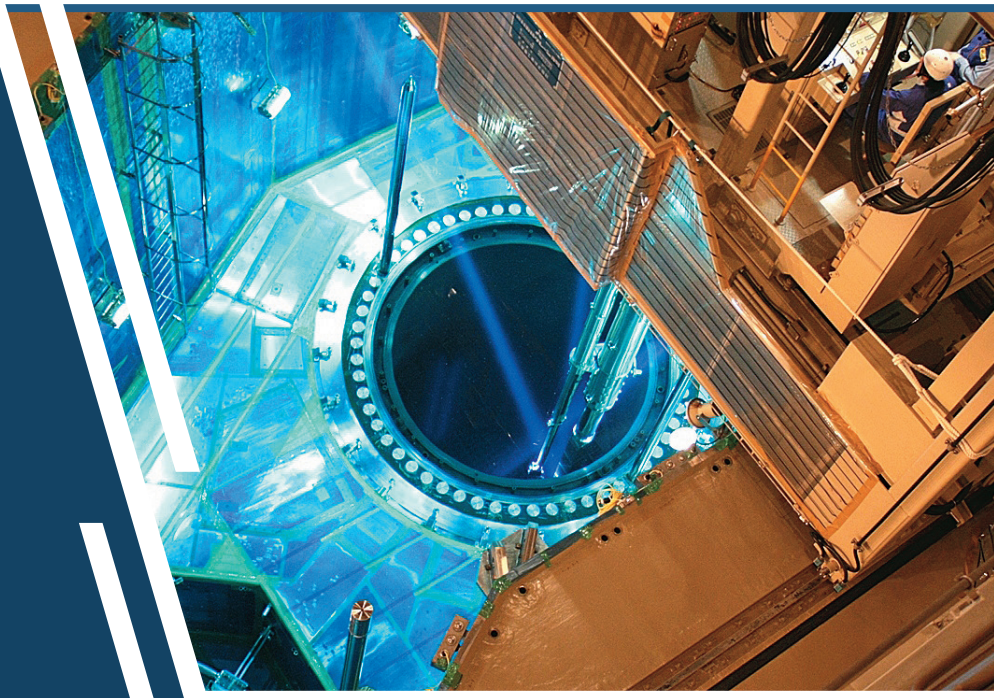
2018 NEA
Annual Report



Nuclear Power in 2018

Building Knowledge for the Future

NEA Activities by Sector

OECD
BETTER POLICIES FOR BETTER LIVES

NEA
NUCLEAR ENERGY AGENCY

2018 NEA

Annual Report

NUCLEAR ENERGY AGENCY
Organisation for Economic Co-operation and Development

The NEA in Brief – 2018

Governing body: The Steering Committee for Nuclear Energy

The NEA and its mission

The Nuclear Energy Agency (NEA) is a semi-autonomous body within the framework of the Organisation for Economic Co-operation and Development (OECD), located just outside Paris, France. The objective of the Agency 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 sound and economical use of nuclear energy for peaceful purposes.

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NEA staff: supporting the technical policy needs of our members for more than 60 years

The year 2018 continued to be one of significant transformation, both in relation to the Agency and the global context within which it operates. In the wider nuclear community, there was increased recognition of the need to sustain nuclear skills and knowledge. The NEA, as a knowledge-based organisation, is already committed to helping its member states to address their knowledge management concerns and needs. The NEA's committees and expert working groups are continuously contributing to the codification and preservation of data, information, expertise, research results, procedures and best practices. We help to share this explicit knowledge through our extensive publications programme, databases, workshops, summer schools, training courses and webinars.

On the other hand, tacit knowledge can really only be acquired through exposure to practical experiences and hands-on projects. Much of the tacit knowledge that makes up the skills and knowledge needed in the nuclear power sector was generated during its pioneering years and expansion phase. This was a period when R&D projects were ramping up and nuclear power plants were being built around the world. As a result, industry personnel were constantly confronted with challenging and ground-breaking projects – as well as the risk of failure. In the current environment, where R&D spending, innovation and new builds are decreasing as a general trend in OECD countries, there are fewer opportunities to acquire hands-on experience, or to work on challenging projects at the national level. Ensuring there is a critical mass of activities and access to state-of-the-art infrastructures, is now really only possible through international co-operation.

The NEA has therefore convened the Nuclear Education, Skills and Technology (NEST) Framework to address these challenges. The NEST Framework exposes younger researchers and engineers (NEST Fellows) to challenging projects and real-world problems. As a result, they will acquire competencies, learn critical thinking and absorb tacit knowledge by working alongside leading experts in the field. The NEST Framework, which is described in depth on page 54, will facilitate the access to a critical mass of activities and capacities to help create the next generation of nuclear experts who will not just acquire, but also exploit this knowledge to generate new innovations and new ideas.

The NEST Framework complements the existing NEA joint projects described elsewhere in this volume. A common challenge these projects face is assuring the continuity of knowledge and encouraging talented individuals. Meeting these challenges requires a long-term investment by every country and organisation. It requires strategic vision and involvement which, in the current context, cannot be achieved by a single country or organisation acting alone. Instead, it requires the concerted effort of all stakeholders. Only then can there be confidence that countries will be able to continue to acquire, transfer and exploit the necessary explicit and tacit knowledge in the nuclear field and to develop safe and effective nuclear technology.

Ultimately, it's all about people, like the NEA staff pictured opposite. Their many contributions in 2018, their skills, and their explicit and tacit knowledge, have benefited the 33 countries we serve and beyond.

William D. Magwood, IV,
Director-General, Nuclear Energy Agency

Nuclear Technology in 2018

Doel nuclear power plant, Belgium.

Developments in nuclear power generation

At the end of 2018, there were 454 operational reactors worldwide, representing 400 GW of capacity, with NEA member countries operating 354 units, representing 326 GW, or 81.4% of the total world capacity.

Nine reactors were connected to the grid in 2018 – seven in China, including the first four AP1000[1] and the first EPR reactors, and two in Russia. These 9 reactors represent an additional capacity of 10.4GW, more than three times the capacity connected in 2017. Construction began on five reactors worldwide, four of which are in NEA countries (Korea, Russia, Turkey and the United Kingdom) and one in Bangladesh, bringing the total number of reactors under construction to 55 (22 in NEA member countries).

Nuclear plant construction is most vigorous in non-NEA member countries, and this trend appears likely to continue. Countries anticipating strong growth in demand for electricity feature prominently among those planning to build additional plants. China is currently constructing 11 reactors (11 GWe), and did not start any new construction in 2018. In terms of global development, more than 60% of the reactors under construction are in non-NEA member countries, with China, India and the United Arab Emirates accounting for almost half.

Among NEA countries the Russian Federation has been most active with six reactors currently under construction, including the two small reactors of the Akademik Lomonosov floating plant. The Russian state-owned corporation, Rosatom, has signed a total of more than twenty agreements with entities outside Russia, some of which are focused on exploratory or feasibility studies, or general co-operative development activities, but others represent more advanced discussions or firmer agreements. About one third of all currently ongoing construction projects, both in NEA and non-NEA member countries, are Russian led.

On the other hand, several currently operating nuclear power plants in NEA countries were set on a path for early decommissioning as a result of non-technical factors, such as economic challenges or policy decisions.

Significant developments in nuclear energy generation in NEA member countries during the year 2018 are described below:

- Argentina continues the negotiations with China for a loan to move forward with the construction of new reactors (including Atucha 3). Argentina also signed a co-operation agreement with the Russian Federation in December 2018.
- Belgium's security of electricity supply became a concern when only one (Doel 3) out of the country's seven reactors (6 000 MWe in total) was generating electricity in early November 2018. Doel 1 and 2 plants had been shut down for repairs for some months after a small leak in the safety injection system of Doel 2 was detected earlier in the year. Extended outages for repairs were also necessary in Doel 4, Tihange 2 and Tihange 3, due to degraded concrete structures in second level emergency buildings. The outage at Tihange 1 was completed in a compressed schedule and the plant was back on line mid-November. Doel 4 was authorised to restart in early December 2018. Doel 2 is expected to restart in January 2019, followed by Doel 1. Tihange 2 and 3 should follow later in the spring of 2019. Belgium currently plans to shut down its seven

1. AP1000 is a pressurised water reactor.

Ohi Nuclear Power Plant, units 3 and 4, Japan.
Wikimedia Commons

operating nuclear reactors by 2025. In October 2018, China and Belgium signed a framework agreement on co-operation in the peaceful uses of nuclear energy.

- Canada released in November 2018 a stakeholder-driven Roadmap that outlines the potential applications for Small Modular Reactors (SMRs) for the country. The Roadmap was convened by the Government of Canada and identifies clear roles for SMRs as a clean alternative to coal-fired power stations, but also as a source of clean heat and electricity to industry, as well as for providing energy to remote communities.
- In Finland, longer than planned commissioning tests for Teollisuuden Voima Oyj (TVO) EPR unit are delaying the regular start of electricity production now planned for January 2020. Based on the progress of the Finnish Radiation and Nuclear Safety Authority (STUK) to date, Fennovoima expects to receive a construction licence for Hanhikivi 1 in 2021, with construction expected to start soon after the licence is granted.
- The French government announced the new energy strategy in November 2018, confirming the objective to decrease the share of nuclear electricity from 75% to 50% by 2035 (not 2025, as earlier announced). To do so, the government announced that 14 of the 58 units in operation would be shut down by 2035. Taking into account France's objective to be carbon neutral by 2050, the authorities announced they would launch a programme of work with the industry to address all issues that need to be considered in order to make a decision on a possible new build programme by 2021.
- In Hungary, initial site work (e.g. engineering surveillance, etc.) for two new units at the Paks site started in 2018. In February 2018, Austria launched a lawsuit against the EC for its approval of Hungarian state subsidies for the two new reactors to be constructed at Paks.
- In Japan, in 2018, four reactors were added up to a total of nine reactors, all PWRs, which have resumed operation after a thorough conformity review by the NRA that confirms whether they meet the new regulatory requirements. These units are: Kyushu's Sendai units 1 and 2 (2015) and Genkai units 3 and 4 (2018); Shikoku's Ikata unit 3 (2016); and Kansai's Takahama units 3 and 4 (2016, 2017) and Ohi units 3 and 4 (2018). Another three PWR units (Kansai's Takahama 1 & 2 and Mihama 3), two ABWR units (TEPCO's Kashiwazaki-Kariwa 6 & 7) and one BWR (Japan Atomic Power Company's Tokai Daini) satisfied the new regulatory requirements respectively in 2016, 2017 and 2018, but no ABWR or BWR units have yet restarted operation. Overall, 12 more reactors, including units under construction are under NRA's review for the permission, and 19 units are or will be under decommissioning as of the end of 2018.
- In Korea, the total number of nuclear reactors in operation has reached 24, with an installed capacity of 22.5 GWe, accounting for 30.3% of the country's total generating capacity in 2017. Five reactors are currently under construction, including Shin-Kori-6 which started construction in September 2018. Grid connection of Shin-Kori-4 is expected to occur in August 2019. The Board of Korea Hydro & Nuclear Power (KHNP) announced the permanent shutdown of the Wolsong-1 nuclear reactor in Gyeongju-si, North Gyeongsang Province, in June 2018, four years before the end of its license.
- In Poland, the Ministry of Energy published in November 2018, its draft energy policy to 2040. The document reaffirmed Poland's plans to develop 6-9 GW of nuclear energy as part of a diverse energy portfolio, moving it away from heavy dependence on coal and imported gas. Poland's first nuclear power plant – with an output of 1 000 or 1 500 MW – could come online in 2033, with another five expected to follow by 2043.
- In Russia, Rostov 4 and the first unit of Leningrad Phase II received operating licences. Fuel loading into the two units of the Akademik Lomonosov floating plant was completed on October 2018. Start-up of the first unit took place in November in Murmansk, and the second reactor is expected to follow shortly. The vessel is expected to be towed to its permanent base at Pevek in Russia's Chukotka region in the summer of 2019. In December 2018, Russian fuel manufacturer TVEL initiated the batch production of MOX fuel assemblies for use in the new BN-800 fast reactor.
- During 2018 in Spain the NPP operators, the government and other stakeholders worked to define a plan for the renewal of the licenses of the nuclear power plants currently in operation and to establish a tentative calendar for their shutdown, in accordance with the Integrated National Energy and Climate draft Plan, to be endorsed in 2019. Nuclear energy is the largest source of electricity

Vogtle Unit 4 - AP1000, United States, August 2016 CA20 module placed.
Georgia Power Company

in Spain with 21%, followed by wind power with 18% and coal with 17%. Nuclear energy provides 40% of the electricity generated low carbon sources in Spain.

- In the United Kingdom, nuclear energy enjoys overall public support. In 2018, 22% of the British population were opposed to nuclear energy, while 35% supported it and 40% expressed a neutral stance. In order to maintain the role of nuclear power in its electricity supply, the UK government published the Nuclear Sector Deal in June 2018. With the ultimate objective of delivering "affordable, reliable and always available nuclear power", this document discusses new business models for the construction of new nuclear power plants that are expected to deliver up to 30% lower costs by 2030, cost savings of up to 20% in decommissioning, as well as a more competitive supply chain and the development of a specialised workforce. First concrete was poured on the "common raft" at Hinkley Point C on December 2018. The reactor building is to be constructed on this basemat. The UK Government is also considering four further projects at Sizewell (EPR, EDF/CGN), Bradwell (HPR1000, CGN/EDF), Wylfa (ABWR, Hitachi) and Oldbury (ABWR, Hitachi). A sixth project at Moorside in Cumbria was abandoned in November 2018, as its original sponsor, Toshiba of Japan, pulled out of nuclear construction altogether and was unable to find a buyer for the project. The UK government, however, confirmed that the site remains available for the construction of a new nuclear reactor.
- In the United States, the sale of nuclear supplier Westinghouse Electric Company to the Canadian financial company Brookfield Business Partners L.P. was completed in January 2018. The construction of two AP1000 reactors continued at the Vogtle site. Vogtle 3 is currently scheduled to enter service by November 2021 and unit 4 by November 2022. Some US states have taken action to provide policy and financial incentives so as to keep existing nuclear power plants operating in the face of historically low electricity prices. In 2018, Connecticut become the latest state to allow nuclear power plants to bid into electricity markets with other such resources as wind, solar and hydropower.

Among non-NEA countries, China continues to lead new reactor construction, connecting seven reactors to the grid in 2018, including the first four AP1000 and the first EPR reactors. However, construction seems to have slowed – as China did not start construction on any new power reactor units in 2018. At the same time, there are several new construction projects planned for 2019. In November 2018 the Chinese State Power Investment Corporation (SPIC) and Westinghouse (now owned by the Canadian Brookfield Business Partners) signed a co-operation agreement in relation to the AP1000 and CAP1400 technologies globally.

India has ambitious goals for the deployment of nuclear energy capacity. There are currently seven reactors under construction in India (four pressurised heavy water reactors, two VVER 1000 and one sodium fast reactor), with a combined capacity of 4.3 GWe. The country has also completed agreements with Russia's Atomstroyexport for two more units at Kudankulam, as well as an industrial agreement between EDF and NPCIL for the construction of six EPR units in Jaitapur. In December 2018 Kaiga unit 1 set a new world record for the longest continuous operation of a nuclear power reactor of any type. The pressurised heavy water reactor has completed 941 days of uninterrupted operation since 13 May 2016.

The United Arab Emirates (UAE) is building four new AP1400 reactors, designed and led by Korea's KEPCO. Unit 1 was completed in March 2018, and in October 2018, units 2, 3 and 4 were 94%, 86% and 76% complete respectively. The fuel loading and start-up is expected in late 2019-2020, once operator training has been completed and all the regulatory licenses for operation have been obtained.

Developments in nuclear fuel supply

Uranium production slowed in 2018 at several mining facilities following depressed market conditions in recent years. Nevertheless, uranium prices have recovered in the second part of the year 2018 mainly as a result of the combined effects of renewed interest in uranium from investors (e.g. Yellow Cake Investment Fund) coupled with production cutbacks by major producers. In Canada, mining at the McArthur River mine and milling at Key Lake were suspended at the end of January 2018 and further announcements in July 2018 indicated the suspension is indefinite. The world's largest producer, Kazakhstan, also announced plans to reduce production by 20% over the next three years. The Langer Heinrich mine in Namibia was placed in care and maintenance at the end of May 2018. In another development, it was reported in late August 2018 that ore processing at Olympic Dam copper, gold, and uranium mine

in South Australia was being impacted by a technical issue at its acid plant. In October 2018, NAC Kazatomprom issued a press release regarding the Kazakhstan's uranium company's plans to proceed with an Initial Public Offering (IPO). Rio Tinto announced in November 2018 that it entered into a binding agreement with China National Uranium Corporation Limited (CNUC) to sell its entire 68.62% share in Rössing uranium mine in Namibia.

Uranium was produced in eight NEA member countries in 2018, with Australia, Canada, Russia and the United States accounting for a significant share of global production (about 35%).

In January 2018, two main uranium producers in the United States filed a petition with the US Department of Commerce requesting an investigation into the effects of uranium imports on US National security. As part of the inquiry and review, it was requested that imports should be limited and that 25% of the US nuclear market be reserved for domestic uranium production. An investigation by the US Department of Commerce is under way.

Commercial uranium conversion facilities were in operation in Canada, France and Russia. The new Philippe Coste uranium conversion facility in France was completed and comprises two plants in southern France, one at the Tricastin, and one at Malvesi, near the town of Narbonne. The new facility has a capacity of 15 000 metric tons per year and it required a construction investment of EUR 1.15 billion over 12 years. The plant converts uranium oxide first to uranium tetrafluoride, or UF4, and then to uranium hexafluoride, or UF6, prior to enrichment for use in nuclear fuel.

Two recently built, high-efficiency uranium centrifuge enrichment plants – Areva's Georges Besse II plant in France and Urenco's facility in the United States – continued commercial operations through 2018. Poor market conditions have caused enrichers to gradually phase out older centrifuges and to make greater use of capacity through underfeeding and tails re-enrichment. Urenco announced in mid-2018 that the Tailings Management Facility (TMF) project in the United Kingdom is nearing completion and commissioning has commenced. In the United States, development of the GE Hitachi laser enrichment technology has slowed, reflecting market conditions. In June 2018, Silex Systems Ltd. reported its board will abandon the acquisition of a majority stake in GE Hitachi Global Laser Enrichment LLC (GLE), which is the exclusive licensee of the SILEX laser uranium enrichment technology. During 2018, Centrus Energy Corp. continued work on American Centrifuge technology, under a contract from the US Department of Energy's Oak Ridge National Laboratory (ORNL). China reported in November 2018 that its commercial demonstration project for the country's latest uranium enrichment centrifuge design had been completed and approved.

With respect to the nuclear fuel market, uranium and conversion prices have increased significantly in 2018, but the enrichment market has experienced a slight decline.

Yellow cake.

Creative Commons, Dean Calma

Nuclear safety and regulation

In 2018, NEA member countries continued their efforts to enhance the robustness of nuclear installations and regulatory frameworks. The international focus on accident management has led to significant progress in strengthening the availability and diversity of mitigation equipment and in improving emergency procedures and strategies. NEA member countries have also continued to co-operate on better understanding the risks associated with natural hazards and external events, such as earthquakes, tsunamis and river flooding. In addition, they have recognised the vital importance of developing and sustaining a strong safety culture in both operating organisations and regulatory bodies.

Technical support organisations and regulatory bodies of NEA member countries have continued to expand their knowledge in many important technical areas with co-operative research activities. Through international research, increased knowledge has been gained in severe accident phenomenology and thermal-hydraulics; computer codes and modelling; fire propagation; and fuel and material properties.

The NEA and its member countries are initiating near-term research activities related to the accident at Fukushima Daiichi to address safety knowledge gaps and to support timely decommissioning. These near-term research activities will help to expand the technical knowledge base of fuel and fission-product behaviour during a severe accident and to improve understanding of the various computer codes used for accident analyses.

The NEA and its member countries remain focused on ensuring the safe operation of nuclear facilities. Efforts related to the long-term operation of nuclear power plants, such as the ageing of plant structures, systems and components, will continue to be an active area of international collaboration among NEA member countries. Additionally, regulatory bodies of NEA member countries are working together to address the increased use of digital technologies in nuclear installations and to ensure quality in the supply chain of nuclear components.

Research and development play a key role in supporting the safety improvement. They are also an important contributor for innovative technologies introduction. Besides, the process for innovation introduction is most effective and timely when the industry, research and regulatory communities are engaged from the early stages of the development process. However, such an early engagement raises several questions. The NEA and the technical support organisations and regulatory bodies of its member countries have confirmed an increasing interest in the area of "innovation and regulatory process": in the near future, they will certainly have further discussions to identify and address the related challenges.

International collaboration and sharing of experiences at the NEA will continue to support the safe construction and commissioning of new reactor designs, as well as the regulatory reviews of advanced reactor designs. The NEA has also confirmed its interest in developing activities on the interface between safety and security. As some nuclear power plants transition to the decommissioning phase, the regulatory issues and challenges that arise are likewise presenting opportunities for NEA member countries to further share experiences and best practices.

NEA collaborative activities and projects aimed at addressing knowledge gaps and sharing best practices in many technical and regulatory areas throughout the life cycle of nuclear installations will continue to contribute to the advancement of nuclear safety and regulation.

Human aspects of nuclear safety

The human aspects of nuclear safety are essential factors in the safe operation of nuclear installations, as well as in the effectiveness of regulatory authorities. This reflects the need to examine complex areas beyond technical issues that may have large impacts on safety, decision-making and ultimately on the current and possible future uses of nuclear technology. It also considers the increasing need to tackle these matters on a cross-cutting and multidisciplinary basis. In 2018, NEA member countries continued to enhance efforts in this regard by addressing the human aspects associated with safety culture, human and organisational factors, leadership, capacity building and personnel training, safety-related public communication, as well as confidence building in long-term waste management.

NEA member countries continued to implement measures in relation to safety culture, reinforcing their regulatory requirements, and by further developing their guidelines and guidance documents.

- In Belgium, the Bel V subsidiary of the Agence Fédérale de Contôle Nucléaire (AFCN/FANC) created a safety culture maturity matrix in alignment with the publication *The Safety Culture of an Effective Nuclear Regulatory Body* (NEA, 2016) to analyse the safety culture within the regulatory body.
- In France, the Nuclear Safety Authority's (ASN) Advisory Committee on Social, Organisational and Human Factors (COFSOH) approved in June 2018 a document entitled *Reflection on the Issues Raised by the Legal Framework for Contracting and Outsourcing in Regulated Nuclear Facilities* drafted by the COFSOH's Working Group on Legal Aspects.
- Germany conducted a workshop on the Safety Culture of the Nuclear Regulatory Body, organized by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU[2]). Representatives from IAEA, Sweden, Finland, and German authorities presented their activities in their regulatory bodies as well as the current state of the art at the OECD-NEA level.
- The Authority for Nuclear Safety and Radiation Protection (ANVS) in the Netherlands recently hired experts with broad experience on safety culture with backgrounds external to the nuclear industry. This member country also began providing training on reflection in action concerning bridging gaps between divergent ideas based on a defensive/productive reasoning model.
- In Poland, the National Atomic Energy Agency (PAA) conducted benchmarking visits co-ordinated with other regulatory bodies, most recently with Switzerland and South Africa. Additionally, all members of PAA were invited to participate in the workshops, where various aspects of safety culture were discussed.
- Within the framework of the Swiss Federal Nuclear Safety Inspectorate's (ENSI) project on Oversight Culture, a set of newly defined management and leadership principles were recently implemented.
- The Office for Nuclear Regulation (ONR) in the United Kingdom published a Guide to Enabling Regulation and developed a User Guide on Intervention Strategy for Leadership & Management for Safety.

Protective clothing.
Areva, Jean-Marie Taillat, France

2. BMU : Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit, (Federal Ministry for Environment, Nature Conservation and Nuclear Safety).

Helmets.
Shutterstock, Nuei57

- Several members of the Working Group on Safety Culture (WGSC) including the Korea Institute of Nuclear Safety (KINS), the Japan Nuclear Regulation Authority (NRA), Russia's State Atomic Energy Corporation (ROSATOM), the Spanish Nuclear Safety Council (CSN), and the United States Nuclear Regulatory Commission (USNRC) are in the various stages of developing, conducting and analysing the results of their self-assessments.

Radiological protection

The circumstances encountered by the radiological protection community during 2018 focused concerns and actions towards the future. Identified areas of focus include: encouraging university students to study radiological protection; maintaining and passing on radiological protection experience and know-how to the next generation of radiological protection leaders. While experience with the implementation of the latest International Commission on Radiological Protection (ICRP) recommendations is bringing new approaches to and interpretation of the ICRP framework, radiological protection science continues to provide interesting but inconclusive evidence of low dose radiological risks, and a study of the preparedness for post-radiological-accident recovery is gaining priority.

Radiological protection (RP) careers have existed and thrived for many years, offering employment in many areas. However, the post-Three Mile Island, post-Chernobyl, and post-Fukushima periods seem to have had significant effects on the number of students entering university RP degree programmes, and on the number of universities offering RP degrees, thereby affecting the future availability of RP specialists in virtually all areas. The importance of addressing these circumstances in a broad sense is widely agreed. This suggests the need to focus on: giving more visibility to the many possible RP career paths as well as to the need for experts in all aspects of RP; and facilitating career mobility to support RP experts' ability to work where they are needed.

Part of the focus of future radiological protection experts will be on management and evolution of the international system of radiological protection. Eleven years after the issuing of the latest ICRP general radiological protection recommendations, international organisations and national governments have gained experience in their interpretation and implementation. Effective ways to approach this new framework and aspects that could be more clearly presented to facilitate their use to address various circumstances, have arisen since 2007. Post-Fukushima recovery work is a key example. Further experience with implementation will provide invaluable input to the future work of the ICRP.

Part of these discussions of system evolution will be driven by the status of state-of-the-art radiological protection science. In particular, ongoing research into the adverse effects of low doses, the order of doses received routinely by workers and members of the public, is expected to bring new insights into possible health effects. At low levels of dose, it is currently not known whether radiation exposure can cause adverse health effects, e.g. cancer or leukaemia. For this reason, the current system of radiological protection takes a prudent approach and assumes that any exposure carries a health risk, proportionally smaller as exposures decrease. Epidemiological and radiation biology studies of such low doses are aimed at better understanding the health risks, if any, and are ongoing around the globe. Increased co-operation and co-ordination are being pursued, in particular with similar studies of chemical toxicology, where it is felt that collaborative efforts can improve the efficiency and effectiveness of research.

The Fukushima Daiichi nuclear accident has clearly demonstrated the complexity of post-accident recovery circumstances. This is an area that has not been extensively studied or exercised in the past, and for which preparation has not been centrally addressed. Attention is now being focused on developing a framework for recovery actions, including the provision of information to help affected stakeholders understand their radiological situations, the structure of responsibilities, and the management of resources.

Radioactive waste management

In 2018, NEA member countries continued to work on the safe management of spent fuel and radioactive waste. With the objective of bringing greater clarity to enhance confidence as well as to address the risks associated with radioactive waste management practices, the regulators, radioactive waste managers, and policy developers are increasingly recognising the importance of transparency and public participation in the decision-making process.

In Europe, EU members completed the first round of reporting on their national waste management programmes to the European Commission (EC) as required by the EU Council Directive 2011/70/Euratom. Such efforts provide an overview of the national radioactive waste management programmes in EU countries, improve public confidence, and allow for better management strategies to be defined.

The revision and development of safety cases for disposal of long-lived radioactive waste continue to improve in many NEA countries. The evolution of safety cases for geological disposal facilities, which aim at improving the robustness of safety assessments and the prediction of long-term performance of geological repositories, is revealed in the 2018 Integration Group for the Safety Case (IGSC) Symposium.

Geological section of the Bure sector, France.

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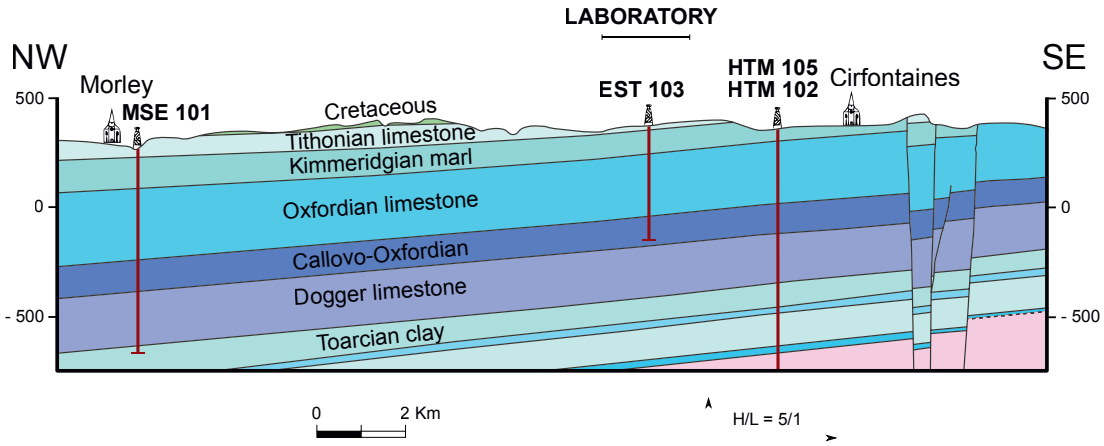


In 2018, construction continued on the first permanent repository for high-level radioactive waste in Olkiluoto, Finland. This work sets precedence and offers valuable experience to other countries developing geological disposal.

Other highlights are as follows:

- In Argentina, the National Atomic Energy Commission (CNEA) carries the main responsibility for radioactive waste management. Spent fuel is not currently considered radioactive waste and is being safely stored in specially designed facilities, until a decision is made regarding the development of a deep geological repository by 2030. The deep geological repository is anticipated to be operational by 2060.
- In Canada, the Nuclear Waste Management Organization (NWMO), the organisation responsible for the final disposal of high-level waste, continues to move forward with its nine-step siting process in order to find a safe, secure and suitable disposal site in an informed and willing community. In 2018, five areas in Ontario remain the focus of the NWMO's site selection process. On the technical side, a revised conceptual container design has been developed that is specific to Canada Deuterium Uranium fuel bundles. The first full-scale prototype containers have been manufactured and have been subjected to failure testing to confirm their design capacity.
- In the Czech Republic, a new Atomic Act (No. 263/2016) came into effect at the beginning of 2018. In November 2017, the process of updating the Czech conception was completed and the government approved a document entitled "The Concept of Radioactive Waste and Spent Nuclear Fuel Management in the Czech Republic". The Concept was subjected to a process of strategic environmental assessment, including a cross-border public consultation with neighbouring countries. The siting process for a spent fuel repository is still being defined, with the implementer – the Radioactive Waste Repository Authority (SÚRAO) – focusing on dialogue with municipalities considering offering to host the repository. SÚRAO has been conducting surface geological surveys at nine potential sites since 2015. Based on survey results from 2015, SÚRAO decided to focus the site selection process in 2018 on four to five potential sites. A site should be selected by 2025, and the on-site underground research facility is being planned for 2030-2045.
- In Finland, the Expert Group in Nuclear Waste Management (Posiva Oy) entered a new phase of repository development and construction in Olkiluoto, with construction beginning in December 2016. The Finland Radiation and Nuclear Safety Authority (STUK) had granted permission in late November 2016 to begin construction of the deep geological repository (DGR) for high-level waste (HLW), and an operational disposal facility is foreseen for 2023. In 2018, a full-scale in situ system test was implemented in ONKALO to demonstrate the feasibility of the KBS 3[3] repository system. Posiva is also working on its latest Safety Case Plan for the Operating Licence Application, foreseeing its submission in the early 2020s.
- In France, the industrial geological storage center (Cigéo) Project continued to develop a DGR for high-level and long-lived, intermediate-level waste in the Meuse-Haute Marne area. In 2018, the regulator (ASN) published its opinion on the "Safety Options Dossier" submitted by the French National Radioactive Waste Management Agency (ANDRA) that sets out the objectives, concepts and safety principles of disposing intermediate, long-lived and high-level radioactive waste in Callovo-Oxfordian (COX) formations. In its opinion, the ASN considers that overall the project has reached a satisfying level of technical maturity as far as the Safety Options Dossier phase is concerned. ANDRA also presented the Cigéo Operations Master Plan, which covers details of waste inventories and the current progress towards various milestones. In 2018, ANDRA has proceeded with the project design studies that will lead to the performance of an Environmental Impact Assessment and the submission of a licence application in 2019.
- In Italy, the Italian state-owned company for decommissioning and management of radioactive waste (SOGIN) submitted to the Italian Institute for Environmental Protection and Research (ISPRA) an updated National Chart of Potentially Eligible Sites (CNAPI) for a near-surface disposal facility for LLW/ILW and a storage facility for long-term storage of ILW/HLW in January 2018. ISPRA submitted the reviewed National

3. Special method for final disposal of the spent fuel. KBS-3 is based on 3 protective barriers: copper canisters, bentonite clay and the Finnish bedrock.

Chart of Potentially Eligible Sites (CNAPI) on 29 March 2018 to the Ministry of Economic Development and the Ministry of Environment, Land and Sea Protection for publication. Once the National Chart has been published, a national discussion will be held to come to an agreement on the siting of the national repository and storage facility.

- In Germany, the "Act on the Organisational Restructuring in the Field of Radioactive Waste Management", which came into force in July 2016, has reorganised the roles and responsibilities of various federal offices. The German Federal Office for the Safety of Nuclear Waste Management (Bundesamt für kerntechnische Entsorgungssicherheit, BfE) is now responsible for the supervision and licensing of nuclear fuel transport, interim storage of radioactive waste, disposal site selection and disposal facility surveillance. The management responsibilities of nuclear waste are assigned to the Federal Company for Radioactive Waste Disposal (Bundesgesellschaft für Endlagerung mbH, BGE), while the responsibility of interim storage of radioactive waste lies with BGZ Gesellschaft für Zwischenlagerung mbH (BGZ). The Repository Site Selection Act was amended and became effective in May 2017 and will continue to serve as the selection basis for the siting of a radioactive waste disposal facility.

- In Japan, the work of the geological disposal research programme is ongoing while a policy for HLW management is being debated among several national organisations. After the government had revised its basic policy in 2015 on the disposal of HLW, underlining the importance of consensus building between the government and local communities, as well as of reversibility and retrievability, the Ministry of Economy, Trade and Industry (METI) then published the "Nationwide Map of Scientific Features for Geological Disposal" in 2017 in order to enhance communication with the public. METI, in co-operation with the NEA, organised a workshop to discuss international experience on safety case communication. The Nuclear Waste Management Organisation of Japan (NUMO) issued a site descriptive model (SDM) based safety case in 2018.

- In Korea, the Ministry of Trade, Industry and Energy (MOTIE) is working on a basic plan for the management of spent fuel based on 2015 recommendations submitted by the Public Engagement Commission on Spent Nuclear Fuel Management (PECOS). These recommendations stipulated that a site should be found for an underground research laboratory (URL) by 2020 to undertake in situ experiments from 2030 and initiate operation of a DGR from 2051.

- In Poland, the National Programme of Radioactive Waste and Spent Fuel Management underwent the ARTEMIS integrated expert peer review in 2017. A group of experts from the International Atomic Energy Agency (IAEA) assessed Poland's management of spent fuel and radioactive waste and determined that the country is approaching the safe handling of radioactive waste while identifying areas for improvement. In 2018, Polish delegates worked with the European Repository Development Organisation (ERDO), the NEA Salt Club, and the NEA Integration Group for the Safety Case (IGSC) in preparation for the creation of a future repository for spent fuel and high-level waste.

- In Russia, the design process continued for the development of a DGR for high-level and intermediate-level waste in the region of Krasnoyarsk. The first stage of the project consists of building a URL by 2025, with a planned test and demonstration of disposal for different types of radioactive waste. The final decision on the DGR is expected should be taken by 2030-2035. Significant progress has also been made in establishing disposal facilities for low-and intermediate-level waste (LILW) (i.e. class 3 short-lived, intermediate and long-lived low-level waste, and class 4 short-lived, low-level waste and very low-level waste). Disposal facilities are planned for class 3 and 4 waste in the Tomsk and Chelyabinsk regions. Currently, since 2016 Russia has one operating disposal facility for low-and intermediate-level waste (LILW) in the Sverdlovsk region. The second part of the facility is scheduled for operation in 2022.

- In Slovenia, the National Assembly of the Republic of Slovenia adopted a new Act on the Protection against Ionizing Radiation and Nuclear Safety, which introduced some provisions of the European Nuclear Safety Directive, on 12 December 2017. The Act went into effect on 6 January 2018. At the NPP Krško site, there is a plan to implement dry storage of spent fuel, which is currently stored in a spent fuel pool, by 2021.

- In Spain, an Integrated Regulatory Review Service Mission (IRRS) and an ARTEMIS review were conducted in October 2018. The Ministry for the Ecological Transition dismissed the renewal of the operational permit for NPP Santa María de Garoña in August 2017, as a consequence steps were taken towards immediate dismantling. In 2018, evaluation works continued for the licensing of the Centralised Spent Fuel Storage (CSFSF) facility for all of the spent fuel, high-level waste and long-lived intermediate-level waste in the country were temporarily suspended at the request of the Ministry for the Ecological Transition until the Integrated National Energy and Climate Plan is endorsed.

- In Sweden, the nuclear regulator, along with the Land and Environment Court in Stockholm and the municipality of Östhammar, are continuing their review of general licence applications for spent fuel disposal. In June 2016, the Swedish Radiation Safety Authority (SSM) determined that the licence application from the Swedish Nuclear Fuel and Waste Management Company (SKB) for an encapsulation plant and Forsmark repository had the potential to comply with its requirements, and subsequently recommended that the Land and Environment Court grant SKB permission to carry out activities in accordance with the Swedish Environmental Code. The main hearing for SKB's application in the Swedish Land and Environment Court took place in autumn 2017. On 23 January 2018, the court submitted its review statement to the government, and the Swedish Radiation Safety Authority will present its review conclusions to the government for decision.

- In Switzerland, stage 2 of the sectoral planning process for deep disposal of radioactive waste is currently underway. A government decision on a stage 2 proposal concerning two or more sites for LILW and HLW is anticipated by the end of 2018. Following the instructions of the Swiss Federal Nuclear Safety Inspectorate (ENSI) to continue development without delay, the National Co-operative for the Disposal of Radioactive Waste (Nagra) carried out a 3D seismic campaign in Nördlich Lägern and submitted drilling licence applications in 2017. Areas for potential siting of deep geological waste repositories for HLW or LLW have been identified from a technical point of view. Stage 3 will examine logistical and economic aspects with the relevant communities and cantons in view of reducing the number of identified sites.
- In the United States, further to the Nuclear Regulatory Commission (NRC) supplement concluding negligible impacts on groundwater and surface discharges, the Department of Energy (DOE) is now on a path to accelerate progress on the disposal of nuclear waste as foreseen in the Presidential Budget Blueprint for 2018.

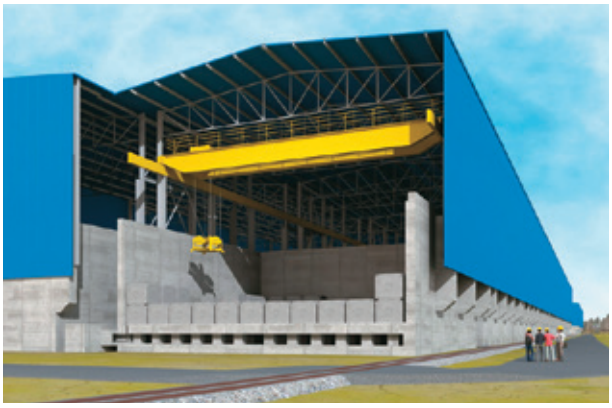
Low- and intermediate-level waste

Progress has also been made in the area of the safe management of low- and intermediate-level waste (LILW). Highlights are provided below:

- In Belgium, the Belgian Agency for Radioactive Waste and Enriched Fissile materials (ONDRAF/NIRAS) provided the necessary details to address outstanding questions in relation to the Dessel disposal project. The organisation plans to complete the update of its safety case in 2018 and is preparing its encounter with the Scientific Council of the Federal Agency for Nuclear Control (AFCN/FANC) in late 2018 or early 2019.
- In Canada, Ontario Power Generation (OPG), the nuclear operator in Ontario, Canada, continued with the development of a geological repository for L&ILW in Bruce County, Ontario. A public review was held in 2017 following OPG's submission of additional information in response to a request from the Minister of Environment and Climate Change in late 2016. An environmental assessment decision from the Minister is required to continue with the proposed project.
- In Germany, the construction of the waste transport shaft (shaft 2) and the emplacement field continued at the former Konrad mine. By 2027, up to 303 000 m^3 of radioactive waste with negligible heat will be permanently stored in this former iron ore mine.
- In Korea, the LILW repository in Wolsong was licensed in late 2014 and started operation in 2015. The LILW disposal facility at Yangbuk-myeon, Gyeongju city, with a total capacity of 800 000 drums (200-liter size) in an area of 2 100 000 m^2, started operation in 2015. The construction of the second phase facility is expected to be completed by 2019 with near-surface disposal having a capacity of 125 000 drums.
- In Russia, a regional LLW & ILW repository system is in the development stage and the siting process is ongoing. In 2017, operations continued at the first LILW near-surface repository that began operation in Novouralsk in 2015.
- In Slovenia, discussions were organised with Croatia regarding common LILW disposal solutions between the two countries in 2018. At the NPP Krško site, volume reduction campaigns took place in the form of incineration, evaporation and super-compaction, and a new building for the manipulation of waste was constructed.
- In the United States, the NRC is in the process of preparing a regulatory basis for the disposal of greater than class C (GTCC) waste since the current regulation (10 CFR Part 61) does not contain general criteria for the disposal of this class of waste, or for transuranic (TRU) waste.

Surface disposal model of the proposed disposal facility, Dessel, Belgium.

ONDRAF/NIRAS, Belgium



Nuclear Decommissioning and Legacy Management

Significant progress continues to be made on decommissioning and environmental remediation projects across NEA countries. A brief summary of the ongoing decommissioning efforts in NEA countries in 2018 follows below:

- In Canada, Canadian Nuclear Laboratories (CNL), a private-sector organisation is responsible for managing Atomic Energy of Canada Limited's (AECL) environmental, decommissioning and waste management liabilities. CNL is planning to construct a near-surface disposal facility at Chalk River Laboratories for the disposal of low-level waste (LLW). CNL is also proposing the in-situ decommissioning of the Nuclear Power Demonstration prototype reactor in Ontario and the Whiteshell research reactor in Manitoba. On behalf of AECL, CNL is also implementing the Port Hope Area Initiative, which involves the cleanup and long-term management of roughly 1.7 million cubic metres of low-level radioactive waste and contaminated soils in communities of Port Hope and Clarington, Ontario. Under the Initiative, two modern facilities for the long-term management of the wastes have been constructed and are now being operated to receive waste from existing waste management facilities, as well as other wastes which are dispersed in the local area.

Whiteshell laboratories decommissioning.
Canada Nuclear Laboratories (CNL)

- In Finland, the Technical Research Centre of Finland Ltd (VTT) is preparing an operating licence application for decommissioning the FiR 1 Triga Mark II research reactor that was shut down in 2015. The Radiation and Nuclear Authority (STUK), the Finnish regulator, will oversee the first decommissioning and dismantling of a nuclear facility in Finland.

- In Germany by the end of 2018, 24 decommissioning projects of NPPs and prototype reactors were in progress with one of them in safe enclosure. Licenses for decommissioning were granted for NPP Unterweser in February 2018, for NPP Grafenrheinfeld in April 2018 and for NPP Brunsbüttel in December 2018. Licensing procedures for the permanently shut down NPPs Krümmel and Gundremmingen-B are in progress. Seven NPPs still are in operation and will be shut down on a step-by-step basis by the end of the year 2022 at the latest, five of them have already applied for decommissioning. The next NPP to be shut down will be Philippsburg 2, which is expected to be shut down at the end of 2019."

- In Japan, the Nuclear Regulation Authority (NRA) revised the Act on the Regulation of Nuclear Source Material, Nuclear Fuel Material and Reactors in 2017, which requires licensees to prepare and announce the Forward Planning of the Decommissioning Policy including measures associated with decommissioning of the nuclear facilities while they are in service. Based on this enforcement, every licensee which is required to prepare and announce it did so in an appropriate manner in 2018.

- In Russia, the decommissioning of four units at the Novovoronezh and Beloyarsk NPPs, and another four nuclear and radiation hazardous facilities, continued in 2018. Units 1 and 2 of the Leningrad NPP, units 1, 2, 3 and 4 of the Bilibino NPP, as well as units 1 and 2 of the Kola NPP, were undergoing preparation for decommissioning in 2018.

- In Spain, the decommissioning of José Cabrera (Zorita) entered its final stages. Tasks including the cleaning of walls and reinforced concrete structures to prepare them for the final conventional demolition are in progress. The washing and sorting out of contaminated soils is completed. The completion of all decommissioning activities is estimated by the end of 2019.

- In Sweden, the final dismantling of Studsvik's R2 material test reactor continued in 2018, and the work is expected to be completed in 2019. Dismantling of the Agesta pressurised heavy water reactor (PHWR) is planned for 2020. To accommodate decommissioning waste from these dismantling projects, a new storage building for low-and intermediate-level decommissioning waste is being planned at the Studsvik site. Nuclear plant licensees also prepared for the shutdown of the four oldest reactors, units 1 and 2 in Oskarshamn were permanently shut down in 2017 and Ringhals (units 1 and 2) will be shut down in 2020. Along with two units in Barsebäck and Agesta, a total of seven reactors are scheduled for decommissioning in the coming years. The remaining six operating reactors at Oskarshamn, Ringhals and Forsmark will continue in long-term operation, their lifetimes having been extended to 60 years.

- In Switzerland, the Swiss Federal Nuclear Safety Inspectorate (ENSI) is reviewing the first decommissioning plan for the commercial nuclear power plant of Mühleberg submitted to the Swiss Federal Office of Energy (SFOE).

- In the United Kingdom, since the Nuclear Decommissioning Authority (NDA) became the owner of the Sellafield site in 2016, a 350-tonne machine has been installed to retrieve radioactive waste out of the storage silo, and the retrieved waste will be packed into nuclear skips while awaiting disposal in the UK's geological disposal facility. The NDA has estimated that it will take 20-25 years to complete clean-up at Sellafield.

- In the United States, clean-up work at the Plutonium Finishing Plant (PFP) in Hanford, Washington, and building demolition and waste disposal at Oak Ridge, Tennessee, as well as at other Department of Energy (DOE) sites (e.g. Savannah River), continued in 2018. The United States Nuclear Regulatory Commission (NRC) continues to oversee 20 permanently shut down power reactor units in various stages of decommissioning. Of these 20 reactors, 6 are undergoing active decommissioning (DECON[4]) and 14 have elected to defer decommissioning (SAFSTOR[5]). Permanently shut down reactors have 60 years to complete decommissioning, in accordance with Federal Regulation 10 CFR 50.82(a)(3). Additionally, the NRC continued with licensing and oversight activities at 4 research and test reactors; 13 complex material decommissioning facilities; 2 fuel cycle facilities; 22 title 1 uranium milling sites and 11 title 2 uranium recovery facilities. Since the issuance of advance notice for proposed rulemaking (ANPR) in November 2015, the NRC has conducted public meetings to seek external stakeholder input and has initiated the research activities required to support decommissioning rulemaking, which is expected to be completed by 2019.

4. A method of decommissioning in which structures, systems, and components that contain radioactive contamination are removed from a site and safely disposed of at commercially operated low-level waste disposal facility.
5. A method of decommissioning in which a nuclear facility is placed and maintained in a condition that allows the facility to be safely stored and subsequently decontaminated.

TREAT subpile room, United States.
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Nuclear science and technology

Innovations in the nuclear sector require the co-operation of all actors in order for advances in nuclear science and technology to be transformed into practical and meaningful knowledge and policies. One of the significant milestones towards fostering innovation would be to maintain and develop the steadily shrinking experimental infrastructure. In 2018, the Halden Boiling Water Reactor (HBWR) was closed, creating a vacuum in the nuclear fuel and material research world. To maintain the required level of continuity, initiatives have been taken at national and international levels to favour the use of selected research reactors for joint experimental programmes. In order to address the future of fuel and material testing needs, and how these needs can be fulfilled, the nuclear community has been identifying what can realistically be achieved with currently operating material test reactors (MTRs).

In September 2018, Belgium's Council of Ministers approved EUR 558 million in funding for the Multipurpose Hybrid Research Reactor for High-tech Applications (MYRRHA) accelerator-driven research reactor at the Belgian Nuclear Research Centre's (SCK•CEN) site. The MYRRHA is a 57 MWt accelerator-driven system in which a proton accelerator will deliver a 600 MeV proton beam to a liquid lead-bismuth (Pb-Bi) spallation target coupled to a Pb-Bi cooled subcritical fast nuclear core. The MYRRHA is expected to replace Belgium's ageing BR2 research reactor, and will be used for producing medical radioisotopes, as well as a variety of research initiatives, such as the demonstration of the concept of transmutation of long-lived radionuclides in used nuclear fuel and nuclear waste.

To address the reinvigorated demand for transient testing, critical for the development of nuclear fuels for both the existing fleet and the new generation of advanced reactors, two nuclear fuel transient experiments were performed in 2018: by the French Institute for Radiological Protection and Nuclear Safety (IRSN) at the CABRI research reactor operated by France's Alternative Energies and Atomic Energy Commission (CEA), and at the Transient Reactor Test Facility (TREAT) at Idaho National Laboratory (INL) in the United States.

The industry is expanding operation of accident-tolerant fuel (ATF)-related concepts in fuel and material (F&M) test reactors and commercial reactors with prototypic segments and rods. Several vendors have been irradiating ATF claddings and initiating fuelled lead test assembly (LTA) programmes in order to gain operating experience and a better understanding of fuel compatibility issues. These base irradiations will produce fuel performance data in realistic normal NPP operating conditions and will make suitable pre-irradiated specimens available that favour both post-irradiation examinations in hot cells and the implementation of new specialised tests in F&M test reactors in the future.

A rapidly advancing area in nuclear science is modelling and simulation, however the ways in which end users from industry and safety confirm the correctness of these simulations continue to evolve. The validation of multi-physics modelling is a major challenge with inherent limitations regarding new technologies and applications. To underpin the validation process, smarter experiments that are physically relevant for the intended application are needed. Such experiments require state-of-the-art design approaches as well as instrumentation and data acquisition advances to occur simultaneously with advances in computing, in ways that optimise the codes' abilities to predict and guide decisions, enhancing reactor safety and economics.

Over several decades, a vast number of experimental campaigns have been performed, including the experiments in fuel and material test reactors. However, the data generated at significant cost remains underutilised. The closure of the Halden reactor has now triggered a rethink on how best to use and preserve the experimental data. An increasingly apparent fact is that international collaborations are of benefit not just during the front end of an experimental campaign, but they also help to preserve knowledge by putting it in the hands of the global community.

Nuclear Law

Sound national and international legal frameworks are essential to the safe and peaceful uses of nuclear energy. The development of the legal frameworks started from the very

beginning of the nuclear power industry, with the original conventions on non-proliferation, radiological protection and nuclear third party liability being adopted in the 1960s. During the 1970s, when the major nuclear programmes were continuing their fast development mainly in Canada, Europe, Japan, the Soviet Union and the United States, focus was put on non-proliferation and the need to regulate nuclear trade. The lessons learnt from the 1979 Three Mile Island and 1986 Chernobyl nuclear accidents, that respectively took place in the United States and in the Soviet Union, gave impetus to a new and important momentum to enhance the international legal framework and a series of international conventions were adopted in the 1980-90s in the field of nuclear safety, safety of spent nuclear fuel, radioactive waste management and public participation, while the nuclear liability regimes were modernised. After the terrorist attacks of September 2001, the international community concentrated on the reinforcement of the legal framework against terrorism.

After the 2011 Fukushima Daiichi nuclear accident, the IAEA Action Plan on Nuclear Safety called for the member states, with or without nuclear power programmes, to improve the effectiveness of the international legal framework, especially with regard to nuclear safety, by encouraging them to join and effectively implement the international nuclear instruments. Since then, several countries have adhered to international instruments, but most of all have reviewed their national laws to strengthen their institutional and legislative framework in the field of nuclear energy in accordance with the international legal framework.

Notwithstanding the best efforts to ensure high levels of nuclear safety, the possibility remains that an accident may occur in a nuclear installation (i.e. not only at nuclear power plants but also at installations storing nuclear fuel, nuclear substances, radioactive products or waste) or during the transport of nuclear substances to and from a nuclear installation. The three above-mentioned types of accident have shown that severe accidents can have varying and potentially far-reaching consequences, affecting people, property and the environment.

A wide consensus exists on the importance of providing nuclear liability regimes, which address the concerns of all countries that might be affected by a nuclear accident, in order to provide adequate compensation for nuclear damage. To date, 27 out of the 33 NEA member countries have adhered to one or more of the international nuclear liability conventions, and some to the Joint Protocol Relating to the Application of the Vienna Convention and the Paris Convention on Third Party Liability in the Field of Nuclear Energy (the "Joint Protocol"). The trend since the Fukushima Daiichi accident has been for countries, especially newcomer or potential newcomer countries (such as Jordan, Kazakhstan and Saudi Arabia), to adhere to at least one of the enhanced conventions – i.e. the Paris Convention on Third Party Liability in the Field of Nuclear Energy as amended by the 2004 Protocol (the "Revised Paris Convention", not yet in force), the Vienna Convention on Civil Liability for Nuclear Damage as amended by the 1997 Protocol (the "Revised Vienna Convention") and the Convention on Supplementary Compensation for Nuclear Damage (CSC). Romania and the United Arab Emirates have opted to join the Revised Vienna Convention, the CSC and the Joint Protocol and have therefore treaty relations with almost all countries parties to a nuclear liability convention.

The purpose of the enhanced nuclear third party liability regimes (i.e. the Revised Paris Convention, the Revised Vienna Convention and the CSC) is to provide better protection to potential victims by, among other, increasing the nuclear liability amounts and allowing States to opt for unlimited liability. They also provide for a broader range of nuclear damage to be compensated: in addition to personal injury and property damage, these conventions include certain types of economic loss, the cost of measures to reinstate a significantly impaired environment, loss of income resulting from the impaired environment and the cost of preventive measures.

NEA member countries that have signed the 2004 Protocols to amend the Paris Convention and the Brussels Convention Supplementary to the Paris Convention continue to work towards implementing the provisions of these protocols. A decision of the European Council (2004/294/EC) of 8 March 2004 requires that the 11 contracting parties to the Paris Convention that are also EU member states take the necessary steps to deposit simultaneously their instruments of ratification or accession to the 2004 Protocol to amend the Paris Convention. Italy is finalising the related ratification and implementation legislation which was submitted before the Parliament in December 2018.[6] In the meantime, other signatories of the 2004 Protocols (such as Belgium, Finland, France, the Netherlands and Spain) have already adopted transitory legislation that implements into national legislation higher compensation levels as provided in the 2004 Protocols, pending their entry into force. More information on the Paris Convention is available at www.oecd-nea.org/law/paris-convention.html.

Reactors continue to be built and "newcomer" countries continue to launch new nuclear power programmes. Evolutionary and revolutionary reactor designs are being developed, constructed and considered around the world. Some, like small modular reactors and floating nuclear power plants, were not foreseen when the international conventions that constitute the legal framework applicable to the safe and peaceful uses of nuclear energy were drafted. Skilled legal experts will be needed to respond to new legal challenges but also to address outstanding legal questions. This is true for countries that have decided to maintain nuclear power programmes, and possibly consider extending the lifetime of certain reactors, as well as those phasing out who will be facing the challenges of decommissioning and spent fuel and radioactive waste management. Maintaining a stable force of knowledgeable, inquisitive and dedicated nuclear lawyers is therefore critical not only at a national level, but also at an international level. This will require that countries ensure that university courses and continued education are provided in this field.

6. The draft bill is available on the website of the Chamber of Deputies, at www.camera.it/leg18/126?tab=2&leg=18&idDocumento=1476&sede=&tipo.

Nuclear Development

The goal of the NEA in this sector is to provide governments and other relevant stakeholders with authoritative, reliable information and analyses on current and future nuclear technologies, as well as on the role of nuclear energy now and in the future from a sustainable development perspective. These studies cover subjects as key and diverse as techno-economics, finance, resource analyses, energy and electricity demand and supply forecast and analysis, public opinion assessment, advances in nuclear reactor design, or nuclear fuel and fuel cycle technologies. This allows the NEA to advise policy makers on national and international energy policies aiming to provide low-carbon energy and electricity cost-effectively and reliably. To meet this goal, NEA staff in the division work closely with the Committee for Technical and Economic Studies on Nuclear Energy Development and the Fuel Cycle (NDC) and its expert groups. The nature of this area is such that some efforts are necessarily cross-cutting, and the staff thus ensures co-ordination with other NEA and OECD work as needed.

Highlights

- *The Full Costs of Electricity Provision* was published in April 2018. This report provides insights on the accounting and internalising of the full costs of electricity provision to take maximum advantage of the energy transitions under way in many countries.
- The joint NEA/IAEA report *Measuring Employment from the Nuclear Power Sector* was published in October 2018. This report measures direct, indirect and induced employment from the nuclear power sector in a national economy.
- The NEA jointly with the IAEA published *Uranium 2018: Resources, Production and Demand*, also known as the "Red Book", in December. This 27th edition features a comprehensive assessment of uranium supply and demand, as well as projections from 1 January 2017 to the year 2035.
- The NEA published *Nuclear Energy Data 2018* providing official information on NEA member countries' nuclear energy programmes.
- The NEA study on *The Costs of Decarbonisation: System Costs with High Shares of Nuclear and Renewables* was completed in December 2018 and was released in early January 2019. This report analyses the behaviour and the costs of a realistic electricity system representative of a typical OECD country subject to a stringent carbon constraint with varying shares of variable renewables and nuclear power.
- Two new projects were launched in 2018 to be carried out by ad hoc expert groups: one to evaluate the economic, technical and policy aspects related to the long-term operation of nuclear power plants, and the second to analyse the key technical, organisational and financial factors that can help reduce the cost of new nuclear power generation. The NEA also completed scoping studies to narrow down the focus and objectives of a new project that will be launched in 2019 on approaching nuclear power from a social science perspective.

Uranium: resources, production and demand

The 27th edition of *Uranium 2018: Resources, Production and Demand* (the "Red Book"), jointly prepared by the Nuclear Energy Agency (NEA) and the International Atomic Energy Agency (IAEA) was published in December 2018. This edition provides a review of world uranium market fundamentals and presents data on global uranium exploration, resources, production and reactor-related requirements. It offers information on established uranium production sites and new mine development plans, as well as projections of nuclear generating capacity and reactor-related requirements through 2035, in order to address uranium supply and demand issues. The report provides analyses and information from 41 uranium producing and consuming countries.

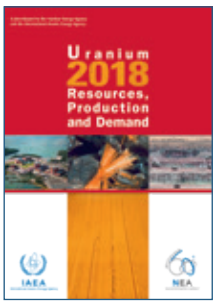
The Nuclear Development Committee (NDC) approved the renewal of the mandate of the Uranium Group for a further three years.

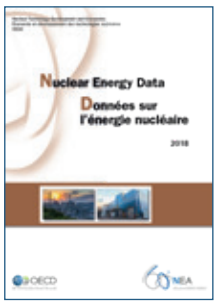
Nuclear energy data

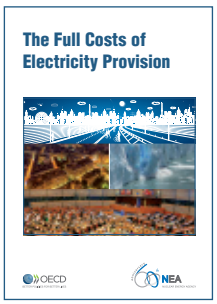
Nuclear Energy Data 2018 was published in December 2018 and contains official information provided by member countries on nuclear energy developments. The "Brown Book" includes projections of total electrical and nuclear generating capacities and fuel cycle requirements up to 2035. Based on actual data through to 2017, the report reveals that total electricity generation in NEA countries declined slightly from 2016 to 2017 (by 0.02%), and the share of electricity production from nuclear power plants also declined slightly (from 18% in 2016 to 17.9% in 2017).

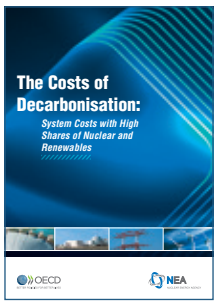
The Full Costs of Electricity Provision

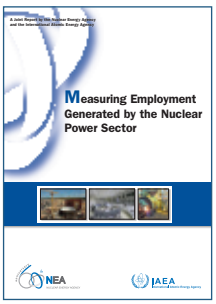
The report on *The Full Costs of Electricity Provision* was completed in 2018 and launched at a webinar with NEA Director-General William D. Magwood, IV, NEI Senior Director for Policy Development Matt Crozat, Energy











for Humanity's President Kirsty Gogan and NEA Senior Economic Advisor Jan Horst Keppler in April 2018. The study provides a synthesis of the large body of work available and ongoing research on the full costs of electricity provision. Full costs include direct economic costs such as plant-level costs and grid-level costs, as well as the costs derived from other impacts on the environment and human health such as climate change, local and regional pollution, land use and the impacts of severe accidents. Other social and economic impacts are also discussed in the study, such as the security of energy supply, the positive externalities for innovation and growth and the impact on local and regional employment.

Costs of Decarbonisation: System Costs with High Shares of Nuclear and Renewables

This study was completed in December 2018 and launched in Budapest, Hungary in January 2019 in the presence of Minister János Süli. The study assesses the costs of several scenarios for low-carbon electricity systems capable of achieving strict carbon emission reductions consistent with the aims of the Paris Agreement. These emission targets are one-eighth of the current levels and will require a rapid and radical transformation of the power system with the deployment of low-carbon emitting technologies such as nuclear, hydroelectricity and variable renewable energy (VRE).

Measuring employment generated by the nuclear power sector

The joint NEA/IAEA publication *Measuring Employment Generated by the Nuclear Power Sector* was published in October 2018. The nuclear energy sector employs a considerable workforce around the world, and where nuclear power projected to grow corresponding jobs in the nuclear power sector will also grow. This report generalises and simplifies the modelling efforts of the OECD member countries to make them more applicable to other economies, in particular, those of IAEA member states. Largely based on publicly available quantitative studies, this study reviews and compares macroeconomic models that can be used to quantify employment effects generated by the nuclear sector, including direct, indirect and induced employment.

Engagement with other elements of the OECD

The NEA continues to work closely with the International Energy Agency (IEA) on numerous studies, including their annual publications *Tracking Clean Energy Progress* (May 2018), *World Energy Investment Report* (July 2018) and *World Energy Outlook* (November 2018), as well as ad hoc reports such as the *Status of Power System Transformation: Advanced Power Plant Flexibility* (May 2018). The NEA also provides support to the IEA on in-depth reviews of member country energy policies. During 2018, the NEA participated in in-depth reports (IDRs) for Sweden, the United Kingdom and the United States. The elaboration of the study *Projected Costs of Generating Electricity* every five years is an important regular co-operation project between the IEA and NEA. The work on the 2020 edition began in October 2018 with a workshop that gathered experts in the modelling of energy markets to discuss an enhanced methodology for the Levelised cost of electricity (LCOE) that would allow current and future energy markets to better assess the true value and cost of the various generation technologies.

A collaboration with OECD-Centre for Entrepreneurship, SMEs, Regions and Cities (CFE) and OECD-Trade and Agriculture Directorate (TAD) has been initiated under the framework of the NEA Uranium Mining and Economic Development (UMED) Expert Group.

A collaboration with the OECD Health Division is ongoing under the framework of the High Level Group on Medical Radioisotopes (HLG-MR).

The NEA routinely participates in the OECD Inter-Directorate Climate Co-ordination meetings, and collaborates on the OECD-wide climate action activities as appropriate.

Nuclear Innovation 2050 (NI2050)

Over three years of work, the NI2050 Advisory Panel met in Paris in November, for the 7th and last time in the present format. This Advisory Panel, which was established after the July 2015 NI2050 Launch Conference, has guided the work of experts and the Secretariat, leading to the production of three successful outcomes: (1) the compilation of relevant data on ongoing nuclear R&D programmes in NEA member countries to be used as background information, (2) a better understanding of concepts and barriers for innovation in the nuclear sector, (3) a methodology to select priority topics and develop corresponding roadmaps to foster innovation. Nine such roadmaps have been developed and are now ready for the implementation phase. For this new phase, NI2050 has been redefined as a high-level cross-cutting NEA incubator to identify, develop, and follow-up innovative ideas for the timely and cost-effective nuclear deployment where multilateral co-operation is most effective. NI2050 will serve as an incubator to identify, develop and follow up nuclear innovation ideas that can be best deployed in a timely and cost-effective manner through multilateral co-operation.

The NI2050 activity report, summarising all the accomplishments of this initiative to date, will be published in 2019.

Security of supply of medical radioisotopes

In 2018, the NEA High-level Group on the Security of Supply of Medical Radioisotopes (HLG-MR) continued its efforts to monitor and help ensure the global security of supply of molybdenum-99 (^{99}Mo) and its decay product, technetium-99m (^{99m}Tc), the most widely used medical radioisotope. The NEA issued the report, "The Supply of Medical Radioisotopes: 2018 Medical Isotope Demand and Capacity Projection for the 2018-2023 Period", reconfirming that market demand for ^{99}Mo/^{99m}Tc remains relatively flat at around 9 400 6-day ^{99}Mo curie per week at the end of processing. There have been positive developments, with more than 70% of the facilities converted to the use of low-enriched uranium (LEU) targets and the licensing of the first alternative technology, the NorthStar RadioGenix technetium Tc 99m generator system in early February 2018. However, delays have been experienced in the introduction of alternative irradiation and processing technologies, and some large conventional technology projects have been pushed back beyond 2023. In 2018, inefficiencies due to the use of LEU targets, extended outages, unexpected outages and reduced capacity periods have resulted in a chronic supply shortage being experienced in many markets. The overall market structure remains economically unsustainable, showing risk to the secure supply and significant risk of delay or cancellation of new investment.

The HLG-MR and the OECD Health Division are in the process of completing a study on the achievement of long-term economic sustainability in the medical radioisotopes market. This study, which will be published in 2019, evaluates the implementation of full cost recovery throughout the supply chain that ensures the continuous and cost-effective availability of medical radioisotopes, based on data collected from OECD member countries.

The fourth mandate of the HLG-MR ended in December 2018, and the NDC approved that the NEA continue with certain aspects of the work currently performed under the HLG MR within the NDC programme of work, in particular by continuing the monitoring of market demand and capacity, through supporting industry and stakeholder communications and by hosting future ad hoc meetings of the community.

Nuclear fuel cycle: Strategies and considerations for the back-end

The Expert Group on Back-end Strategies (BEST) is in the last stages of completing a report that will be useful to policy makers in identifying areas of technical consensus and key distinctions between fuel cycle systems. The group was created to examine the aspects that play an important role in countries' decisions on whether and how to deploy partially and fully closed nuclear fuel cycles. The study considers various differentiating characteristics of nuclear fuel cycles such as the challenges and the opportunities encountered to implement the diverse fuel cycle options, and it includes an assessment of the decision drivers that are being pursued for the back-end fuel cycle by member countries. The BEST Expert Group has compiled examples from a broad range of situations: large and small countries and nuclear programmes; those with nuclear power growing, stable, and phased or phasing out; and countries focused on direct disposal, those undecided and exploring options, and those already recycling spent fuel at full scale.

Advanced reactors and future energy market needs

This study aims to assess how advanced reactors under development today, including small modular reactors and more innovative Generation IV systems, will meet the demands of rapidly evolving energy and electricity markets. A key step in the study involves the forecast of what future energy and electricity markets may look like, including an in-depth understanding of their technical needs. The NEA has assembled the insights of a number of experts from industry (vendors, utilities), research institutes, regulators, grid operators, energy analysts and economists, renewable energy experts and international organisations. The study covers such diverse topics as non-electric applications of nuclear energy as heating and desalination, energy storage through the production of hydrogen, operational flexibility, or integration with variable energy sources. The outcomes of the study will provide insight into how well nuclear energy can cost-effectively participate into the low-carbon energy markets of the future, and it will help identify challenges related to new operational, regulatory or market requirements.

Ensuring the adequacy of funding arrangements for decommissioning and spent fuel disposal

The majority of working nuclear reactors in NEA member countries will reach their originally planned operational lifetimes in the coming two decades. There is thus strong social demand to ensure adequate plans and financial arrangements for the timely and cost-effective decommissioning of permanently shut down power plants, as well as for the long-term management and disposal of spent fuel. In response to this need, this project aims at assisting member countries to ensure that their funding arrangements are adequate, both in terms of the provisions being constituted and the institutional processes that ensure equivalence between assets and liabilities over time. Based on a broad overview of the very diverse funding arrangements in NEA member countries, the systematic compilation of all assembled data, as well as the identification of first lessons learnt, is near completion. The report will focus on the interdependencies between costs and funding requirements on the one hand and nuclear policies, such as long-term operations (LTO) or premature shut downs, as well as technological progress on the other hand. The basic approach is to frame the question of the adequacy of funding arrangements in terms of the transparency, flexibility and political sustainability of current institutional arrangements

Meeting of the NI2050 Advisory Panel, held at the NEA, November 2018.

and processes rather than in pure accounting terms, where assumptions about discount rates, which are often ad hoc, are usually decisive.

Contribution of uranium mining to economic development

Mining is a critical economic driver in many countries, accounting for a major percentage of foreign direct investment, mineral exports and government revenue. These contributions can act as an economic catalyst for supporting the development of communities, regions and whole economies. The objective of the project led by the NEA Expert Group on Uranium Mining and Economic Development (UMED) is to enhance understanding of the potential contribution of uranium mining in the economic and social development. Based on the lessons learnt from case studies from various countries, the Expert Group aims to understand the impacts and benefits of uranium mining on employment, education and training, local business development, tax revenues, and the environment. The OECD Centre for Entrepreneurship SMEs, Regions and Cities (CFE) and the OECD Trade and Agriculture Directorate (TAD) are also contributing to this study, providing insights on local and regional policies related to mining, as well as with regards to good practices in benefits sharing and working with local communities.

Economic, technical and policy aspects of long term operation of nuclear power plants

In 2012, the NEA Division of Nuclear Technology Development and Economics (NTE) published its first report about the economics of long-term operation (LTO) on nuclear power plants (NPPs). This report showed that the LTO of NPPs had significant economic advantages for most countries envisaging LTO programmes. However, the final decision will rely on numerous factors (i.e. technical, regulatory, etc.), and not only on economic aspects, given the holistic nature of LTO assessment.

Since 2012, the macro-environment surrounding LTO decisions has significantly evolved, especially the market conditions due to the higher share of variables renewables on the grid and the abundance of cheap shale gas. In addition, with an average age of 30 years, around 40% of the world's nuclear fleet will face decisions of extended operation beyond their authorised lifetime in the coming years. If these authorisations are not renewed, the world's low carbon capacity will drop substantially by 2040 having important implications in emissions trajectory. The NEA NTE has therefore started in June 2018 a new study to assess the role of LTO in the low carbon economy using a holistic approach. Technical, economic and policy aspects will be analysed. With regard to economics, this study will provide updated figures of merit (overnight costs, LCOE, etc.) and further insights into operating and maintenance O&M cost reduction opportunities. New topics like information and knowledge management and the role of digitalisation will also be covered.

Reducing the costs of nuclear power generation

The economics of nuclear new build are being challenged in OECD countries by the combined effects of falling costs of renewables and cost overruns and delays experienced by first-of-a-kind (FOAK) Generation III reactors. Large capital outlays, long pay-back time, and significant uncertainties about overnight costs and completion time are significant challenges for nuclear in OECD member countries. As a result, nuclear power is not on track to reach the worldwide capacity needed to achieve the emissions targets set in the Paris Agreement. These challenges have contributed to a misalignment of key stakeholders in nuclear projects (industry, government and regulators) increasing the gap between risks and perceived risks and thus, the investment costs.

At the same time, the nuclear industry is currently performing quite well in other parts of the world with new nuclear capacity built almost on time and on budget (i.e. China and UAE). In addition to these recent success stories, there is extensive historical data from past nuclear programmes (France, Japan, Korea) showing that nuclear power can be delivered cost-effectively if the appropriate conditions are put in place.

The NEA initiated in 2018 a new study to assess the main opportunities to reduce the cost of new nuclear generation. Three main areas of cost reduction will be covered: industrial performance, financing costs and interactions with the regulatory body. Political involvement, market frameworks and digitalisation may play an important role in reducing the costs of new build. On a long-term basis, SMRs and the possible harmonisation of licensing regimes will be also analysed.

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Secretariat-serviced bodies

Generation IV International Forum (GIF)

Established in 2001, the Generation IV International Forum (GIF) brings together 13 countries – (Argentina, Australia, Brazil, Canada, China, France, Japan, Korea, Russia, South Africa, Switzerland, the United Kingdom and the United States), as well as Euratom, representing the 28 European Union members – to co-ordinate R&D on advanced nuclear energy systems. The Framework Agreement which oversees the R&D activities was extended on 26 February 2015 for an additional ten years. The United Kingdom, one of the founding members of GIF, which had not yet ratified the Framework Agreement and was involved in R&D activities through Euratom, deposited its instrument of ratification on 17 October 2018. Argentina and Brazil have yet to accede to the Framework Agreement, and are not involved in any R&D activities within the GIF.

Six conceptual nuclear energy systems were selected in 2002 for collaborative R&D: the sodium-cooled fast reactor (SFR), the very-high- temperature reactor (VHTR), the supercritical water- cooled reactor (SCWR), the gas- cooled fast reactor (GFR), the lead-cooled fast reactor (LFR) and the molten salt reactor (MSR). These six Generation IV systems were confirmed in the Technology Roadmap Update for Generation IV Nuclear Energy Systems published in 2014. GFR, SCWR, SFR and VHTR research activities within GIF are organised into four system arrangements, under which project arrangements have been set up (ten at the end of 2018, covering areas such as safety and operation, fuel, materials, thermal-hydraulics, hydrogen production and system integration and assessment). The four system arrangements were extended for another ten years in 2016 by agreement of the signatories. MSR and LFR activities are not yet organised into system arrangements and projects, and these activities operate under memoranda of understanding that govern information exchanges between the signatories and observers. However, the MSR provisional System Steering Committee agreed to move towards a system arrangement and is currently preparing its System Research Plan.

During 2018, GIF continued to work on the goals of achieving the highest levels of safety for Generation IV systems, with the development of safety design criteria (SDC) and safety design guidelines (SDG) that incorporate lessons learnt from the Fukushima Daiichi nuclear power plant accident. Initially developed for the SFR, the SDC and SDG are being adapted to other systems. GIF also continued in its efforts to engage with regulators in discussions on reactor safety criteria and objectives, whether at the national or the international levels, and particularly through the NEA Working Group on the Safety of Advanced Reactors (WGSAR) under the aegis of the NEA Committee on Nuclear Regulatory Activities (CNRA) and the Committee on the Safety of Nuclear Installations (CSNI).

Through its Education and Training Task Force, the GIF has addressed the need to reach out to students and researchers by setting up a series of monthly webinars that started in September 2016, and continued throughout 2017 and 2018, with participation extending beyond the GIF membership to universities and industry. These webinars are available on the GIF website. GIF also re-engaged with industry through the feedback of the GIF Senior Industry Advisory Panel (SIAP).

In October 2018, the GIF organised its fourth symposium, as part of the conference "Atoms for the Future" which attracts young professionals and researchers. Over 160 participants attended the symposium, over 90 papers were submitted and half of them presented in oral sessions. The symposium was followed by the 46th Policy Group meeting, hosted by the NEA, during which the new Chair was elected, Mr Hideki Kamide of the Japan Atomic Energy Agency (JAEA) who will succeed Mr François Gauché

Representatives of the United Kingdom Department for Business, Energy and Industrial Strategy (UK BEIS) handing over the ratification of the Framework Agreement to the NEA Director-General and senior staff on 17 October 2018.

of the Commissariat à l'énergie atomique et aux énergies alternatives (CEA, France) in January 2019. During the Policy Group meeting, Turkey also presented its application to join the GIF. Turkey's bid will be evaluated in the coming months after further technical exchanges between GIF members and the scientific and technological research council of Turkey (TÜBITAK).

The NEA has continued to provide support to the technical bodies in charge of the development of the six systems and the three methodology working groups, as well as to the SIAP at the request of the Policy Group (PG). It also maintains the GIF public website and extranet, and organises and hosts one of the two yearly PG meetings, with the other one hosted by a GIF member country; the United States hosted the May 2018 meeting. The NEA is fully compensated for its support to GIF through voluntary, financial and in-kind contributions made by individual GIF members.

International Framework for Nuclear Energy Cooperation (IFNEC)

The International Framework for Nuclear Energy Co-operation consists of 34 Participant countries, 31 Observer countries and 4 Observer organisations (Euratom, GIF, the IAEA and the NEA). Of the 33 NEA member countries, 26 are members of IFNEC.

In 2018, IFNEC continued to work with its member countries and organisations, under the chairmanship of Mr Julián Gadano, undersecretary for nuclear energy of Argentina, and also reached out beyond its current membership to countries that are taking an interest in the work of IFNEC. Several meetings took place in 2018, including in May, a Steering Group meeting and a two-day workshop organised by the Infrastructure Development Working Group on "new challenges facing regulators", that brought together experienced regulators to discuss the challenges of licensing advanced Generation III/III+ reactors, new regulators from countries embarking on nuclear programmes as well as regulators involved in licensing small modular reactors. All these meetings were hosted by the NEA.

The Nuclear Supplier and Customer Countries Engagement Group published the outcomes of the Conference on Global Supply Chain and Localisation Issues which took place in November 2017. The group decided to address the topic of safety and safety culture as part of its 2018-2019 activities, with a first meeting in November 2018 in Tokyo, Japan, jointly organised with the Infrastructure Development Working Group.

In September 2018, the Chair and the IFNEC Secretariat organised an IFNEC side-event meeting during the IAEA General Conference in Vienna, which was extremely well attended, and helped promote the work of IFNEC.

The most important activity during the year was the organisation of a conference jointly sponsored by IFNEC and the Nuclear Innovation Clean Energy Future (NICE Future) initiative, entitled "Challenges and Opportunities Facing Nuclear Energy in an Energy Transitions Context: Innovation and Actions to advance Clean Nuclear Energy", and hosted by the Ministry of Economy, Trade and Industry (METI) in Tokyo on 13-14 November 2018. This conference, which attracted over 130 participants, was followed by the 2018 Executive Committee presided by Japan, during which the revised Governance of IFNEC was approved and a joint statement issued. New Vice-Chairs from Kenya, the Russian Federation and the United States were elected. They will support the current Chair Mr Gadano together with the other Vice Chairs from China and Japan.

Finally, in December 2018, the Reliable Nuclear Fuel Services Working Group held a one-day workshop on the financing of multinational repositories, drawing on the experience of organisations developing national repositories, as well as economic and financial experts.

IFNEC Executive Committee, Tokyo, 15 November 2018.

Nuclear Safety and Regulation

The goal of the NEA in this sector is to assist member countries in their efforts to ensure high standards of safety in the use of nuclear energy, by supporting the development of effective and efficient regulation and oversight of nuclear installations and activities, and by helping to maintain and advance the associated scientific and technological knowledge base. The staff works closely with the Committee on the Safety of Nuclear Installations (CSNI), the Committee on Nuclear Regulatory Activities (CNRA) and their subsidiary groups in this area.

Highlights

- A new NEA international joint research project, the Preparatory Study on Analysis of Fuel Debris (PreADES), held its first meeting in January 2018, as one of the two near-term projects recommended in the "Safety Research Opportunities Post-Fukushima – Initial Report of the Senior Expert Group", issued in 2017.
- Several international workshops or conferences were held in 2018. In the field of inspection, one workshop addressed, among other topics, the role in each regulatory body's assessment of the licensee's human and organisational aspects and how to inspect a licensee's corrective action programme. In the area of Probabilistic Safety Assessment (PSA), workshops were held on the status of site-level (as opposed to reactor-level) PSA developments and on the use of NEA database information in PSA studies.
- A joint workshop sponsored by the CNRA and the Multinational Design Evaluation Programme (MDEP) on Supply Chain Management was held in November 2018, attracting over 100 participants from 16 countries. The two-day workshop aimed at identifying emerging risks, shared regulatory practices, lessons learnt, and recommendations for reducing risk and promoting safety culture in the nuclear supply chain. The workshop culminated with a moderated panel discussion to examine international regulatory activities and opportunities to enhance the effectiveness of regulatory arrangements for the oversight of the nuclear supply chain extended enterprise.
- In the framework of MDEP activities, significant milestones were achieved with the successful completion of First Plant Only Tests (FPOT) for the EPR and the AP1000 units in China. These FPOTs provide a unique opportunity for regulators involved in MDEP to demonstrate the efficiency of using common positions to effectively collaborate and share information on commissioning test results that can be credited for subsequent EPR and AP1000 plants in other countries.

Nuclear safety technology

Analysis and management of accidents

The NEA Working Group on Analysis and Management of Accidents (WGAMA) has continued to focus on the in-vessel and ex-vessel behaviour of degraded cores, the thermal-hydraulics of the reactor coolant system, containment behaviour and protection, computational fluid dynamics, and fission-product release and transport.

The WGAMA completed three reports in 2018. First, a status report on long-term management of a damaged nuclear power plant was produced. It reviews lessons learnt from Three Mile Island, Chernobyl and Fukushima Daiichi regarding challenges and actions needed after the plants had reached a safe stable state. It further discusses, from a generic standpoint, risk evaluation and action ranking for long-term management after a severe accident. Additionally, two reports in the area of computational fluid dynamics (CFD) for nuclear safety were issued. One report focuses on requirements for CFD grade experiments, which is identified as a crucial component in validating CFD codes for safety applications. Furthermore, an update to an existing CSNI report summarises available data on two-phase flow (i.e. flow of boiling water and steam). Finally, the seventh workshop on CFD for nuclear reactor safety was held in Shanghai in September 2018. The workshop attracted 120 participants from 13 countries and covered areas such as two-phase flow, high resolution measurements, uncertainty quantification, and reactor and containment applications. The utilisation of CFD in licensing was also addressed.

Ageing and structural integrity of reactor components

The NEA Working Group on Integrity and Ageing of Components and Structures (WGIAGE) focuses on the integrity, ageing and seismic behaviour of metal components and concrete structures.

In 2018, two reports were completed. A report on seismic behaviour at operating nuclear plants sites was finalised based on recommendations of NEA workshops on these issues. The report summarises a comparison between results from probabilistic seismic hazard analysis studies performed in regions of high seismicity and regions of moderate or low seismicity.

Transport containers for shipment of spent fuel.
Nuclear Regulatory Authority (NRA), Slovak Republic

The second report of the working group is a summary of the results on a couple of benchmark studies for pressurised water reactor (PWR) and boiling water reactor (BWR) plant types. In these benchmark studies the behaviour of selected components and structures under severe accident loading were assessed with the structure mechanical analysis methods designed for integrity assessment of metallic components.

Risk assessment

The main objective of the NEA Working Group on Risk Assessment (WGRISK) is to advance the understanding and use of PSA as a tool to support nuclear safety decision making in member countries. Reports were completed in 2018 on an update on the general use and development of the PSA in member countries and on an update of the technical opinion paper on fire PSA. Ongoing tasks of the WGRISK focus on the use of human reliability analysis in external PSA events, developments in the application of the PSA at the site level, an update of a technical opinion paper on seismic PSA, approaches for modelling the behaviour of digital instrumentation and controls (I&C) in PSA, and on the use of NEA database information in PSA studies.

Fuel safety

The NEA Working Group on Fuel Safety (WGFS) focused its work in 2018 on five activities. The first report on *Pellet-Cladding Interaction (PCI) in Water-Cooled Reactors* was approved by CSNI in 2018. The second is the completion of an update of the state-of-the-art report (SOAR) on fuel behaviour in loss-of-coolant conditions that was published in 2009; work on the update first started in early 2017. A third activity involved the launch of an update to the SOAR on fuel behaviour in the conditions of a reactivity-initiated accident (RIA) that was published in 2010. Fourthly, a new phase (phase 3) of benchmarking RIA fuel codes has started based on a well-known RIA experiment; this activity will include investigating sensitivities and drawing conclusions from all three phases of the benchmark. Lastly, the WGFS started a new activity on so-called accident-tolerant fuels; the principal aim is to see how existing safety criteria for uranium oxide fuels with zirconium-alloy claddings (reviewed in a WGFS report published in 2012) may apply to the newer fuel technologies.

Fuel cycle safety

The NEA Working Group on Fuel Cycle Safety (WGFCS) brings together regulatory and industry specialists to address a broad range of interests, including safety assessments, nuclear criticality safety, PSAs, safety management, decommissioning, site remediation, chemical hazards, human factors and fire protection. The working group follows and periodically reviews the joint International Atomic Energy Agency (IAEA)/NEA Fuel Incident Notification and Analysis System (FINAS), which is the only international system providing regulators and government bodies with information about lessons learnt from safety-significant events at fuel cycle facilities.

In 2018, the group finalised the proceedings for an International Workshop on Chemical Hazards in Fuel Cycle Facilities Nuclear Processing held in Boulogne-Billancourt in April 2018. The workshop concluded that it is important to consider radiological and chemical releases from all facilities situated at the same site in safety analysis and emergency procedures. The report also noted the need for an effective process for assessing the lessons learnt and operating experiences of chemical release events and the need to have adequate co-operation between various national regulatory organisations to ensure an appropriately graded approach to safety.

External events

The objective of the NEA Working Group on External Events (WGEV) is to improve the understanding and treatment of external hazards to support the continued safety performance of nuclear installations and improve the effectiveness of regulatory practices. In 2018, the proceedings of the workshop "Riverine Flooding: Hazard Assessment and Protection of Nuclear Installations" held in March 2018 were approved. A technical report on "Examination of Approaches for Screening External Hazards" was also finalised in 2018.

Going forwards, the WGEV is working on two activities: to develop insights into the concepts used to establish effective protective measures to cope with flooding hazards and to develop a common understanding of the terminology used to discuss protective measures related to flooding. The second activity will facilitate a benchmark exercise focused on the quantitative technical analysis used for assessing hazard frequency and magnitude for external events risk assessment. The technical report will identify commendable modelling practices for quantifying external events.

Robustness of electrical systems

The NEA Working Group on Electrical Power Systems (WGELEC) collaborates on enhancing the robustness of electrical systems, improving the analysis of electrical system performance and addressing safety challenges associated with electrical systems. In 2018, reports were produced on early identification of electrical failure mechanisms that affect safety at nuclear facilities, and on a comparison of methodologies for simulation of electrical systems. Ongoing activities are aimed at identification of good practices for advancing electrical power system robustness in case of deviation from their normal operating conditions, and on the establishment of measures against accelerated degradation of batteries and failure of batteries that affect safety at nuclear facilities. A new activity was started in 2018 on "New devices for electrical equipment replacement/retrofit and new build". The working group is preparing an IAEA-NEA co-hosted technical workshop on electrical equipment in December 2019 in Vienna, Austria as a part of the work to support the activity on the degradation of batteries and the activity on new devices for retrofit and new build.

Control room.
EDF, France

Regulation of Nuclear Installations

With a focus primarily on existing nuclear power reactors and other nuclear installations, the NEA has continued to exchange information on the safety and regulation of nuclear installations with the objectives of better understanding the national regulatory requirements and of harmonising regulations.

A workshop to share experience on supply chain quality management issues and to identify recommendations to address these issues was held in November 2018. It highlighted emerging risks and recommendations to further improve supply chain management oversight arrangements, including the need for additional regulatory tools, assessments or international guidance.

The Working Party on Boiling Water Reactors (WPBWR) newly established under the CNRA, met twice in 2018. This working party will serve as a regulatory forum to discuss BWRs and specific issues associated with advanced BWRs. It will work for one to two years to determine what kind of issues would have added value to be discussed under the umbrella of a BWR regulators group and then suggest a mandate, programme of work and the right institutional arrangements for a more permanent group.

The new permanent CNRA Working Group on Codes and Standards (WGCS) was transferred in 2018 from the Multinational Design Evaluation Programme (MDEP) and met in December for the first time. It will focus on international co-operation, convergence and reconciliation of codes and standards and regulatory requirements for pressure-boundary components for both operating and new NPPs.

The CNRA has noted the interest of some member countries in initiatives in the field of SMRs. The committee will first review the status of international SMR activities before deciding whether complementary work should start under the auspices of the appropriate working group.

Inspection practices

In April 2018, the NEA Working Group on Inspection Practices (WGIP) held in Heidelberg, Germany an international workshop to address three topics: i) the inspector's role in regulatory body assessment of the licensee's human and organisational aspects, ii) inspection of the licensee's corrective action programme, and iii) inspection of the current design basis. The proceedings were approved at the December 2018 CNRA meeting and are expected to be issued in early 2019.

The working group co-ordinated the nuclear power plant benchmarking inspections hosted in September by Canada, with the participation of France, Hungary, Slovenia and Spain. By participating in and observing planning, performance and inspection enforcement actions, member countries assist in overall improvements to inspection techniques. The WGIP also began to prepare for the next benchmarking inspection, which will take place in Belgium in 2019.

The group continued together with the CNRA Working Group on Digital Instrumentation and Control (WGDIC) to prepare for a workshop to be held in Canada, in June 2019, dedicated to the identification of commendable practices for inspection of digital instrumentation and control hardware and software.

Operating experience

The NEA Working Group on Operating Experience (WGOE) continued to share information and follow-up actions related to national trends and lessons learnt from national events. The WGOE has approved the proceedings of the 2017 international workshop held in Madrid, Spain, on best practices derived from regulatory operating experience databases. The proceedings were approved at the December 2018 CNRA meeting and are expected to be issued in early 2019.

In August 2018, the working group issued a report on heavy load accidents in nuclear installations. This report compares regulatory requirements among several countries, reviews more than 100 events and identifies lessons learnt from operating experience to date.

The WGOE continued to examine events submitted to the joint IAEA/NEA International Incident Reporting System (IRS) for Operating Experience, which is the only international system that provides regulators with information about safety-significant events at NPPs. It has started to draft the reference document "Nuclear Power Plant Operating Experience from the IAEA/NEA International Reporting System" (the "Blue Book"), which covers the approximatively 240 events that occurred during the period 2015 to 2017. This Blue Book is expected to be published in 2019.

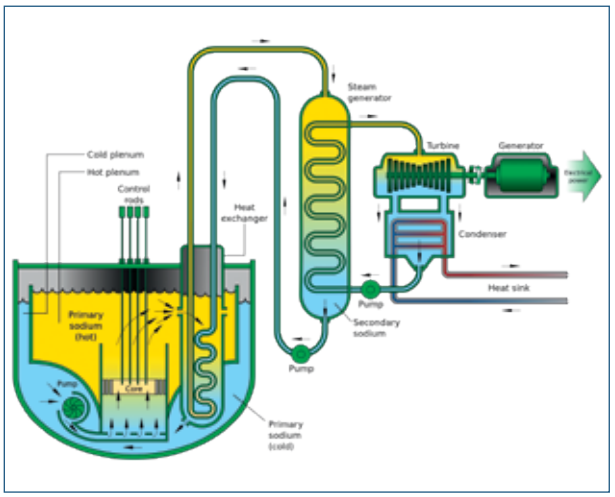
The WGOE also updated the guidance and template used to identify and share among members information about non-conforming, fraudulent and suspect items (NCFSI). The group issued a report in early 2018 reviewing operating experience, comparing regulatory requirements and identifying lessons learnt with regard to more than 100 heavy load lifting events reviewed by the working group in 2017.

Regulation of new reactors

In the field of new reactor regulation, the NEA Working Group on the Regulation of New Reactors (WGRNR) focuses its activities on regulatory activities in the area of siting, licensing and overseeing new commercial NPPs. In 2018, the working group completed two workshop reports, "Nuclear Regulatory Organisations' Oversight of New Licensee Organisational Capability" and "Regulatory Oversight of the Commissioning Phase for New Nuclear Reactors". The working group also completed a revision of the passive systems report, "Report on the Survey of the Regulatory Practice to Assess Passive Safety Systems used in New Nuclear Power Plant Designs". The working group is currently working on the migration of the Construction Experience (ConEx) database to the IAEA IRS database.

Safety of advanced reactors

The NEA Working Group on the Safety of Advanced Reactors (WGSAR), established in 2018 as a permanent working group under the CNRA, provides regulatory perspectives on selected advanced reactor designs, including the identification of required safety research. It currently focuses on areas such as severe accident prevention and mitigation measures, neutronics and criticality safety, and analytical codes and fuel qualification for sodium fast reactors. The technical report on severe accident prevention and mitigation measures was completed in June 2018 and two reports on neutronics and criticality safety, and fuel qualification were approved in December 2018. The last report will be finalised in 2019. Two new WGSAR activities were launched in 2018. the first an activity on regulatory approaches to fuel qualification for advanced reactors will identify safety criteria and additional research needs to support the regulators' safety review. The second activity will identify regulatory expectations for the development, validation and use of codes and methods, and highlight relevant knowledge gaps, to support the regulators' assessment of advanced reactors. WGSAR members also continue their interaction with the Generation IV International Forum (GIF). A new initiative on risk informed approach for event selection and component classification was proposed in October 2018 for further discussion between GIF and WGSAR.



Sodium-cooled Fast Reactor (SFR).

Digital instrumentation and control

The NEA Working Group on Digital Instrumentation and Control (WGDIC) addresses regulatory issues associated with the use of digital technologies in existing and new nuclear installations. The working group has been publishing a series of consensus positions (CP) concerning current and emerging technical challenges in the digital instrumentation and control (I&C) field, first under MDEP, and now under the CNRA.

The WGDIC has updated the CP on Data Communication Independence in 2018 and started reviewing the CP on the Impact of Cyber Security Features on Digital I&C Safety Systems, to determine if a revision is warranted. It also finalised a new CP on Qualification of I&C platforms for use in systems important to safety.

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Joint Projects

▶ Nuclear safety research

The Halden Reactor Project

The Halden Reactor Project, operated by the Norwegian Institute for Energy Technology (IFE), was established in 1958 and was the doyen of NEA joint projects. It brought together an important international technical network in the areas of nuclear fuel reliability, integrity of reactor internals, plant control/monitoring and human factors. The programme was primarily based on experiments, product prototype developments and analyses carried out at the Halden establishment in Norway, and supported by approximately 130 organisations in 20 countries. The project benefited from a stable and experienced organisation and a technical infrastructure that has undergone substantial developments over the years. The objectives of the project have been continuously adapted to users' needs.

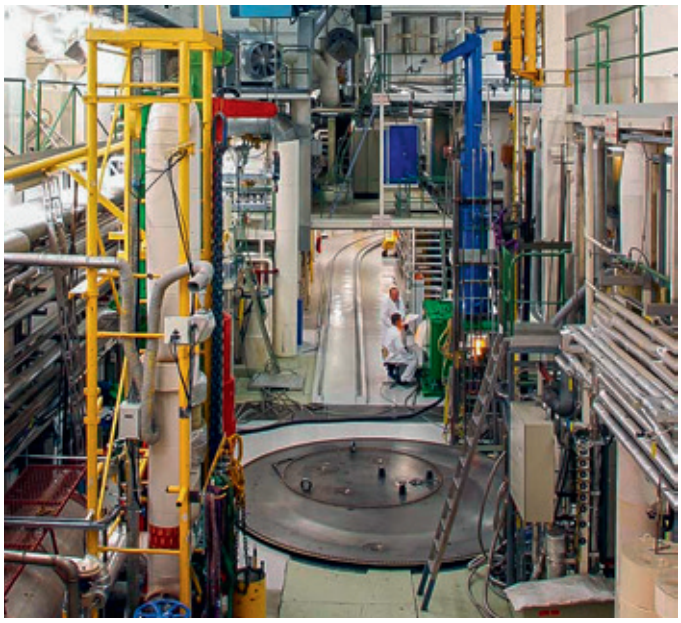
Work in the fuel area has included continued testing of high burn-up fuel under loss-of-coolant accident (LOCA) conditions. Until the permanent shutdown of the reactor in 2018, these were the only LOCA tests that were performed in-pile worldwide, and they complemented the work done at laboratory scale in other institutions, notably in Japan and the United States.

Long-term irradiations have been carried out with advanced and standard nuclear fuel at high initial rating conditions. Corrosion and creep behaviour of various alloys have been studied. The experimental programme continued to examine the effect of water chemistry variants on fuel and reactor internals materials. Tests to investigate the cracking behaviour of reactor internals materials in boiling and pressurised water reactors also continued, with the aim of characterising the effect of water chemistry and material ageing. The project also contributed to international Generation IV research in the areas of instrument development and materials testing.

The programme on human factors focused on experiments in the Halden Man-Machine Laboratory, related data analyses, new control station designs, evaluations of human-system interfaces, process and instrumentation optimisation, and digital instrumentation and controls (I&C). These activities involved the use of the Halden Virtual Reality Centre, among others. Progress was made in the area of human reliability assessment (HRA), which aimed to provide data suitable for PSAs and to improve the validity of HRA methods.

The current three-year phase (2018-2020) of the Halden Reactor Project had begun when, at the end of June 2018, the Norwegian Institute for Energy Technology decided to terminate the operation of the Halden reactor due to technical and financial challenges. Since the nuclear Fuels and Materials work programme was planning to continue work on fuel safety and operational margins, as well as on plant ageing and degradation, a revision to the agreement is currently ongoing to take the permanent shutdown of the reactor into account. In the Man, Technology, Organisational programme, research continued in the areas of human factors, digital instrumentation and controls, and maintenance, outage and decommissioning.

View of the Halden reactor hall.
IFE, Norway



The ATLAS facility.
KAERI, Korea

The ATLAS Project

The Advanced Thermal-hydraulic Test Loop for Accident Simulation (ATLAS) is a thermal-hydraulic integral effect test facility for advanced light water reactors (LWRs) located in Korea. It was commissioned in 2006 and has been carrying out beyond-design-basis accident (BDBA) tests since 2012.

Phase two of the ATLAS project is aimed at topics identified by the participants as having high safety relevance for both existing and future NPPs. The following topics will be addressed:

- passive core makeup during station blackout and small break LOCAs;
- intermediate break LOCAs, including the risk-informed break size definition;
- design extension condition scenarios such as steam line break, followed by steam generator tube rupture and shutdown coolability without a residual heat removal system;
- open tests to address scaling issues by performing counterpart tests to previous integral effects tests.

The experimental programme is to provide an integral effect experimental database, which will be used to validate code predictive capability and accuracy of models. The experimental programme and associated analytical activities will help to create a group among NEA member countries that share the need to maintain or improve the technical competence in thermal-hydraulics for nuclear reactor safety evaluations.

The experimental programme was devised to allow for an open test, targeting a small-break LOCA with total loss of the high-pressure safety injection system. In November 2018, a joint analytical workshop was held, together with the PKL-4 project; it is described in more detail under that project.

The ATLAS Phase 2 project runs between October 2017 and September 2020 and is supported by the safety organisations and industry in the following countries: Belgium, China, the Czech Republic, France, Germany, Korea, Spain, Switzerland, the United Arab Emirates and the United States

The BIP

The Behaviour of Iodine Project (BIP), hosted by Canadian Nuclear Laboratories (CNL, formerly AECL) and supported by 13 member countries, started in September 2007. Phase 1 was completed in 2011 and phase 2 in 2015.

A 3-year follow-up project, BIP-3, supported by 11 member countries, started in January 2016 and is attempting to answer some of the outstanding questions raised during BIP-1 and BIP-2. Interactions between iodine and paint (i.e. primarily iodine adsorption onto paint and the subsequent production and release of organic iodides during irradiation) were investigated during BIP-1 and BIP-2. While painted surfaces are a very important iodine sink within containment, they represent a pathway that converts molecular iodine into organic iodine, which is less easily trapped than molecular iodine by conventional iodine filtration methods (charcoal, wet scrubbers). The specific technical objectives of BIP-3 are to:

- perform experiments that will resolve outstanding questions and improve the simulations of BIP and the NEA Source Term Evaluation and Mitigation (STEM) Project results, including by improving the ability to simulate iodine adsorption and desorption on containment surfaces; predicting organic iodine behaviour (formation and degradation) under accident conditions; and investigating the effects of paint ageing on these processes;
- further investigate the effects of contaminants (nitrous oxides, chlorine and other potential contaminants);
- share simulation strategies involving all partners in, for example, a code comparison exercise.

Excellent progress was made in 2018 in advancing the programme of experiments on iodine adsorption/desorption and formation of methyl iodide. The testing has provided information on the effects of irradiation on methane degradation and on the effects of paint ageing and paint-layer thickness on iodine deposition. In addition, the latest experiments and calibrations identified the need to use a new glass vessel in which to perform the remaining tests.

The BSAF

The Benchmark Study of the Accident at the Fukushima Daiichi Nuclear Power Station (BSAF) was established among eight NEA member countries in 2012. The BSAF is intended to improve severe accident (SA) codes, and to analyse accident progression and current core status in detail for the preparation of fuel debris removal as a part of R&D projects related to the mid- to long-term response for the decommissioning of the Fukushima Daiichi nuclear power plant.

The project is hosted by Japan and brings together international experts to advance the understanding of the phenomena of SA behaviour specific to the Fukushima Daiichi NPP accident while also improving the methods and codes for modelling such behaviour.

A phased approach was applied in this NEA benchmark exercise. The first phase, completed in 2015, was a full-

scope analysis of the Fukushima Daiichi units 1 to 3 using currently available SA integral codes, with a time span for the analysis of accident events of about six days from the occurrence of the earthquake. A complete analysis was also undertaken of a number of key phenomena such as initial transient, core heat-up, core melt, release of fission products (FPs) from fuel, core status including debris behaviour and molten debris-concrete interaction. BSAF phase 2 began in 2015 with membership expanded to 11 NEA member countries. The scope of analysis for phase 2 is approximately the first three weeks following the accident, and it includes FP behaviour in the reactor buildings, as well as releases into the Fukushima site and beyond the site. The sixth phase-2 meeting was held in January 2018 at the NEA to share the latest estimations regarding plant status and new findings from the damaged Fukushima Daiichi reactors. BSAF members discussed their calculation results and co-operation with other NEA post-Fukushima research activities. The final report is being discussed and the summary report will be released in 2019.

The CIP

The Cabri International Project (CIP) is investigating the ability of high burn-up pressurised water reactor (PWR) fuel to withstand the sharp power peaks that can occur in power reactors due to postulated rapid reactivity insertions in the core, or RIAs. The project participants, from 12 member countries, intend to determine the limits for fuel failure and the potential consequences of possible ejection of fuel into the coolant environment. Different cladding materials and fuel types are being studied. The project is operated and managed by the Institut de radioprotection et de sûreté nucléaire (IRSN) and performed in the Cabri Facility, which belongs to the French Alternative Energies and Atomic Energy Commission (CEA), in Cadarache, France. The facility is operated by the CEA and funded by the IRSN.

The Cabri tests are complemented by additional RIA tests performed in Japan. These tests, which constitute an in-kind contribution from the Japan Atomic Energy Agency (JAEA), are being carried out in both cold and hot coolant conditions, and using both BWR and PWR fuel.

After 13 years of major refurbishment financed by the IRSN, the Cabri research reactor returned to criticality at low power in October 2015. Low-power tests from October 2015 to June 2016 allowed for complete neutronic characterisation of the core. In 2015-2016, qualification of the experimental equipment was completed, in particular the imagery and spectroscopy measurement station, as well as the hodoscope; the pressurised water loop was also qualified at 280°C and 155 bars. High power (23 MW) operation was attained during the last quarter of 2016. This test was part of the commissioning tests in 2017, including high power pulses that reached up to 20 GW. The final phase of testing in relation to RIA-type power transients was completed in 2017 and included sixty-six power pulses of different magnitudes and durations. A request made in late May 2017 to the French Nuclear Safety Authority (ASN) for authorisation of the first test in the water loop led to this test being carried out in April 2018. This first water-loop test used a MOX-fuel test rod with Zr-4 cladding and a burn-up of 47 GWj/t and post-test analysis is progressing very rapidly.

The procedure of obtaining approval from each project partner for a three-year extension of the project to March 2021 began at the end of 2017.

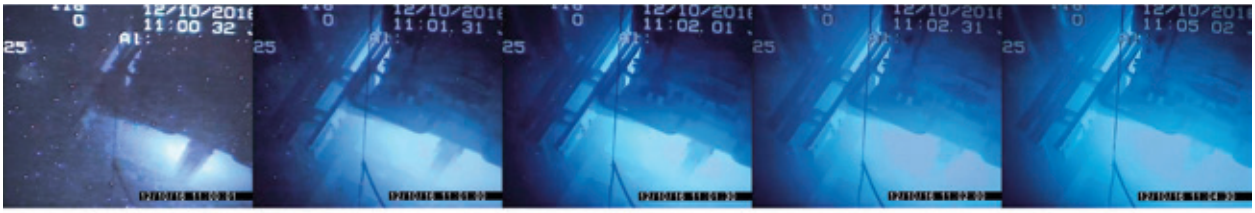
The HEAF Project

Massive electrical discharges, referred to as high energy arcing faults (HEAF), have occurred in nuclear power plant switching components throughout the world. These incidents have been increasing as a result of ageing infrastructures and growing energy demands. The HEAF Project was initiated in 2012 to perform experiments in order to obtain scientific fire data on HEAF phenomena through carefully designed experiments. Phase 1 of the HEAF project was completed in 2016 with a final report describing the testing and data generated. The report concluded with recommendations for areas requiring further testing.

In February 2017, an International Phenomena Identification and Ranking Table (PIRT) exercise was held to identify phenomena of the highest importance where the least amount of knowledge is available on HEAF events. This exercise tentatively identified aluminium oxidation, pressure effects, the characteristics of target structures and mitigating factors (e.g. HEAF shields) as being areas of interest for HEAF phase 2. Discussions are almost completed with representatives from 9 countries to initiate a second phase of the project, which is planned to start in late 2018. A kick-off meeting of the project was held in November 2018.

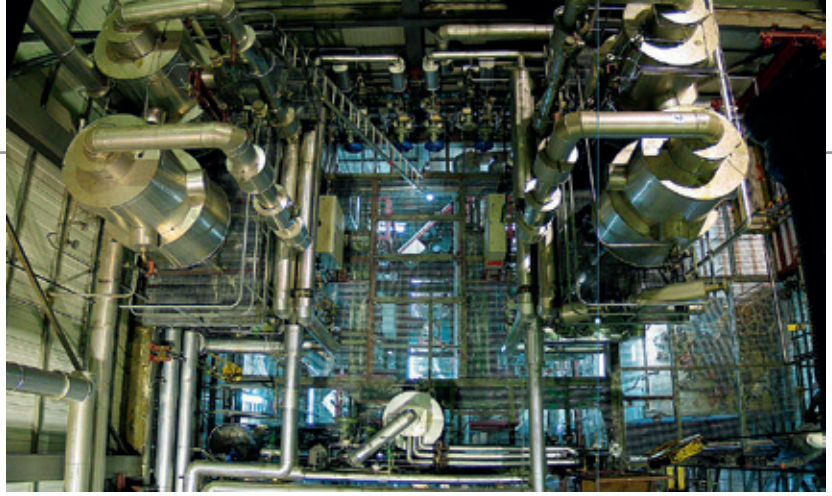
The HYMERES Project

The Hydrogen Mitigation Experiments for Reactor Safety (HYMERES) Project was initiated in 2013 with the objective of improving the understanding of hydrogen risk phenomenology in containment, and of enhancing the modelling of hydrogen behaviour in sup-



Photos looking down into the reactor pool showing the Cherenkov radiation characteristic of the different core powers.

IRSN, France



Top view of the PKL facility, Germany.
ORANO (AREVA), France

port of safety assessments that will be performed on current and new NPPs. The HYMERES Project is specifically aimed at topics of high safety relevance for both existing and future NPPs. It explores measured parameters as well as configurations and scales, and thus enhances the value of the data in terms of code improvements.

The unique and complementary features of the Multipurpose Integral Test Facility for LWR Safety Investigations (PANDA) in Switzerland and the Storage of Thermal Reactor Safety Investigations (MISTRA) facility in France, with their differences in size and configuration and their comprehensive instrumentation in terms of both spatial and temporal resolution, allows for high-quality experimental data. This data can be used to improve the modelling capabilities of CFD and advanced lumped parameter (LP) computer codes designed to predict post-accident, thermal-hydraulic conditions in containments, and thus enhance confidence in their use in plant analyses.

The first phase of HYMERES was concluded at the end of 2016. In July 2017, a second phase of the project started and a kick-off meeting was held in October 2017. A total of 11 countries – China, the Czech Republic, Finland, Germany, Japan, Korea, Russia, Spain, Sweden, Switzerland and the United States – are continuing their joint research to improve and validate safety codes for the simulation of reactor containment conditions in accident scenarios.

By means of experiments being carried out in the PANDA facility in Switzerland, the influence on containment thermal-hydraulics is being investigated during phase 2 of the project. The work programme focuses on four main topics: flow impacting obstructions and containment internal structures, radiative heat transfer, suppression pressure pool and BWR systems and the performance of safety component operations. The project members are currently preparing a benchmark exercise on the basis of a PANDA experiment.

The LOFC Project

Following a recommendation of the CSNI Task Group on Advanced Reactor Experimental Facilities (TAREF) for gas-cooled reactor safety studies, the Loss of Forced Cooling (LOFC) Project started in April 2011 with seven countries participating. The LOFC experiments study the effects of the reduction of reactor cavity cooling system (RCCS) performance and are highly relevant for safety assessments of advanced reactors such as the high-temperature reactor. The project remains on hold with a tentative schedule to restart the reactor now estimated in the Japanese fiscal year 2019. Experiments are to be carried out by the JAEA in its high-temperature engineering test reactor (HTTR) in Oarai, Japan.

The objectives of the project are to conduct integrated large-scale tests of LOFC in the HTTR reactor, to examine high-temperature gas-cooled reactor (HTGR) safety characteristics in support of regulatory activities, and to provide data useful for code validation and improvement of simulation accuracy. The objectives of the experimental programme are to provide experimental data to:

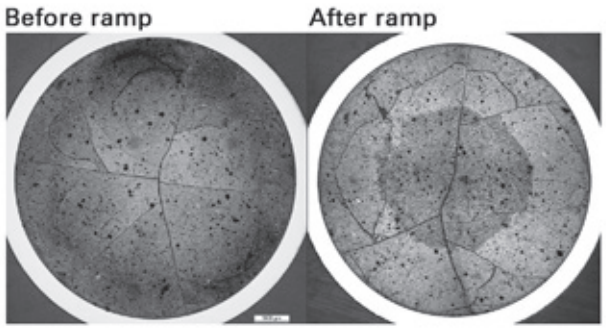
- clarify the anticipated transient without scram (ATWS) in case of LOFC with occurrence of reactor re-criticality;
- validate the most important safety aspects regarding reactor kinetics, core physics and thermal-hydraulics;
- verify the capabilities of the codes regarding the simulation of phenomena coupled between reactor core physics and thermal-hydraulics.

A meeting was held in 2018 to review the status of preparations to restart HTTR and to discuss actions required to resurrect the project's management board and programme review group.

The PKL Project

The PKL-4 test programme is investigating safety issues relevant for current PWR plants as well as for new PWR design concepts and will focus on complex heat transfer mechanisms under two-phase flow, boron dilution and precipitation, and on cool-down procedures. These issues are being investigated by means of thermal-hydraulic experiments that will be conducted at the Primärkreislauf-Versuchsanlage (primary coolant loop test facility) PKL. This facility is owned and operated by Framatome and is situated in Erlangen, Germany. Areva NP have for a number of years conducted valuable experiments on reactor thermal-hydraulics in the PKL facility, including earlier experiments carried out in the framework of the CSNI Senior Group of Experts on Safety Research (SESAR) Thermal-Hydraulics (SETH) Project (2001-2003), the PKL-1 Project (2004-2007), the PKL-2 Project (2008-2011), and the PKL-3 Project (2012-2016), which included tests run in the PMK[1] facility in Budapest, Hungary and in the PACTEL[2] facility in Lappeenranta, Finland and in the ROCOM[3] facility at Dresden-Rossendorf, Germany.

1. The PMK is an experimental facility at the Hungarian Academy of Sciences Centre for Energy Research in Budapest, Hungary. It is a full pressure scaled down model of the primary and partly the secondary circuit of the PAKS NPP equipped with VVER-440/213 type reactors.
2. PACTEL is a test facility designed to model the thermal-hydraulic behaviours of VVER-440 pressurised water reactors.
3. The test facility ROCOM (Rossendorf Coolant Mixing Model) was erected for the investigation of coolant mixing in the reactor pressure vessel of pressurized water reactors (PWR). ROCOM is a 1:5 model of the PWR KONVOI.



Studsvik Cladding Integrity Project (SCIP) ramp test.

After ramp: lot of small radial pellet cracks.

Also in the current programme, in addition to tests to be run in the PKL facility, additional tests will be run in the PMK facility in Budapest, Hungary and in the PACTEL facility in Lappeenranta, Finland. The PKL Phase 4 project started on 1 July 2016 and will end on 30 June 2020. It will focus on parametric studies on thermal-hydraulic procedures for model development and validation of thermal-hydraulic system codes, and on experimental verification of cool-down procedures and operation modes for different incidents and accidents.

The first category addresses test subjects related to current safety issues that either suffer from the lack of a dedicated database for analysis and validation of computer codes or from uncertainties in the safety evaluation stemming from open issues or questions. The extension to already-existing databases related to these subjects is the foremost goal of this first category of experiments. The second category of tests mostly contains transient tests either on test subjects already investigated in the former OECD/PKL-projects as answers to questions that could not yet finally be completed or on subjects that represent current topics from the international debate on PWR safety. Complementary tests in PMK and PWR PACTEL are also considered in the test programme. During the course of the project, a benchmark exercise is being carried out where blind and, possibly later on, open calculations will be benchmarked against one of the experiments. The experiment decided on by the project will target a small break LOCA in the upper head of the pressure vessel. This scenario has deliberately been chosen because it can be compared with a previous test performed in the large scale test facility (LSTF) in Japan. Because of the physical differences between the two plants, it will be possible to address scaling effects and distortions when comparing the two tests. The specifications of the PKL test will be defined specifically for this purpose.

The PKL-4 project runs between July 2016 to June 2020 and is supported by safety organisations, research laboratories and industry from the following 14 countries: Belgium, China, the Czech Republic, Finland, France, Germany, Hungary, Japan, Korea, Russia, Spain, Sweden, Switzerland and the United States. In November 2018, a joint analytical workshop was held together with the ATLAS project, in Barcelona. Here, the analyses (pre- and post-test) of different tests performed within the projects were discussed in depth. Also, the PKL benchmark was discussed in detail.

The PreADES project

The Preparatory Study on Analysis of Fuel Debris (PreADES) was one of the two near-term projects that were recommended by the Senior Expert Group on Safety Research Opportunities Post-Fukushima (SAREF). The main objectives of PreADES are to collect information for improving knowledge and methodologies for fuel debris characterisation that will support future fuel debris sampling analysis at Fukushima Daiichi units 1-3, to identify the needs for fuel debris analyses that will contribute to the decommissioning of the Fukushima Daiichi plant and deepen the knowledge base on severe accidents, and to prepare a future international R&D framework on fuel debris analysis.

Following the preliminary meeting organised in July 2017 in Fukushima, the kick-off meeting of the PreADES project was held in January 2018 at the NEA so as to discuss the details of the work programme proposed by the JAEA as Operating Agent of the project. The second meeting was held in Tokyo in July 2018. The project organised a one-day workshop on the status of Fukushima Daiichi decommissioning and relevant NEA post-Fukushima projects. The workshop was attended by experts involved in relevant NEA activities and experts from Japanese organisations as well as by the PreADES Project meeting participants. Participants discussed updates on the decommissioning operations at the Fukushima Daiichi site, as well as the estimation and evaluation of accident progression scenario and fuel debris distribution. The workshop programme also included discussions on the Analysis of Information from Reactor Building and Containment Vessel and Water Sampling in Fukushima Daiichi Nuclear Power Station (ARC-F) Project proposed by the NRA and JAEA.

The PRISME project

Fire is a significant contributor to overall core damage frequency for both new and old plant designs. Some of the technical studies related to fire probabilistic safety analysis that remain open are: the propagation of heat and smoke through a horizontal opening between two superposed compartments; fire spreading on real fire sources such as cable trays and electrical cabinets; and fire extinction studies of the performance of various fire extinction systems.

A third phase of the Fire Propagation in Elementary, Multi-room Scenarios (PRISME) project is under way and is planned to run from 2017 to 2021, with eight participating countries. The project's objective is to answer questions concerning smoke and heat propagation inside a plant by means of experiments tailored for code validation purposes, mainly within the IRSN DIVA facility[3] at Cadarache, France. The third phase will aim in particular to provide

3. Experimental facility for the study of fires, ventilation and airborne contamination.

The EPICUR apparatus used for experiments on irradiating iodine species for the STEM project.
IRSN, France

information on smoke stratification and on spreading, cable fire propagation and electrical cabinet fire spreading. A combined benchmark study between the PRISME and the NEA Fire Incidents Records Exchange (FIRE) projects will be conducted as well.

The SCIP

The Studsvik Cladding Integrity Project (SCIP) started in July 2004 and completed its first five-year mandate in 2009, when several power ramps and a hot cell programme addressing the various failure mechanisms were executed. SCIP-2 began in July 2009 with the objective of generating the high-quality experimental data needed for improving the understanding of dominant failure mechanisms for water reactor fuels and to devise means for reducing fuel failures. A third phase of the project began in July 2014 and will run until June 2019. China joined SCIP-3 in 2016 and Ukraine in 2018. The experimental campaigns of the SCIP-3 project progressed well in 2018, and at the end of the year only a few experiments remained. The shutdown of the Halden reactor has influenced the work programme since planned ramp tests could not be performed. Procedures were established to identify and approve replacement tests within the current phase. With the obtained results of this phase, it was possible to perform in-depth analyses and to draw the first preliminary conclusions (e.g. about a burn-up threshold for fine fuel fragmentation). In November 2017 and May 2018, the fourth and fifth SCIP modelling workshops were organised by Studsvik, and eight organisations presented their individual approaches.

The objectives of phase 3 are to:

- determine parameters affecting fuel fragmentation and dispersal in LOCAs;
- analyse the consequences of off-normal peak cladding temperatures and transients for the handling and storage of fuel rods;
- study the impact of power ramp rates on PCI failure risk;
- support model development and verification.

The STEM Project

The Source Term Evaluation and Mitigation (STEM) Project was initiated in 2011 to improve the general evaluation of the fission-product (FP) source term for reactor accidents in relation to two major FPs: iodine and ruthenium. Phase 1 of the project, which ended in 2015, addressed three main issues: experiments on radioactive iodine release due to irradiation of iodine-bearing aerosols; a literature survey on interactions between iodine and paints; and experiments on the transport of volatile ruthenium species through pipes. Supported by eight countries, a new four-year phase, STEM-2, started in January 2016 with the aim of conducting experimental investigations of iodine and ruthenium issues. One further country joined in 2017, while another is in the process of joining.

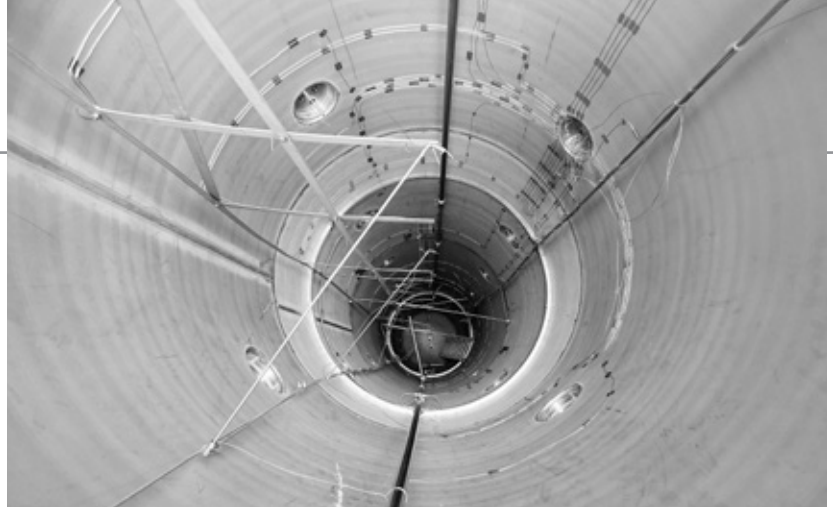
The following investigations concerning iodine are being undertaken:

- assessing to what extent molecular and organic iodine-release kinetics can be modified by the dose received by paint before and during an accident since paint ageing by irradiation, especially high doses, may lead to significant chemical modifications in paint;
- measuring the production of molecular and organic iodine (gas/vapour), and studying the influence of the dose, temperature and higher humidity rates on the radiolytical decomposition of iodine- oxide species (solid particulate);
- explaining the radiolytical oxidation of representative, multi-component iodine-bearing aerosols that would be produced in the reactor coolant system and lead to production of volatile iodine;
- assessing the decomposition of iodine oxides by carbon monoxide and/or hydrogen, leading to the production of volatile iodine.

In 2018, good progress was made on experiments investigating the liberation of iodine from iodine-oxide compounds as well as from particulate containing iodine compounds.

In terms of ruthenium, experiments in more representative conditions than used in STEM are being performed on simulations of ruthenium transport in the reactor coolant system in accident conditions. In particular, this means more representativity for the deposition surface (i.e. corroded stainless steel), the use of stronger oxidising conditions like those induced by air radiolysis products (such as ozone and nitrous oxides) and the use of representative gaseous and/or aerosol "pollutants" (i.e. seed particles, silver aerosols, aerosol deposits) that could significantly influence ruthenium behaviour. Good progress was made on these experiments in 2018.

It should be noted that the STEM and BIP projects have strong scientific links, with complementary objectives and many common partners.



THAI test facility: top view into the open PAD vessel during instrumentation work.
Becker Technologies, Germany

The THAI Project

Phase 2 of the Thermal-hydraulics, Hydrogen, Aerosols and Iodine (THAI) Project ended in 2015. A new three-and-a-half-year phase of this project, THAI-3, started in January 2016, and new experiments are once again being conducted in the THAI facility operated by Becker Technologies GmbH in Germany. The facility has been modified and now includes a second tank, narrower than the original one, which is connected by pipes at the top and the bottom to the original tank and now permits circulating flows. The agreement for phase 3 was approved in late 2017 with 15 partner countries. Canada joined in 2018.

The objective of THAI-3 is to address specific water-cooled reactor aerosol and iodine issues, as well as hydrogen mitigation under accidental conditions. The project is exploring open questions concerning:

- operation of passive autocatalytic recombiners (PARs) in the adverse conditions of counter-current flow;
- hydrogen combustion and flame propagation in two-compartment systems allowing simulation of natural-convection-driven flows in the containment, and looking in particular at the impact of higher flow velocities of unburned gas on flame acceleration;
- FP re-entrainment from water pools at elevated temperatures relevant to phenomena in BWR pressure-suppression pools, steam generator tube ruptures with the tube rupture submerged, wet filtered-containment-venting systems and long-term PWR accident scenarios with a flooded containment sump;
- re-suspension of FP deposits (aerosol and molecular iodine) resulting from hydrogen deflagration.

Experiments on all phases of the project have been completed except for final integral tests on iodine and aerosol re-suspension in the conditions of a hydrogen deflagration.

▶ Nuclear safety databases

The CADAK Project

The Cable Ageing Data and Knowledge (CADAK) Project started in 2011 as a follow-up to the cable ageing part of the Stress Corrosion Cracking and Cable Ageing Project (SCAP).

The CADAK Project focused on the relevance of cable ageing for plant ageing assessments and the implications for nuclear safety. The main objective of the CADAK Project was to establish the technical basis for assessing the qualified life of electrical cables in light of the uncertainties identified following initial (early) qualification testing and for estimating the remaining qualified lifetime of cables used in NPPs.

The CADAK Project has been discontinued due to lack of interest by participating countries. In 2018, a report was issued summarising the results of the CADAK database project during its two terms: 2012 to 2014 and 2015 to 2017.

The CODAP

The Component Operational Experience, Degradation and Ageing Programme (CODAP) started in 2011, building on two earlier NEA projects: the Piping Failure Data Exchange (OPDE) Project that ran from 2002 to 2011 and produced an international database on piping service experience applicable to commercial nuclear plants, and the Stress Corrosion Cracking and Cable Ageing Project (SCAP), which ran from 2006 to 2010 to assess stress corrosion cracking (SCC) and the degradation of cable insulation, both of which have implications for nuclear safety and for plant ageing management.

The objectives of CODAP include:

- collect information on passive metallic component degradation and failures of the primary system, reactor pressure vessel internals, the main process and standby safety systems, support systems (i.e. ASME code classes 1, 2 and 3, or the equivalent), and components not related to safety (non-code) but with significant operational impact;
- develop topical reports on degradation mechanisms in close co-ordination with the CSNI Working Group on Integrity and Ageing of Components and Structures (WGIAGE).

CODAP has produced a number of insight reports analysing events in the database. In 2018, the fifth topical report was issued, describing the basic principles of collecting and evaluating

operating experience data on metallic passive components and a summary report, which describes the status of the CODAP Project at the conclusion of the second phase (2015-2017). At the end of the second phase, the CODAP database included about 4 900 records on degraded and failed metallic piping and non-piping passive components.

The FIRE Project

The FIRE Project started in 2002, and phase 5 of the project began in 2016 for a duration of 4 years, with 14 countries participating. The main purpose of the project is to collect and analyse, on an international scale, data related to fire events in nuclear environments. The specific objectives are to:

- define the format for, and collect fire event experience (through international exchange) in a quality-assured and consistent database;
- collect and analyse fire events data over the long term so as to better understand such events, their causes and their prevention;
- generate qualitative insights into the root causes of fire events that can then be used to derive approaches or mechanisms for their prevention or for the mitigation of their consequences;
- establish a mechanism for the efficient feedback of experience gained in connection with fire events, including the development of defences against their occurrence, such as indicators for risk-based inspections;
- record event attributes to enable quantification of fire frequencies and risk analysis.

The structure of the database has been well defined and arrangements have been made in all participating countries to collect and to validate data. The quality-assurance process is in place and has proven to be efficient on the first set of data provided. An updated version of the database, which now contains more than 490 records, is provided to participants every year. A common benchmark activity is being planned between the FIRE database and PRISME-3 experimental project.

The ICDE Project

The International Common-cause Data Exchange (ICDE) Project collects and analyses operating data related to common-cause failures (CCF) that have the potential to affect several systems, including safety systems. The project has been in operation since 1998, and was extended with a new phase-7 agreement covering the years 2015 to 2018.

The ICDE Project comprises complete, partial and incipient CCF events. It currently covers the key components of the main safety systems, such as centrifugal pumps, diesel generators, motor-operated valves, power-operated relief valves, safety relief valves, check valves, control-rod drive mechanisms, reactor protection system circuit breakers, batteries and transmitters. These components have been selected because several PSAs have identified them as major risk contributors in the case of CCFs.

Qualitative insights from data will help reduce the number of CCF events that are risk contributors, and member countries use these data for their national risk analyses. Additional activities in the area of quantification are under discussion. Reports have been produced for pumps, diesel generators, motor-operated valves, safety and relief valves, check valves and batteries. Data exchange for switchgear and breakers, and for reactor-level measurements, have been completed. An ICDE Project report concerning the Lessons Learnt from Common-Cause Failures of Emergency Diesel Generators was finalised in 2017. The report concluded that the most frequently occurring causes of emergency diesel generator failures are errors related to design, manufacture or construction inadequacy.

In 2018, the ICDE project has identified how to define root causes of events more precisely and improve event descriptions in the project database. Also, reports were finalised on multi-unit CCF events, on modifications related to CCF events, on improving testing related to CCF and on a summary of project work and results during the years 2014 to 2017.

Secretariat-serviced body

Multinational Design Evaluation Programme

Vogtle Unit 3 & 4, AP1000 north view, United States, October 2018.

Georgia Power Company

The Multinational Design Evaluation Programme (MDEP) is a multinational initiative to develop innovative approaches to leverage the resources and knowledge of national regulatory authorities who are engaged in new reactor power plant design activities. The main objective of MDEP is to enable increased co-operation and establish reference regulatory practices to enhance the safety of new reactor designs. Enhanced co-operation among regulators strengthens the effectiveness and efficiency of the regulatory design reviews. MDEP co-operation is structured around its design-specific working groups. The portfolio of new reactor designs that are part of MDEP have increased from two in 2006 to six in 2018, with the addition of the Hualong One (HPR1000) reactor design from China. Other MDEP design-specific working groups include the EPR, AP1000, APR1400, ABWR and VVER working groups. MDEP's membership has continued to grow, as well, to 16 national regulators with the addition of the Nuclear Regulatory Authority (ARN) of Argentina, as its newest member. Other MDEP members are regulators from Canada, China, Finland, France, Hungary, India, Japan, Korea, Russia, South Africa, Sweden, Turkey, the United Arab Emirates, the United Kingdom and the United States. In 2018, the ABWR design-specific working group completed its programme of work under MDEP with the publishing of its ABWR closure report. MDEP working groups address a broad spectrum of technical issues and regulatory challenges that can arise during the licensing and commissioning phases of new reactor design, construction and early phase operation. Active, constructive engagement among member regulators has led to a productive year in terms of sharing information on regulatory decisions and identifying lessons learnt. In line with the MDEP Policy Group's decision to focus on design-specific activities, MDEP has taken steps to transfer MDEP generic activities to the NEA. Last year, digital instrumentation and control activities were successfully transferred to the Nuclear Energy Agency (NEA) under the CNRA. A second generic issue-specific working group, the Codes and Standards working group, concluded its programme of work under MDEP in June 2018 and started its new mandate under the CNRA. In both areas the aim is to broaden the scope to include operating reactors and to expand membership to include other NEA member countries. Currently, only one issue-specific working group dedicated to vendor inspection co-operation, supports the programme by addressing cross-cutting issues. The IAEA is involved in generic MDEP activities to support consistency and co-ordination.

2018 MDEP highlights

In 2018, the MDEP working groups have been very active in issuing common positions on areas such as the Vienna Declaration on Nuclear Safety, the boron dilution during a small break LOCA, thermal conductivity degradation and issues associated with the return of condensate to the In-containment Refuelling Water Storage Tank (IRWST) in postulated fault conditions that were equally applicable to the AP1000 designs proposed for each country. Technical reports issued in 2018 include the design, manufacturing and testing of the reactor coolant pump (RCP) and the design, qualification and application of pyrotechnic-actuated (squib) valves used in the AP1000.

Co-operation on commissioning activities is part of the programme of work for all design-specific working groups. Over the past year, MDEP design-specific working groups have increased their focus on reactor commissioning activities as new EPR, APR1400 and AP1000 plants are preparing for or have commenced commercial operations. The EPR and AP1000 working groups are particularly active in this area, as together they are overseeing 12 new reactor constructions worldwide. This reporting period marks a significant milestone for MDEP since it provided a unique opportunity for regulators involved to demonstrate the efficiency of using common positions to effectively collaborate and share information on First Plant Only Test (FPOT) results conducted in the EPR and AP1000 plants in China. In addition, MDEP has enhanced co-operation on areas of emerging risk in supply chain management and vendor activities, specifically with regard to counterfeit, fraudulent and suspect items (CFSIs). The ongoing cooperation has enabled participating regulators to consider the adequacy of their activities aimed at mitigating the risks of CFSIs entering licensee facilities through vendors. The vendor inspection co-operation working group published a common position on CFSI procedures and policies. Other common positions published by the vendor inspection co-operation working group include: witnessed, joint and multinational vendor inspection protocol and the preparation and performance of vendor inspections. They also published a technical report on its assessment of the Multinational Vendor Inspection conducted at AREVA NP Creusot Forge.

For more information on the MDEP structure, and to consult publicly available technical reports and common position papers, see www.oecd-nea.org/mdep.

Human Aspects of Nuclear Safety

The goal of the NEA in this sector is to assist member countries in their efforts to enhance the focus on human aspects impacting nuclear safety that have been highlighted as critical elements leading to all past nuclear power plant accidents. This sector also includes issues associated with effective public communication and stakeholder engagement regarding nuclear safety, waste management and related issues. The staff works closely with all NEA committees and relevant expert groups in this area, most prevalently the Committee on Radiological Protection and Public Health (CRPPH), the Committee on Nuclear Regulatory Activities (CNRA), the Committee on the Safety of Nuclear Installations (CSNI) and the Radioactive Waste Management Committee (RWMC).

Highlights

- In March 2018, the CRPPH took the lead in preparing the NEA Workshop on Stakeholder Involvement on Risk Communication in 2019 and initiated planning activities.
- The Working Group on Safety Culture (WGSC) continued to progress on the two tasks approved by the Committee on Nuclear Regulatory Activities (CNRA) in June 2018. The group of senior experts also continuously updated their safety culture programmes in general and specifically pertaining to the following two tasks: Self-Assessments/Self-Reflection and Building Safety Culture Competency.
- Wishing to increase the understanding of human performance under accident conditions, the members of the NEA Working Group on Human and Organisational Factors (WGHOF) participated in an international conference on severe accident management hosted by the Canadian Nuclear Safety Commission.
- The NEA Working Group on Public Communication of Nuclear Regulatory Organisations (WGPC) conducted its first national case study in Bern, Switzerland.
- The NEA Forum on Stakeholder Confidence (FSC) continued its "Intergenerational Outreach" by inviting a teacher from Belgium and students from Switzerland to exchange on ways to build engagement during its September annual meeting.
- Two International Mentoring Workshops on Science and Engineering were held in 2018, in Japan and in Spain, providing a forum for accomplished women to encourage girls at high school to consider studies and careers in the science and engineering fields.
- The NEA held a first-of-a-kind country-specific safety culture forum to examine the national context and its impact on safety in Sweden in 2018 and published its results.

Safety culture and leadership

The Working Group on Safety Culture (WGSC) aims to facilitate an open exchange among regulators on safety culture, to address influences and factors affecting licensees' safety cultures and the wider interconnected system, and to consider the related implications on regulatory effectiveness. During the two meetings of the WGSC held in 2018 members shared the current status of their safety culture programmes. The group continued to develop the tasks based on the two main themes which emerged from the first working group meeting. The first was the need for reflection and assessment of the regulatory body, with the objective of providing member countries with comprehensive and practical guidance on ways in which regulators can improve their self-awareness. The second focused on building safety culture competence, with the objective of developing and promoting a healthy safety culture through guidance on how to foster good practices. The working group will continue to focus on the goal of providing practical tools and guidance to regulatory bodies.

The working group members held detailed discussions on a variety of developments intended to positively affect the safety culture. They exchanged specific information on the current status and recent developments of their national programmes. These recent developments include various methods of self-assessments/self-reflection such as the development of a safety culture maturity matrix, development of comprehensive safety culture surveys

"Insights from Leaders in Nuclear Energy", Toyoshi Fuketa, Chairman, Nuclear Regulation Authority in conversation with William D. Magwood, IV, Director-General, Nuclear Energy Agency, 10 August 2018, Japan.

and administering independent assessments. In relation to building competency in safety culture, WGSC members engaged in external seminars, provided training focused on the gap between policy and what is revealed in self-assessment activities.

The NEA recognises that leaders influence the safety culture of their organisations and have a major impact on nuclear safety. Considering the essential role of leadership for safety, the NEA is exploring leadership activities that engage both regulatory authorities and operating facilities. Considering that effective leadership can be subjective, and that setting regulatory requirements in this area may be challenging, the NEA has developed a new concept to learn from leaders around the world through one-on-one interviews. With the support of the WGSC and its work programme to address leadership for safety competence, the intention of this project is to build a series of dialogues on leadership, starting with a first interview held in Japan in August 2018. The outcomes were compiled in a booklet. The various nuances and challenges concerning leadership and how it affects safety will be infused into the activities and tasks of the WGSC. The objectives would be to ensure that leadership helps sustain a healthy safety culture and ensures safe operations.

Country-Specific Safety Culture Forum

Recognising that the national context has an impact on the safety culture of regulatory authorities and the industry they regulate, a first-of-its-kind forum was created by the NEA to raise awareness on potential safety culture challenges related to national context, with the objective of helping organisations maintain a healthy safety culture for the safe operations of nuclear installations and for effective regulatory activities. In collaboration with the World Association of Nuclear Operators (WANO), the first country-specific safety culture forum (CSSCF) was held in Sweden in January 2018 and brought together over 60 experts from the Swedish nuclear community and international observers from France, Finland, Japan, Korea, South Africa and the United States, representing the industry and regulatory organisations. The forum was a culmination of data-capturing exercises and analysis of Swedish national attributes that were embedded in a technical scenario played out by the forum participants. Through this role play, participants could reflect and discuss the national attributes and find ways to work within this context in order to sustain a healthy safety culture. A report was published in September 2018, in both English and Swedish.

The next host country will be in Finland in March 2019. Canada, Russia, Switzerland and the United Kingdom have all confirmed their intention to host a CSSCF in the near future, with other countries considering doing so as well. The series of workshops will contribute to building a suite of CSSCF reports.

Human and organisational factors

The NEA Working Group on Human and Organisational Factors (WGHOF) focuses on improving the understanding and treatment of human and organisational factors within the nuclear industry, with the goal to support the continued safety performance of nuclear installations and improve the effectiveness of regulatory practices in member countries.

In 2018, the group collected information from nuclear regulatory organisations on actions taken since the accident at Fukushima Daiichi effort to improve mitigation capabilities in the face of extreme external events and severe accidents. The group is also examining specific human and organisational factors that may have been addressed through these actions.

Building on its consensus report "Human Factors Validation of Nuclear Power Plant Control Room Designs and Modifications" published in 2017, the group advanced its work on a new report defining a multi-stage approach to validation through a series of successive, co-ordinated activities performed at multiple points or periods during the development or modification of a control room design. It is set to provide a promising pathway towards enhancing confidence in the validation outcomes, as the approach has the potential to reduce risk in the design process, increase effectiveness and efficiencies in the validation process and increase overall confidence in the results. The report on multi-stage validation of control room designs and modifications will be published in 2019.

With the overall goal of increasing the general understanding of human and organisational factors and demonstrating the advantages of addressing such concepts within a systemic approach to safety, the WGHOF continued work on human and organisational performance. The objectives are to increase the shared understanding of commonly used concepts in this area, to develop a model that visualises the dynamic relationships and interactions between human, technical and organisational factors, and to provide practical guidance on the application of the model.

The report Nuclear Regulatory Organisations' Oversight of New Licensee Organisational Capability was published in August 2018, as a result of a joint CNRA Working Group on the Regulation of New Reactors (WGRNR) and WGHOF workshop held in 2017 in Chester, United Kingdom and in collaboration with the UK Office of Nuclear Regulation. Future work identified in this area includes the provision of guidance on building and assessing organisational capabilities, and more specifically on project management guidance with a focus: on safety culture; decision making; competency building; and supply chain oversight throughout the various life cycle stages of a new build project.

To assist countries facing early or unplanned phase out of nuclear power plants, the WGHOF has been preparing a report on prioritised organisational capabilities for all phases of decommissioning. With input from the Working Party on Decommissioning and Dismantling (WPDD), several themes related to human and organisational factors during decommissioning have been identified: competence, socio-economic capabilities, leadership and regulation, asset management, culture and motivation, and project management. These themes are being explored by the WGHOF to provide best practices and practical examples of how to develop and apply the identified capabilities.

The WGHOF is working with the NEA Working Group on Risk Assessment (WGRISK) to examine human reliability assessments in external events. The results will contribute to a realistic and consistent treatment of operator actions in probabilistic safety assessments (PSAs) for each hazard type and of related human performance issues that are associated with different hazards.

Public communication and stakeholder involvement

Building on the January 2017 NEA workshop on the same subject, the NEA has begun preparations for the second Workshop on Stakeholder Involvement to be held on 24-26 September 2019. Led by the CRPPH and supported by the NEA Working Group on Public Communication of Nuclear Regulatory Organisations (WGPC), the workshop will focus on risk communication and on how to create dialogue towards a shared understanding of radiological risks. It will involve all NEA standing technical committees, their subsidiary bodies and stakeholders.

The WGPC provides a forum for nuclear regulatory organisation communicators to exchange information, experiences and practices. It also aims to exchange views regarding the policies of nuclear regulatory organisations in the area of public communication and identify ways of promoting efficient collaboration. In 2018, the group conducted its first national communications case study in Bern, Switzerland. The goal was to analyse the communications consequences from a specific event, as presented by those involved or impacted by the event. This activity brought together a nuclear power plant operator, a non-profit organisation, a member of the media, a local government representative and the nuclear regulator who shared their own perspectives and understanding of the event and the communications around it. The WGPC members then assessed the case for the lessons learnt and best practices that could be applied in their own countries. A report will be published in 2019, with a second case study exercise planned for 2020 in Helsinki, Finland. Recognising that social media has become a major source of information for the general public, the group conducted a survey of its members to find out how each organisation is using the various platforms available to inform and engage with their stakeholders. Members also submitted case studies showcasing their use of such tools as Twitter, YouTube, and Facebook. The outcomes were captured in a report on the evolving use of social media as a communication tool which will be published in 2019. This report will be an update to *Nuclear Regulatory Organisations, the Internet and Social Media: The What, How and Why of Their Use as Communication Tools* published in 2014.

The "Country-Specific Safety Culture Forum" January 2018, Stockholm, Sweden.

Accounting for the socio-political considerations of waste management programmes is a major challenge. The Forum on Stakeholder Confidence (FSC) provides a neutral forum to facilitate dialogue among all relevant stakeholders in this area, and, in 2018, continued to analyse stakeholder confidence factors. The FSC updated and produced easy to use documents such as flyers and policy reports on partnering, social media use, exploring the potential value of radioactive waste facilities for local communities and stakeholder confidence in waste transportation. FSC members are currently updating the 2010 Partnering Report for Long-term Management of Radioactive Waste that described the evolution and current practice in thirteen countries (2010) and the Annotated Glossary of Key Terms (2013) with the addition of the term "Added Value" and what it may mean to different stakeholders.

Collaboration on communication issues with the RWMC Integration Group for the Safety Case (IGSC) and the WGPC continued after a successful joint workshop on public perception enhancement held in 2017. The FSC participated in the WGPC annual meeting in April 2018 and presented at the IGSC symposium on Current Understanding and Future Direction for the Geological Disposal of Radioactive Waste in October 2018. To increase its ongoing collaboration and enhance its communication, the FSC distributed two newsletters highlighting cross-cutting issues.

The FSC was invited to participate in the strategic development of the new Committee on Decommissioning of Nuclear Installations and Legacy Management (CDLM). During the 2018 annual meeting, the FSC focused on updating its governing documents so that its activities fully support the CDLM.

Recognising the importance of ensuring that the voices of the younger generation are heard, the FSC is also exploring further methods to enhance youth engagement, such as the development of an online tool or database of what educators are using to exchange experience and approaches. The FSC remains committed to engaging with young people and invited an educator and a young stakeholder to share insights during its annual meeting. Both guests participated in discussions and a world café to impart their perspectives on how best to engage young stakeholders.

The working group continues to explore how the next workshop can be designed to be more streamlined so that member countries will not have to exploit overwhelming resources to host a national workshop.

International Mentoring Workshop in Science and Engineering

As part of its overall strategy and mission, the NEA is committed to supporting its members in their efforts to secure qualified human resources, nuclear skills capability building and the development of a new generation of nuclear experts. It is in this spirit that, following the successful debut in July 2017 in Chiba, Japan, the NEA held two additional mentoring workshops in 2018 in Tokyo, Japan and in Ávila, Spain.

The "Joshikai II for Future Scientists: International Mentoring Workshop in Science and Engineering" was held on 8-9 August in Tokyo, Japan in co-operation with the Japan Atomic Energy Agency (JAEA). The workshop brought together 50 female students from Japanese high schools and junior high schools with highly accomplished women scientists and engineers from Japan and from three additional NEA member countries. Another NEA International Mentoring Workshop in Science and Engineering was convened for the first time in Europe. The workshop, entitled *Impulsando a las futuras líderes en ciencia y tecnología*, took place on 24 September in Ávila, Spain and was jointly organised with the Spanish Women in Nuclear Association. With the same objective as those previously held in Japan, the Spanish mentoring workshop gathered fifty female students from high schools with twelve highly accomplished women scientists and engineers from Spain. The NEA stands ready to support more International Mentoring Workshops in both NEA and partner countries.

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Radiological Protection

The goal of the NEA in this sector is to assist member countries in the regulation, implementation and further development of the system of radiological protection by identifying and effectively addressing conceptual, scientific, policy, regulatory, operational and societal issues. The staff works closely with the Committee on Radiological Protection.

Highlights

- The NEA held the first International Radiological Protection School (IRPS) in August 2018, sponsored by the Swedish Radiation Safety Authority (SSM) and hosted by Stockholm University, and agreed to hold the second IRPS, to be held on 19 – 23 August 2019, sponsored by SSM and hosted by Stockholm University.
- The CRPPH Expert Group on Recovery Management (EGRM) was established in co-operation with the NEA Working Party on Nuclear Emergency Matters (WPNEM).
- The NEA completed Phase 1 of the Expert Group on Legacy Management's (EGLM) work programme.
- The experimental work of the CRPPH Joint Undertaking on Organ Dose Variability with Gender, Age and Body Mass Index (BMI) was finalised.
- The NEA held the CRPPH-76 Topical Session on Communicating Radiation Hazards: Index/Scale Concepts.
- The NEA report, *Towards an All-Hazards Approach to Emergency Preparedness and Response: Lessons Learnt from Non-Nuclear Events*, was published in January 2018.
- The INEX 5 summary document was published and 5 new Expert Groups were initiated to update the protective measures handbook, benchmark projection code outputs, involve decision makers in protective action strategic planning, develop a real-time communications strategy, and to study non-radiological post-accident public health aspects.
- Within the framework of the Information System on Occupational Exposure (ISOE), three As Low As Reasonably Achievable (ALARA) symposia were held and a table of new occupational exposure data was developed for reactors being decommissioned.

Supporting future RP leaders

Concern over the availability of qualified Radiological Protection (RP) experts in the coming five to ten years continues to be an issue for regulatory and industrial organisations. This drove the CRPPH to address this issue from two different angles: the International Radiological Protection School (IRPS); and a programme to develop a career framework.

The IRPS held its first session in August 2018 at Stockholm University, supported by the Swedish Radiological Safety Authority (SSM). The school's objective was to provide a clear understanding of the RP system and how it is intended to be interpreted for application in diverse and emerging circumstances where the "spirit" of the RP system – its nuances and history – needs to be fully understood. A total of 40 early- to mid-career participants from 26 countries attended IRPS-1. A total of 15 world-renown RP experts gave lectures covering a broad span of radiological protection expertise, and participated during the entire week discussing with students outside the formal sessions. It has been agreed that IRPS-2 will be held at Stockholm University, with support from SSM, on 19-23 August 2019.

To further help assure the availability of RP expertise where and when it is needed, the idea of a globally-recognised qualification level is being explored. It is felt that a recognised level of RP expertise would greatly facilitate the acknowledgement of an individual's qualifications, and thus facilitate the assessment of their ability to appropriately address RP issues associated with a given position. The development of a recognised level of RP expertise would also encourage employers to calibrate their position requirements in a fashion comparable to those of the globally-recognised qualification level, also facilitating experts moving to the place when and where they are needed. Previous efforts to achieve a standard, recognised qualification level (e.g. by HERCA[1], EUTERP[2], IRPA[3]) will be collaboratively built upon by the NEA's work in this area. The NEA's policy-level organisations will then build an instrument for official, national recognition of this qualification level. A communication strategy, addressing both the qualification and the interesting and long-term possibilities of a career in radiological protection, will be developed.

1. Heads of the European Radiological Competent Authorities.
2. European Training and Education in Radiation Protection Foundation.
3. International Radiation Protection Association.

Webinar of 12 January 2018 with William D. Magwood, IV, Director-General, Nuclear Energy Agency (NEA); Thierry Schneider, Director of the French Nuclear Protection Evaluation Centre and Vice Chair of the NEA Committee on Radiological Protection and Public Health; Anthony Cox, Acting Director of the OECD Environment Directorate; and Jack Radisch, Senior Project Manager at the OECD Directorate for Public Governance.

Low dose effects of radiological exposure

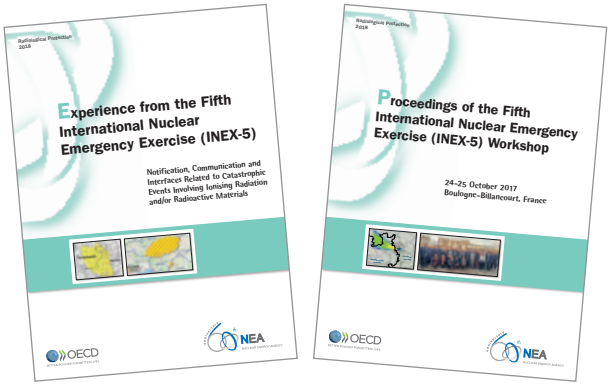
Most exposures of members of the public and workers are scientifically considered as being relatively small in terms of the risk they might bring. In fact, such exposures are generally at a level where the scientific understanding of exposure and associated risk is extremely uncertain, or in fact non-existent. While it is known that any exposure can cause cellular damage, at these low doses an exposed population shows a statistically similar number of cancers as would appear in a population that is not exposed. The upper bound of possible risks is small, but it is not known if there is any measurable risk at all. For this reason, there is much radio-biological and epidemiological research ongoing to find a more definitive understanding of how cells, tissues, organs and living creatures react to radiological exposures. To improve the efficiency and effectiveness of such research, in 2018 the NEA created a high-level group of experts from funding and research organisations to foster improved co-ordination and collaboration.

The rationale behind the interest in such work is based on the evolving notion of optimisation of protection, as recommended by the ICRP and broadly applied in international standards, and regional and national regulations. The NEA has for some time been working with the ICRP in particular with respect to integrating the concerns and views of stakeholders in radiological protection decisions. This is particularly true of optimisation of protection, which is recommended as an approach to identify the most appropriate protective measures under the prevailing circumstances, taking social and economic aspects into account. A key aspect of such assessments at low doses, where risks are unknown or at best extremely uncertain, is an assumption with regard to possible levels of risk against which protection is needed. The NEA has concluded that any circumstances needing protection choices should be addressed from an "all hazards" standpoint. As such, balancing all risks can be more effectively achieved if levels of risk are more accurately known. This is important when considering such situations as how much protection to afford workers or members of the public from radioactive emissions, residual contamination from accident or installation clean-up activities, medical screening exposures, radon in homes and public buildings, etc. A workshop addressing such choices will be organised in 2019. In September 2018, the 5th Science and Values in RP Decision Making Workshop was held in Milan to better understand aspects of RP science and social values considered in RP decision making, and how such decision rationale can be more articulately expressed to stakeholders.

Lessons in post-accident recovery

Seven years after the Fukushima Daiichi nuclear power plant accident, its effects continue to affect many stakeholders. The lessons that can be gleaned from this experience focus broadly on confidence: in experts capable of explaining radiological effects and protection options; in the functioning of municipal infrastructures such as schools, medical support, stores, etc.; in economic livelihoods remaining viable; and in society, mostly in family, friends, and neighbours remaining in contact and rebuilding a social infrastructure. Confidence in an individual's global view of the multi-faceted, complex circumstances caused by such a disruption to life can facilitate individual, municipal, regional, national and international decisions. Such confidence cannot be directly rebuilt by central governments, but the elements in which affected people want to have confidence can be rebuilt and supported directly and indirectly by central government. This suggests that the slow redistribution of "responsibilities" for protection choices (e.g. from the emergency planning phase, to the emergency phase, to the transition phase, to the recovery phase) should be further analysed and factored into emergency and recovery planning frameworks. To identify and document these important lessons the CRPPH has created the Expert Group on Recovery Management (EGRM), with member country experts in both emergency and recovery management.

In the context of post-accident recovery, the NEA continued to support the ICRP Phase 2 Dialogue meetings during 2018. The ICRP dialogue series with Japanese stakeholders has demonstrated that confidence in the understanding of the radiological situation has supported decisions to stay in affected territories, or return to these territories. It has also helped to develop a positive attitude towards the future, accepting the post-accident normality.



Nuclear emergency management

Nuclear emergency management planning, implementing, decision-taking, stakeholder involvement, etc. has continued to evolve as studies of the Fukushima Daiichi accident, and of the more numerous chemical accidents have continued to yield valuable lessons. The results of the fifth International Nuclear Emergency Exercise (INEX-5), presented and discussed at an October 2017 NEA workshop and an NEA report on lessons learnt from non-nuclear accidents contributed significantly to the 2018 identification of the highest priority aspects to improve or further study. As a result, five new expert groups were created under the WPNEM and mandated to study these important areas.

National and international inter-agency communication during the emergency phase of an accident has been an important issue for some time. In view of the complex nature of national emergency response organisation and responsibilities, many countries have developed inter-ministerial communications mechanisms. The INEX-5 exercise suggested that some improvement in real-time emergency-management communications, both nationally and internationally, would be of use. An expert group was created to address this question, building on national experience and existing models.

Non-radiological public health impacts, such as stress, depression, family and social conflicts, etc., are generally the most serious and numerous effects of emergency situations. To study how planning and information might alleviate some of these effects, both long- and short-term, an expert group was established. In parallel, a joint workshop on non-nuclear emergency response is being organised.

Recovery management is an area that is in the early stages of development. The complexity of effects and remediation approaches is significant, broadly due to the enormous scope of the aspects (e.g. social, economic, municipal, national, and personal) to be taken into account. All these aspects play a part in how prevailing circumstances are perceived and managed by affected stakeholders. Experience from Chernobyl and Fukushima will be used by a newly created expert group of recovery and emergency management specialists to develop a framework document on good experience and good practice.

On a more pragmatic level, dose projection codes are central elements of emergency response planning, preparation and implementation. However output from such codes tends to be dependent on the nature of the inputs used, such that two different codes may yield significantly different results. While this does not mean that one code's results are inherently better than another one's, understanding why such differences exist will facilitate the interpretation of divergent results. An expert group was created to develop a benchmarking exercise for the assessment of dose projection code outputs.

Depending on local geographic and demographic details, the most appropriate emergency protective measures may vary between hazardous sites. Many countries have developed national handbooks for emergency management to address the variety of situations under their responsibility. A newly created expert group will update the WPNEM member country Protective Measures Handbooks.

Finally, emergency exercises are used to test planning and preparation aspects, but also to train operators and decision makers. The participation of decision makers, often elected officials, in protective action strategy development can be challenging. An expert group will develop an approach to further encourage decision maker participation.

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INEX-1
Early phase / communication / decision-making process in national responses / food safety / emergency assistance

INEX-2
Decision making in uncertain conditions / real time communications / public and media interactions

INEX-2000
Monitoring and data management strategies for nuclear emergencies / international co-ordination / aspects of Conventions on Third Party Liability

INEX-3
Consequence management / long-term issues / decision making in the medium and longer term

INEX-4
Post-crisis emergency management / response to widespread radiological contamination of the urban environment

INEX-5
Notification and communication aspects / transboundary aspects / interfaces / identifying and obtaining resources

Joint Project

The Information System on Occupational Exposure

Since its creation in 1992, the Information System on Occupational Exposure (ISOE), sponsored jointly by the NEA and the IAEA, has been facilitating the exchange of data, analysis, experience and lessons learnt in occupational radiological protection (RP) at nuclear power plants worldwide. It maintains the world's largest occupational exposure database and a network of utility and regulatory authority RP experts.

As the end of 2018, the ISOE programme included 79 utilities and 28 regulatory authorities from a total of 31 participating countries. The ISOE operates in a decentralised manner. Decisions and overall direction are provided by the ISOE Management Board, composed of representatives from utilities and regulatory authorities from all participating countries. The ISOE Bureau, elected by the Management Board, guides ISOE and Secretariat work between Management Board meetings. Both are supported by the joint NEA/IAEA Secretariat. Four ISOE Technical Centres (Asia, Europe, the IAEA and North America) serve the programme's day-to-day technical operations and are contact points for the transfer of information from and to participants. A national co-ordinator in each country provides a link between ISOE participants and the ISOE programme. Specialised working and expert groups are created on an as-needed basis by the Management Board to support the goals of the ISOE on specific topics. There are currently three active working groups: the Working Group on Data Analysis (WGDA) and the Working Group on Radiological Protection Aspects of Decommissioning Activities at Nuclear Power Plants (WGDECOM) and a newly created expert group to update the ISOE Work Management book (TGWM). The Management Board also created a Task Group to review and recommend modifications to the ISOE structure, in particular the Technical Centres and their funding practices, and to recommend approaches to support the NEA's secretarial services.

The ISOE occupational exposure database contains information on occupational exposure information for 355 operating units and 68 units in cold shutdown or at some stage of decommissioning in 31 countries, thus covering about 80% of the world's operating commercial power reactors. The ISOE database, publications, benchmarking visits and annual symposia, along with the ISOE Network website, facilitate the exchange among participants of operational experience and lessons learnt in the optimisation of occupational radiological protection.

In 2018, the ISOE programme continued to concentrate on the exchange of data, analysis, good practices and experience in the area of occupational exposure reduction at nuclear power plants, and on improving the quality of its occupational exposure database.

Key outcomes of work during 2018 include the collection and integration of 2017 data into the ISOE database and the publication of ISOE country reports for 2017, the publication of the new ISOE information sheets, and the organisation of three benchmarking visits.

The ISOE programme organised an International ALARA Symposium in Kyoto (Japan) in October 2018 and two regional symposia: North American Regional ISOE Symposium in Fort Lauderdale (USA) in January 2018, and European ISOE Regional Symposium in Uppsala (Sweden) in June 2018. These symposia serve as important venues for utilities to meet in an international setting.

Radioactive Waste Management

The goal of the NEA in this sector is to assist member countries in the development of safe, sustainable and broadly acceptable strategies for the long-term management of all types of radioactive waste and spent fuel, and to provide governments and other relevant stakeholders with authoritative, reliable information on the political, strategic and regulatory aspects of decommissioning nuclear installations.

Highlights

- In 2018, the NEA continued participation in the joint initiative of the European Commission (EC), the International Atomic Energy Agency (IAEA) and the NEA on the Spent Fuel and Radioactive Waste for the Status and Trends Project. The NEA Expert Group on Waste Inventorying and Reporting Methodology (EGIRM) methodology for presenting national radioactive waste inventory was also presented in the draft Second Status and Trends report.
- In 2018, the NEA Steering Committee approved the creation of a new standing technical committee – the Committee on Decommissioning of Nuclear Installations and Legacy Management (CDLM) – to increase the visibility of decommissioning and legacy management activities within the NEA, as well as to further support the increasing needs of member countries in these areas.
- In 2018, the NEA, in co-operation with the METI, organised the International Workshop on Deepening Comprehension on Safety Case on Deep Geological Repository (DGR) and Public Confidence on Japan's DGR Programme, in order to discuss international best practice of effective communication with stakeholders, particularly strategies for communicating technical information with non-technical stakeholders.
- The NEA RWMC published a number of reports in 2018. These include: i) *Microbial Influence on the Performance of Subsurface, Salt-Based Radioactive Waste Repositories*; ii) "Managing Information and Requirement in Geological Disposal Programmes"; iii) *National Inventories and Management Strategies for Spent Nuclear Fuel and Radioactive Waste*; and iv) *Recycling and Reuse of Materials Arising from the Decommissioning of Nuclear Facilities*.

Knowledge management activities

The Preservation of Records, Knowledge and Memory (RK&M) across Generations initiative came to an end in April 2018. The group used the rest of the year to finalise its final report and five other supporting documents. The supporting documents will include reports on: i) records, knowledge and memory, ii) developing a key information file for a radioactive waste repository, iii) compiling a set of essential records for a radioactive waste repository, iv) reference bibliography and v) catalogue of legislation, regulation and guidance governing the preservation of RK&M for radioactive waste repositories. Furthermore, the RWMC started the investigation and preparation for the next activities in the field of information, data and knowledge management (IDKM) following a holistic approach. In January 2019, a dedicated workshop will be held to analyse and integrate the outcomes of the past activities (i.e. RK&M, RepMet, EGIRM) and to create the first draft of a roadmap for future IDKM activities.

Regulators' Forum

The RWMC Regulators' Forum (RWMC-RF) discussed the future role of RF after the creation of the CDLM. In addressing the regulatory aspects of the back-end activities of the nuclear fuel cycle, the RF will provide support to both the RWMC and the CDLM. In 2018, the RF drafted a report on "Competency Management of Regulators," which addresses the challenge of potential loss of current regulatory knowledge and expertise in regulating radioactive waste

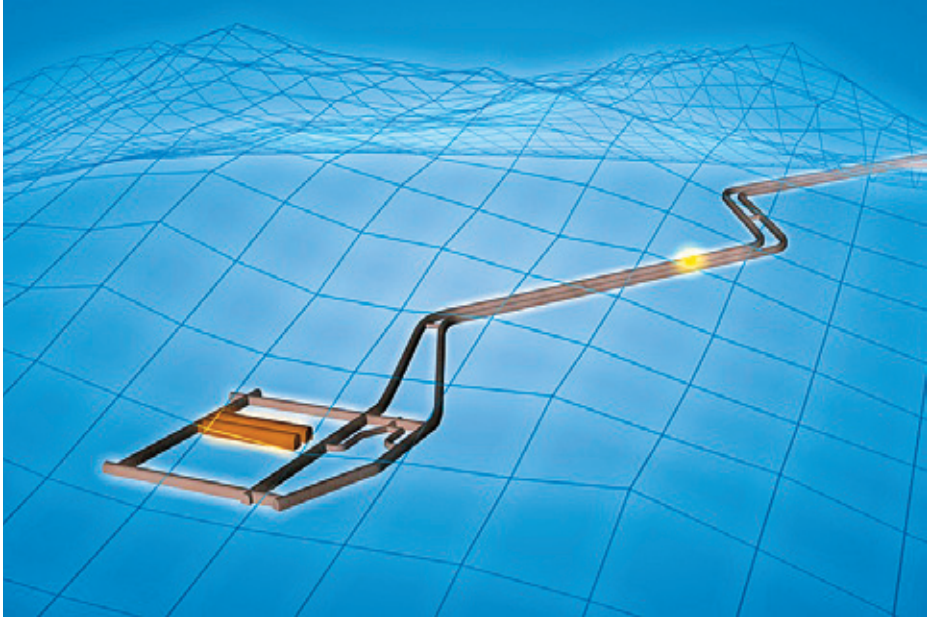

Diagram of the underground storage chambers.
Bátaapáti NRWR, Hungary

activities. Concerning regulating nuclear-decommissioning activities, the RF jointly held a workshop with the Working Party on Decommissioning and Dismantling (WPDD) in June 2018 to assess potential collaboration between the two groups and identify areas of improvement in existing regulations of decommissioning.

The safety case for geological disposal

In 2018, the NEA organised the Third International Symposium of the Integration Group for the Safety Case on the theme of "Current Understanding and Future Direction for the Geological Disposal of Radioactive Waste". This International Symposium, held every five years, is a key event of the IGSC as it reveals the evolution and latest status of safety cases developed for radioactive waste geological disposal. More than 140 participants representing 17 countries took part in discussions of progress of safety case development since 2013 and in challenges for the future.

In 2017, the NEA Integration Group for the Safety Case (IGSC) created the Crystalline Club – a scientific club that aims at improving the understanding of the behaviours and characterisation of crystalline rocks for hosting deep geological repositories for long-lived radioactive waste. Following the model of the successful Clay and Salt Clubs, the Crystalline Club began by collecting existing rock property and scientific data for crystalline rocks. The group is preparing a status report summarising the current knowledge and the attributions of granitic rocks in hosting a deep geological repository for radioactive waste in 2018.

The IGSC issued a report on "Managing Information and Requirement in Geological Disposal Programmes" in 2018 to summarise how information and requirements management is implemented and executed in the various member organisations, including similarities and differences, and to identify potential areas of collaboration.

In 2018, the NEA IGSC released the new International Features, Events and Processes (IFEP) List (V3.0). This update represents a milestone for this tool that the radioactive waste management community uses for the safety assessment of post-closure for DGRs. This release accompanied the launch of the new version of the FEP Database on the NEA website, which hosts the IFEP List V3.0 and makes consultation easier thanks to a modern and intuitive graphical user interface.

The Clay Club has made progress in its study of the pore water properties in clay formation at the University of Bern, Switzerland – the CLAYWAT Project. More detailed results of this project will be published in 2019-2020.

The NEA Expert Group on Operational Safety (EGOS) continued to work on fire risk management in underground facilities, transportation and emplacement technologies, waste acceptance criteria and operational hazard databases.

Radioactive Waste Repository Metadata Management (RepMet)

RepMet was an IGSC initiative that aimed to promote a better understanding of a key aspect of data management: the identification and administration of metadata to support national programmes in managing their radioactive waste repository data in a way that is both harmonised internationally and suitable for long-term management and use.

RepMet completed its activities at the end of 2017. The group issued its final reports in 2018. They are i) a high-level report illustrating the importance of metadata implementation in the RWM field (i.e. *Metadata for Radioactive Waste Management*), ii) three technical reports providing the conceptual design for databases on RWM relevant topics (i.e. "Site Characterisation Library", "Waste Package Library", "Repository Library") and iii) a guide book on tools and techniques adopted for the conceptual design of such databases (i.e. "RepMet Tools and Guidelines").

Radioactive waste inventorying and reporting

In 2018, the RWMC Expert Group on Waste Inventorying and Reporting Methodology (EGIRM) finalised its work on the development of the common radioactive waste and spent

The reactor pressure vessel of a nuclear power plant undergoing decommissioning.

Nuclear Regulatory Commission, United States

fuel inventory presenting scheme, tested the associated methodology and developed recommendations on the harmonisation of reporting processes to be used in the reporting tool established by the IAEA and EC with the NEA support. The expert group also developed recommendations on presenting national spent fuel/radioactive waste (SF/RW) inventories in a more comparable form (e.g. recalculation of raw RW volume to the conditioned form which will be disposed of). The completed methodology is able to address the main requirements that potential implementers may be subject to, including those outlined in the Joint Convention, Council Directive 2011/70 Euratom and the Status and Trends Joint Project. All spent fuel and radioactive materials inventoried as waste can be presented in this scheme, in a common format, according to the waste disposal strategy established in the given country. The NEA report with all EGIRM outcomes will be published in 2019.

In 2018, the EGIRM methodology was presented to the nuclear community in a number of events – a special session during the 5th International Summit on Decommissioning (January 2018, Berlin), the NEA workshop on the implementation of the EGIRM methodology (February 2018, Paris) and a technical meeting on this topic organised by the State Corporation Rosatom (June 2018, Moscow). The NEA, IAEA, and EC joint Status and Trends Project is also evaluating the potential of integrating the EGIRM method into its future reporting methodology.

Fukushima waste management and decommissioning

The Expert Group on Fukushima Waste Management and Decommissioning R&D (EGFWMD) completed its work in 2016, and the outcomes have been reflected in Japanese programmes on Fukushima Daiichi decommissioning. In 2018, a new expert group, the Expert Group on Characterisation Methodology on Unconventional and Legacy Waste (EGCUL), was established to discuss strategic approaches to characterising large amounts of waste with unknown properties. The EGCUL held its first meeting on November, in Fukushima, Japan.

The Thermochemical Database Project

The Thermochemical Database (TDB) Project was initiated in 1984 as a joint activity of the NEA Data Bank and the RWMC. The project fulfills the need for a high-quality database for modeling purposes in the safety analyses of radioactive waste repositories. Implementation of the new software designed and completed in 2016 is still ongoing. The TDB project has produced 13 volumes of internationally recognised and quality-assured thermodynamic data. Work is currently in progress to complete four reviews. For further information on the TDB project and for more details on activities in 2018, see page 57.

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Decommissioning of Nuclear Installations and Legacy Management

The goal of the NEA in this sector is to foster international co-operation to develop the scientific, technological and legal bases required for the safe and economical decommissioning of nuclear facilities and the management of legacy sites.

Highlights

To achieve the NEA goal and improve the support to member countries in the areas of decommissioning of nuclear installations and legacy management, the NEA created a new Standing Technical Committee on Decommissioning of Nuclear Installations and Legacy Management (CDLM) on 18 April 2018. The new committee will support member countries in managing a broad range of decommissioning issues, including the management of legacy sites and waste. To guide the establishment of the CDLM as well as to ensure effective co-operation among NEA standing technical committees, the NEA held an Advisory Group meeting in June 2018 with the chairs of the relevant committees and working groups. The Advisory Group produced a list of detailed recommendations to guide the CDLM in developing and managing its activities. In July, the NEA invited all member countries to nominate delegates to the CDLM, and a kick-off meeting was held in October 2018 for CDLM members to discuss administrative issues and preliminary work organisation. The CDLM will organise a workshop on 16 January 2019 in order to further assess the high-priority decommissioning and legacy management work topics and better understand the needs of member countries in this regard. The first plenary meeting of the CDLM will be held in March 2019, during which the committee will discuss its Programme of Work for 2019-2020, elect its Chair, and confirm its Bureau composition.

The CDLM topics of interest include:

- the decommissioning and dismantling of various nuclear facilities (e.g. radioactive waste and spent fuel storage facilities, spent fuel reprocessing facilities or other nuclear installations) and all reactor types;
- the development of practical guidance on regulating and managing legacy waste, waste sites and releases of legacy sites.

Decommissioning

The NEA Working Party on Decommissioning and Dismantling (WPDD) held its 19th and last plenary meeting in November at the NEA premises in Boulogne-Billancourt, France. The meeting was attended by over 40 delegates from 15 NEA member countries and 2 international organisations. After the creation of the Committee on Decommissioning of Nuclear Installations and Legacy Management (CDLM) in 2018, the mandate of the WPDD was to be terminated and the group to dissolve at the end of 2018. During the meeting the two WPDD subgroups, the Decommissioning Cost Estimation Group (DCEG) and the Task Group on Optimising Management of Low-level Radioactive Materials and Waste from Decommissioning (TGOM), presented their final reports for the Working Party's review. The topical session concerned the transfer of knowledge from the WPDD to the newly created CDLM and resulted in recommendations from WPDD members for the CDLM Programme of Work.

The WPDD Decommissioning Cost Estimation Group (DCEG) continues its work on benchmarking in the context of NPP decommissioning costs, aiming to provide policymakers and regulators with an overview of different benchmarking approaches for collecting and sharing sensitive data on decommissioning costs. Four meetings were held in 2018 to develop a final report to illustrate the practical application of benchmarking concepts and methodologies, as well as establishing a potential roadmap for the implementation of these benchmarking approaches. The report is expected to be issued in 2019.

The WPDD Task Group on Preparing for Decommissioning during Operation and after Final Shutdown (TGPFD) completed its work, published a report *Preparing for Decommissioning during Operation and after Final Shutdown* in May 2018. The report focuses on strategic approaches, different issues that might arise, risks and observations of good practice. It supports ongoing and new decommissioning projects by providing observations and recommendations relating to the development and optimisation of strategies, as well as plans to prepare for the decommissioning of nuclear facilities.

The WPDD Task Group on Optimising Management of Low-level Radioactive Materials and Waste from Decommissioning (TGOM) continued to examine strategies and approaches that can enhance national approaches to the management of slightly radioactive materials from decommissioning. The group had two meetings in 2018 to study the different measures and various interrelations among drivers, identifying and presenting in a status report the mechanisms behind those drivers, along with constraints in the practical implementation of optimisation. The report is expected to be issued in 2019.

Legacy management

In 2018, the NEA Committee on Radiological Protection and Public Health (CRPPH) Expert Group on Legacy Management (EGLM) continued its activities in assessing challenges and identifying best practices in managing legacy sites from a radiation protection perspective. In this exercise, the EGLM reviewed 13 case studies of the nuclear legacy situations in 13 member countries. The EGLM report, including the case study results, will be published in 2019. In 2019 the CDLM will take over legacy management activities and the work of the EGLM will be transferred from the CRPPH to the CDLM.

Under the auspices of the CDLM, a broader work scope of the developing guidance for regulating and managing legacy waste and waste sites is anticipated.

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Joint Project

The Co-operative Programme for the Exchange of Scientific and Technical Information Concerning Nuclear Installation Decommissioning Projects

The NEA Co-operative Programme for the Exchange of Scientific and Technical Information Concerning Nuclear Installation Decommissioning Projects (CPD) is a joint undertaking of a limited number of organisations actively executing or planning the decommissioning of nuclear facilities. The objective of the CPD Programme, launched in 1985, is to exchange and share information from operational experience in decommissioning nuclear installations useful for current and future projects. Initially consisting of 10 decommissioning projects in 8 countries, the programme has since grown to the present 73 projects (42 reactors and 31 fuel cycle facilities) in 14 NEA member countries, 1 non-member economy and the European Commission (EC). The current agreement came into force on 1 January 2014 and expired on 31 December 2018. A new agreement for the period 2019-2023 will take effect on 1 January 2019.

Information exchange also ensures that best international practice is made widely available and encourages the application of safe, environmentally sound and cost effective methods in all decommissioning projects. Biannual meetings of the Technical Advisory Group (TAG) are held, during which the site of one of the participating projects is visited, and positive and less positive examples of decommissioning experience are openly exchanged for the benefit of all. In 2018, a site visit to José Cabrera NPP was held in Pastrana, Spain.

Increasing decommissioning needs worldwide have given rise to other challenges such as the dismantling and decontamination of highly contaminated tanks. To address this issue, in April 2017, the CPD initiated a new task group in order to exchange and share experiences gained among members on the dismantling of highly contaminated tanks, as well to evaluate lessons learnt and best practices. In October 2018, a meeting of the task group was held during TAG-65 in Karlsruhe, Germany.

To make use of decommissioning knowledge and experience accumulated within the CPD, a TAG Knowledge Base Database that allows CPD members to easily access the CPD reactor project and fuel facility information has been created on the NEA website, after being approved by the CPD in 2017. The database continues to develop with more data from members being added as it became available.

José Cabrera Nuclear power plant, Pastrana, Spain.
Creative Commons, Mr. Tickle

Nuclear Science

The goal of the NEA in this sector is to help member countries identify, collate, develop and disseminate the basic scientific and technical knowledge required to ensure the safe, reliable and economic operation of current and next generation nuclear systems.

The staff works closely with the Nuclear Science Committee (NSC) and its expert groups in this area.

Highlights

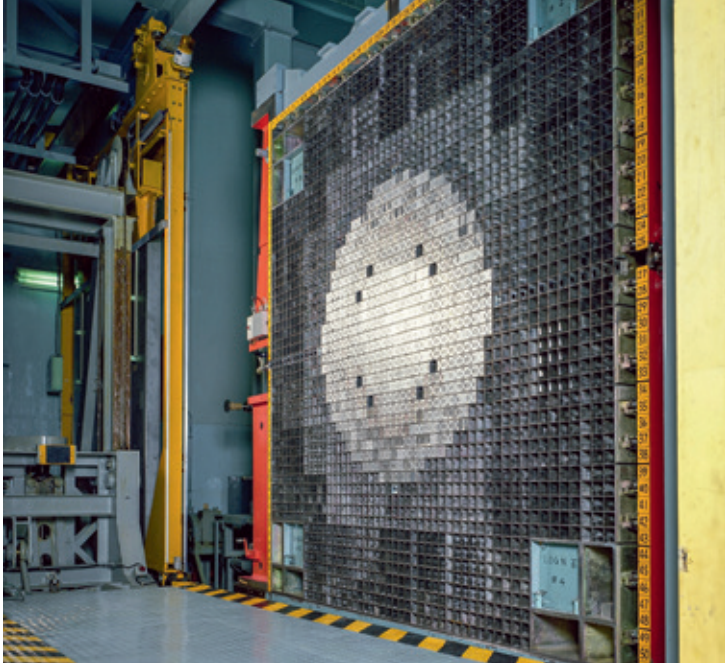
- The State-of-the-Art Reports on Progress in Nuclear Fuel Cycle Chemistry and on Light Water Reactor Accident-Tolerant Fuels (ATF) were published in March and October 2018, respectively.
- New subgroups were created within the Working Party on International Nuclear Data Evaluation Co-operation (WPEC) and the Working Party on Nuclear Criticality Safety (WPNCS).
- A relational database and associated user interface for international fuel performance experiments (DATIF) were developed to leverage the legacy data from the IAEA/NEA International Fuel Performance Experiments (IFPE) data collection and to host fuel-related data generated in new experimental campaigns.
- The joint project on the Thermodynamic Characterisation of Fuel Debris and Fission Products Based on Scenario Analysis of Severe Accident Progression at the Fukushima Daiichi Nuclear Power Station (TCOFF) has completed a call for R&D proposals and granted funding to four organisations.
- The Thermodynamics of Advanced Fuel International Database (TAF-ID) joint project has entered into its second phase, holding a kick-off meeting in October 2018.
- The workshops on "Enhancing Experimental Support for Advancements in Fuels and Materials" and "Building Multinational Fuel and Materials Testing Capacities for Science, Safety and Industry" were organised in January and October 2018, and were aimed towards establishing a new NEA Framework and joint project that will strengthen experimental capabilities for advances in nuclear fuels and materials.

Reactor physics

NEA work in relation to reactor physics has been mainly devoted to the verification and validation of codes to predict both existing and advanced reactor systems. Expert group activities cover the fields of reactor fuel performance, radiation and shielding for reactors, accelerators and fusion facilities, reactor physics and advanced nuclear systems, and uncertainty analysis.

The handbook of the International Reactor Physics Experiment Evaluation (IRPhE) Project was extended in 2018, adding criticality benchmarks of the Experimental Breeder Reactor-II (EBR-II) in the United States and the Fast Critical Assembly (FCA) in Japan. The handbook now also includes spectral indices to provide much needed data for the validation of nuclear data. Accompanying the IRPhE Handbook for the first time is an uncertainty guide that captures the lessons learnt during the project and needed to transform the measurement into a suitably evaluated experiment-based benchmark. The new edition of the IRPhEP Handbook was published at the end of 2018.

The Expert Group on Multi-Physics Experimental Data, Benchmarks and Validation (EGMPEBV) deals with the certification of experimental data and benchmark models, along with establishing the processes and procedures for using such data, for the validation of multi-physics modelling and simulation tools and data. In 2018, the group finalised its summary report, "Existing Procedures and Guidelines for Multi-physics Validation". Furthermore, two benchmarks kicked off in 2018: the Rostov-2 plant data benchmark and the Studsvik R2 multi-physics pellet-clad mechanical



Fast Critical Assembly (FCA).
Japan Atomic Energy Agency (JAEA), Japan.

interaction validation (MPCMIV) exercises, which will enable the findings of the group to be applied. Specifications for these benchmarks were prepared and discussed during the meetings that took place as part of the combined "Uncertainty Analysis in Modelling (UAM) Workshop", which were held in conjunction with the "Best Estimate Plus Uncertainty (BEPU) Conference" in May 2018 in Lucca, Italy. A third benchmark based on the Watt's Bar unit 1 reactor fuel cycle data, in conjunction with the United States Department of Energy Consortium for Advanced Simulation of Light Water Reactors (CASL) is now in preparation and will be ready for launch at the next annual UAM workshop in Knoxville, Tennessee in the United States, during May 2019.

Fuel cycle physics and chemistry

Activities in this area cover all aspects of the nuclear fuel cycle from the front end to the back end, and deal with issues arising from various existing and advanced systems, including fuel cycle scenarios, innovative fuels and materials, separation chemistry, and waste disposal and coolant technologies. Over the last couple of years, experts of the Working Party on Scientific Issues of the Fuel Cycle (WPFC) and its expert groups have consolidated a substantial programme of work, mainly focusing on advanced fuel cycles and cross-cutting activities. The *State-of-the-Art Report on the Progress of Nuclear Fuel Cycle Chemistry*, prepared by the Expert Group on Fuel Recycling Chemistry, was published in March 2018. Two more reports, the report on Phase 2 of the Task Force on Benchmarking of Thermal-Hydraulic Loop Models for Lead Alloy-Cooled Advanced Nuclear Energy Systems (LACANES) and the report on user facilities for material testing and R&D facilities for spent fuel reprocessing, were published at the end of 2018.

The 15th Information Exchange Meeting on Actinide and Fission Products Partitioning and Transmutation was hosted by the National Nuclear Laboratory in Manchester, United Kingdom, from 30 September to 3 October, 2018. Some 120 participants from 15 countries and 3 international organisations discussed state-of-the-art developments in the fields of partitioning and transmutation (P&T) and advanced nuclear fuel cycles.

There has been notable progress in the activities initiated in 2017 relating to fuel properties for fast reactors in the context of the Expert Group on Innovative Fuels (EGIF), including an international review of the recycling and reuse of components from spent fuels. In addition, the development of a database of extractants for spent fuel reprocessing led by the Expert Group on Fuel Recycling Chemistry (EGFRC) began in 2018.

Nuclear criticality safety

The NEA WPNCS is responsible for the co-ordination and maintenance of the International Database of Spent Fuel Isotopic Composition Data (SFCOMPO) and the International Criticality Safety Benchmark Evaluation Project (ICSBEP). It is also responsible for the co-ordination of technical activities in the fields of uncertainty quantification for criticality safety assessment, use of Monte-Carlo transport, assay data of spent nuclear fuel and investigations on used nuclear fuel criticality, as well as criticality excursion analyses.

Seven new subgroups, established in July 2018, will focus their activities around the following topics: the role of integral experiment uncertainties in criticality safety validation; the simulation of MOX damp powders; the effect of temperature on the criticality of pressurised water reactor (PWR) fuel assemblies; the analysis of past criticality accidents; the experimental needs for criticality safety assessment; fission source convergence and under-sampling in Monte-Carlo criticality calculations; and the sensitivity and uncertainty analysis for used fuel inventory.

The Technical Review Group (TRG) for evaluation of the assay data available in the SFCOMPO database was also created and will hold a kick-off meeting in March 2019.

The annual ICSBEP TRG meeting was held at the NEA offices on 22 October 2018. Four evaluations underwent technical review and will be incorporated into the next version of the ICSBEP handbook upon resolution of comments. Minor updates were made to the Database for the ICSBEP (DICE). The new edition of the ICSBEP Handbook was published at the end of 2018.

The WPNCS is working closely with the Institut de Radioprotection et de Sûreté Nucléaire (IRSN) to organise the 2019 International Conference on Nuclear Criticality Safety (ICNC 2019) in France.

Materials science

The NSC has consolidated a substantial programme of work on nuclear fuels and structural materials, particularly around advanced modelling, advanced materials research, and database creation and maintenance.

The Working Party on Multi-scale Modelling of Fuels and Structural Materials for Nuclear Systems (WPMM) is an international forum for information exchange and discussion focusing on the review, evaluation and promotion of the multi-scale modelling and simulation techniques applied to the research and development on the materials for nuclear systems.

In 2018, the Expert Group on Multi-scale Modelling of Fuels released the state-of-the-art report (SOAR) on "Unit Mechanisms of Fission Gas Release: Current Understanding and Future Needs", which was published in the Journal of Nuclear Materials. The Expert Group on Multi-scale Modelling Methods is currently working on another SOAR that will provide an overview of the models and the computer simulation methods employed at different length and time scales to describe the properties of the materials of interest for the nuclear energy industry. The publication of this report is expected by mid-2019

The NEA Expert Group on Accident-tolerant Fuels for LWRs (EGATFL) delivered an SOAR summarising the fundamental properties and behaviour of accident-tolerant fuels and core materials under normal operations and accident conditions. It was presented at an NEA webinar and during the opening session of the Top Fuel 2018 conference in Prague. The expert group is now tasked with identifying research areas for further exploration, driven by safety requirements.

Nuclear data

The NSC Working Party on International Nuclear Data Evaluation Co-operation (WPEC) completed the activities of two subgroups, including the Collaborative International Evaluated Library Organisation (CIELO) project and one focusing on new methods in the evaluation of thermal scattering kernels. The CIELO project resulted in the production of re-evaluated uranium, plutonium, iron, oxygen and hydrogen isotopes, with improvements due to modern experiments, new modelling capabilities, more complete uncertainty analysis and refined validation against integral experiments. The latter activity greatly benefited from other NSC activities and applications, notably the Nuclear Data and Sensitivity Tool (NDaST). The new evaluated nuclear data have been adopted by all participants and represent state-of-the-art data of critical importance for the simulation of nuclear systems. New thermal scattering evaluations, based on ab initio calculations, have been included in evaluations, signifying a revolutionary improvement in a technical area that has had limited activity over the last two decades. This reinvigoration was due to breakthroughs within research communities, and the WPEC brought all relevant parties together to translate improvements in theory into application-ready datasets for the nuclear community.

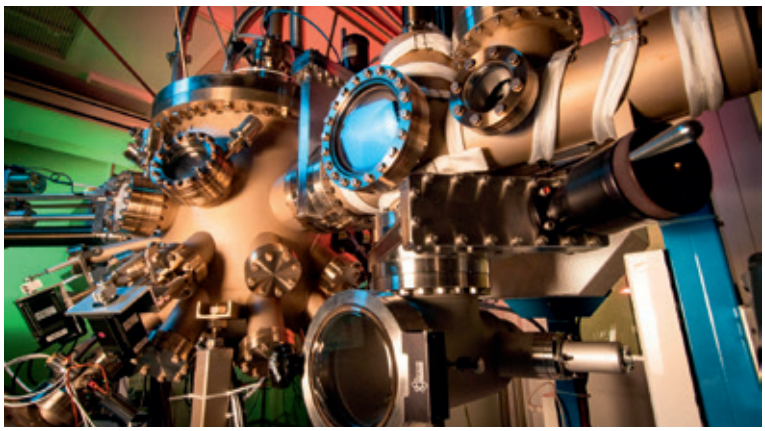
The WPEC programme of work now includes a review of integral experiments required for validation of nuclear data. In particular, a subgroup created in 2018 has been tasked with prioritising experiments from the Shielding Integral Benchmark Archive and Database (SINBAD) to be evaluated under the auspices of the WPRS.

In order to support WPEC activities, a new NEA GitLab system was implemented. Collaborative spaces have been established for multiple groups, including repositories for data, documentation and code projects. This system offers interactive version control and management tools, as well as automated quality assurance processes that will enhance the co-operation between the various groups'.

Data preservation and management

The NSC in co-operation with the NEA Data Bank establishes and maintains databases/collections of data to preserve and evaluate information on criticality safety (ICSBEP), reactor physics (IRPhE), shielding (SINBAD), fuel performance (IFPE) and isotopic composition of spent fuel (SFCOMPO). In addition, the NDaST includes data on both criticality safety (DICE) and reactor physics (IDAT) databases, with access to features of the nuclear data viewing tool, JANIS.

Education Research Center "Nanocenter" training in the method of pulsed laser deposition.
MEPHI, Russia



The NSC workshop "Enhancing Experimental Support for Advancements in Fuels and Materials" held in January 2018, Paris, France.

The ICSBEP and IRPhEP handbooks have been recognised as the international standards for conversion of raw experimental data into high-fidelity benchmarks and have enabled the nuclear community, over decades, to enhance validation of basic nuclear data and simulation tools. Over the last two years, the NSC has stepped up its efforts to expand this experience into other subject areas. As part of these efforts, 2018 featured the development of a new relational database and associated user interface, called DATIF. DATIF will improve accessibility of data within the existing International Fuel Performance Experiments (IFPE) collection of experiment documents, jointly created by the NEA and IAEA. This refurbishment was demanded by the community and, in particular, the expert group in charge of IFPE maintenance – the Expert Group on Reactor Fuel Performance (EGRFP). At the beginning of 2019, the schema for the database will be finalised and a prototype will be reviewed by the expert group. The beta-version will be released in 2019. Further, the International Experimental Thermal HYdraulics Systems (TIETHYS) database, released in 2017, has been extended with additional entries, references and materials, including an example model development resource for the Loss-of-Fluid Test (LOFT) facility taken from the Standardized Consolidated Calculated and Reference Experimental Database (SCCRED) documentation.

Education and skills

In the area of nuclear technology education, the NEA continued to implement the Nuclear Education, Skills and Technology (NEST) Framework, initiated in 2016. NEST aims to establish a multinational and multidisciplinary framework among several partners, including academia, research organisations and industry, in order to foster a new generation of nuclear experts and leaders by transmitting practical knowledge and offering hands-on training. The NEST Framework Agreement came into in force in February 2019.

International organisations provide important opportunities for the career growth of nuclear professionals. For this reason the IAEA, NEA and OECD senior staff participated in a ROSATOM Technical Academy workshop for potential future candidates to international organisations held in Moscow in October 2018. The workshop was part of the ROSATOM Target Programme on Human Resources Capacity Building.

In order to enhance co-operation in the field of nuclear education and training, the NEA signed an agreement with the European Nuclear Education Network (ENEN) in October 2018.

In addition, the Division of Nuclear Science offered internships to four graduate and undergraduate students to enable them to gain first-hand experience in several technical areas and in the area of knowledge management and preservation.

Experimental needs

In 2018, the NSC launched an initiative to strengthen experimental capabilities for advances in nuclear fuels and materials. A core aspect of this work is to establish a co-ordinated approach to the development and implementation of key experiments at various facilities around the world. This initiative has become even more relevant given the closure of the widely-used Halden test reactor in Norway. In the context of this strategy, the workshop on "Building Multinational Fuel and Materials Testing Capacities for Science, Safety and Industry" was organised, in line with NI2050, and under the auspices of the NSC and the CSNI in October 2018. It brought together participants from utilities, fuel vendors, technical support organisations (TSOs), regulatory bodies and research organisations. It continued the dialogue begun during the NSC workshop "Enhancing Experimental Support for Advancements in Fuels and Materials" held in January 2018 with the aim of establishing a new NEA joint project that would involve multiple key infrastructures. Several test reactors around the world hold considerable promise to serve as essential facilities in this strategy. The NEA is currently working with the workshop participants to establish a new joint project and to finalise the workshop statement, which will be discussed further with the relevant NEA standing technical committees and distributed among NEA member countries to help inform the decision processes in this field.

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Joint Projects

The TAF-ID Project

The Thermodynamics of Advanced Fuels – International Database (TAF-ID) Project is supported by ten organisations in seven NEA member countries. It is devoted to establishing a comprehensive, internationally recognised and quality-assured database of phase diagrams and of the thermodynamic properties of advanced nuclear fuels so as to meet specialised requirements for the development of such advanced fuels for a future generation of nuclear reactors. New versions of both the working and public database were created by the TAF-ID project in 2017.

The second phase of the project (TAF-ID Phase II) was established in October 2018 by 11 signatories from 7 countries and the European Commission (EC). It will aim to:

- test the validity of the TAF-ID database by performing thermodynamic measurements on complex fuel compositions and compare the experimental results to calculations;
- identify the origin of the discrepancies between experiments and calculations that emerged within the first phase of TAF-ID;
- continue the development of the database by introducing models for missing binary and/or ternary systems;
- organise training sessions for users of the TAF-ID database.

The TCOFF Project

The joint project on the Thermodynamic Characterisation of Fuel Debris and Fission Products Based on Scenario Analysis of Severe Accident Progression at Fukushima Daiichi Nuclear Power Station (TCOFF), supported by the Collaborative Laboratories for Advanced Decommissioning Science (CLADS) of the Japan Atomic Energy Agency (JAEA), was launched as part of NEA post-Fukushima activities within the NSC in 2017.

A total of 16 organisations from 9 member countries and the EC participate in the TCOFF Project. Its current activity is increasingly concentrating on the integration of the improved knowledge on the thermodynamics of the severe accidents into the severe accident analysis codes.

The project has achieved substantial progress during its second year. In particular, the project has completed a call for R&D proposals and granted funding to four organisations from Japan, the Netherlands and Russia. The thermodynamic databases benchmark addressing the phase formation tendency in the core region of unit-1 during the Fukushima Daiichi Nuclear Power Station (FDNPS) accident progression was completed. This study, addressed both the in-vessel and ex-vessel region with focus on the molten core-concrete interaction (MCCI). A second benchmark is now being prepared to address the influence of the fission products.

The NEST Framework

The NEA NEST Framework Agreement was finalised during the summer of 2018 by the representatives of the ten "Core-Group" countries: Belgium, Canada, France, Germany, Italy, Japan, Korea, Russia, Switzerland and the United States. The "Core-Group" has met twice to discuss the establishment of the framework through the preparation of an agreement and potential projects to be launched. The NEST Framework Agreement has been approved by the parties and signature of the agreement took place in February 2019.

In parallel, several ideas for NEST projects were suggested and developed:

- hydrogen mitigation research project (HYMERES-2), led by Switzerland;
- advanced remote technology (CLADS), led by Japan;
- radioactive waste management (including irradiated graphite handling) and characterisation, decommissioning, decontamination and radioactive waste disposal, led by Russia;
- small modular reactors (SMRs), led by Canada, with participation by the United States, Belgium, and other European partners.

Other fields of interests have been identified: geological repositories; material testing experiments; and low dose effects. These fields may be of interest to countries engaged in the NEST Framework who wish to develop related proposals. The four projects cited above were developed in 2018 and are ready to start once the Framework Agreement enters into force.

Data Bank

The goal of the NEA Data Bank is to serve as the premier international centre of reference for basic nuclear tools, such as computer codes and data, which may include experimental and evaluated microscopic nuclear data or nuclear or thermochemical data, together with benchmark experiment data used for the analysis and prediction of phenomena in the nuclear field. The Data Bank also maintains and distributes the databases developed within the NEA working parties and expert groups as well as the NEA joint projects. The Data Bank provides a direct service to its users by making such tools available on request and by co-ordinating international initiatives.

Highlights

- The Management board of the Data Bank (MBDAV) approved the introduction of a single-user licence for the computer codes dispatched by the Computer Program Services (CPS) of the Data Bank.
- Two "Nuclear Data Weeks" were held in 2018, gathering a community of nuclear data experimentalists, evaluators and expert users across diverse nuclear data projects.
- The mandate of the Joint Evaluated Fission and Fusion (JEFF) Nuclear Data Library Coordination Group was extended up to 2021 with the objective to start the preparatory work for the future release of the JEFF nuclear data library (JEFF-4).
- The MBDAV agreed to organise a high level meeting in 2019 to engage and strengthen the links of the JEFF project with nuclear data stakeholders including industry players.
- Twelve training courses and workshops were organised in 2018 by the NEA Data Bank Computer Program Service (CPS), the Nuclear Data Services (NDS) and the Thermochemical Database (TDB).
- The new TDB electronic database was released in July 2018 and it was decided to start 6th Phase activity (TDB-6) in 2019 with the participation of fifteen funding organisations.

Computer program services

More than 900 officially nominated establishments are using the Computer Program Services (CPS) in NEA Data Bank participating countries.

The NEA Data Bank collection contains more than 2 000 computer programs and 350 integral experiments, covering all areas related to reactor design, dynamics, safety and radiation shielding, material behaviour and radioactive waste applications. In 2017, a total of 12 new or new versions of computer programs and 3 integral experimental data packages were added to the collection. Some 1 024 computer programs and 2 328 integral experiment data, 253 NEA safety project data, 28 legacy books were dispatched upon request to Data Bank participating countries. In 2018, by October, 16 new or new versions of computer programs and 4 safety joint-projects were added to the collection, and more than 800 computer programs and 1 500 integral experiment packages were dispatched.

The current co-operative arrangement between the United States Department of Energy (DOE) and the NEA authorises the NEA Data Bank to also issue user licences and distribute US computer codes to Data Bank participating countries.

In 2018, two meetings of the Computer Program Services Task Force (CPS TF) were organised, in April and October. This CPS TF is dedicated to the evolution of CPS and adapted in 2018 a new strategy which aims to provide better services to the end users and to adapt to new computing infrastructures. Following the April 2018 meeting, the CPS TF recommended introducing a single-user licence for the computer codes dispatched by CPS of the Data Bank. This proposal was discussed and approved by the Management Board of the Data Bank in June. The details of this new licensing scheme and its implementation were further discussed during CPS TF meeting in October. Based on these discussions, the final implementation plan will be submitted to the MBDAV in 2019 for approval. In addition to this new licence, other initiatives to offer better services to the end users, focusing on the computer program collection, the Data Bank website and the training courses were also discussed during 2018.

Nuclear data services

The Data Bank maintains large databases containing bibliographic (Computer Index of Nuclear Data [CINDA]), experimental (Experimental Nuclear Reaction Data Retrievals [EXFOR]) and evaluated nuclear data, all of which are made available online. As a member of the International Network of Nuclear Reaction Data Centres (NRDC) since 1966, the NEA Data Bank is responsible for the compilation, in EXFOR, of neutron and charged particle data arising from experimental programmes in its participating countries.

Twisting tunnel of digital binary computer code.
Shutterstock, Robert Eastman

In the first half of 2018 this involved the evaluation and processing of 137 new or updated entries with over 100 000 new data points added, following a strict verification procedure. A new system for managing workflow was implemented using the new NEA GitLab platform on the Data Bank server. In total, the Data Bank has compiled around 25% of all entries in the current EXFOR database, which is a compilation of worldwide experimental nuclear reaction data.

Since 1981, the NEA Data Bank has hosted the Joint Evaluated Fission and Fusion (JEFF) Nuclear Data Library project, a collaborative effort among Data Bank participating countries to produce and distribute evaluated nuclear data libraries, mainly for fission and fusion applications. The members of the JEFF project met in April and November 2018 for the NEA Nuclear Data Week, where the objectives for the future nuclear data library JEFF-4 were examined. The mandate of the JEFF project was extended at the Management board meeting in June 2018 and the board also endorsed holding a first stakeholder meeting in 2019 to strengthen the links between the JEFF project and nuclear data stakeholders – in particular industry players, at the start of the development period of JEFF-4 (2018-2021).

As part of its nuclear data services, the Data Bank continues its efforts to develop quality assurance processes for evaluated nuclear data files. In 2018 it implemented a prototype web application for evaluated nuclear data verification, processing and testing under the name of NDEC (Nuclear Data Evaluation Cycle) and developed internal processes that streamline the workflow necessary for the integral benchmarking of nuclear data files. In 2018, a second NEA training course on nuclear data processing was organised.

The Data Bank is responsible for developing and maintaining the Java-based Nuclear Data Information System (JANIS), a leading cross-section visualisation tool. JANIS is designed to facilitate the visualisation, comparison and manipulation of nuclear data and experimental data from EXFOR. In 2018 it has been updated with databases of the most recent nuclear data, including JEFF-3.3, JENDL/AD-2017, ENDF/B-VIII.0, GEFY-6.2 and others. JANIS continues to be the most used NEA DB service, with over 27 000 individual user launches made in 2018.

As part of its work in nuclear data, the nuclear data services team collaborates closely with the Nuclear Science Committee Working Party on International Nuclear Data Evaluation Co-operation (WPEC), which oversees the Expert Group on the High Priority Request List (HPRL) for Nuclear Data. The Data Bank is responsible for maintaining the HPRL as an interactive database and updating all materials following the decisions of the EG-HPRL. In 2018, this included a major revision following a thorough review of all content and archiving of completed or inactive requests.

Databases of experiments, nuclear knowledge management

To support the activities of the other standing technical committees under the NEA, the Data Bank keeps developing and providing support to the databases built and maintained by the NEA. This includes, in 2018, and in the area of Nuclear Science, the Spent Fuel Isotopic Composition Database (SFCOMPO-2.0), the Database for the International Handbook of Evaluated Criticality Safety Benchmark Experiments (DICE), the International Reactor Physics Handbook Database and Analysis Tool (IDAT), Nuclear Data Sensitivity Tool (NDaST) and the Thermal-Hydraulic Safety Experiments (TIETHYS). The Data Bank also supports nuclear safety and radiological protection activities by maintaining such databases as Fire Incidents Records Exchange (FIRE), Component Operational Experience, Degradation and Ageing Programme (CODAP), Construction Experience Program (CONEX), and Information System on Occupational Exposure (ISOE).

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Joint Project

The Thermochemical Database Project

The Thermochemical Database (TDB) Project was initiated in 1984 upon the recognised need acknowledged by the NEA Radioactive Waste Management Committee for a high quality database to model the safety assessments of radioactive waste repositories. The project's current agreement runs until March 2019. A total of 15 organisations representing 12 countries currently participate in the TDB project.

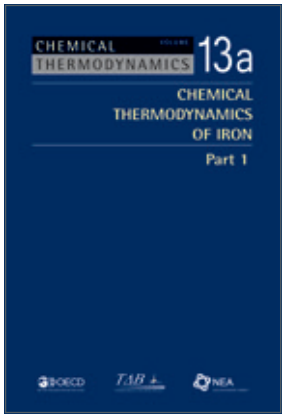
The project has thus far produced 13 volumes of internationally recognised and quality-assured thermodynamic data, and work is currently in progress to complete four reviews, expected for publication in 2019:

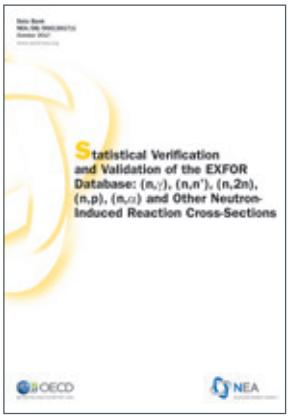
- Chemical thermodynamics of iron – second volume.
- Chemical thermodynamics of molybdenum.
- Chemical thermodynamics of selected ancillary compounds.
- A second thermodynamic data update of uranium, americium, neptunium, plutonium and technetium.

Two state-of-the-art reports are under development, and the publication of both reports is expected in 2020:

- A report on thermodynamic considerations for cement minerals.
- A report on assessing the modelling and experimental approaches of high ionic-strength solutions.

The new TDB electronic database was released in July 2018. The second edition of the TDB course on *Thermodynamic Data Collection and Assessment* was organised by the NEA and took place in Boston, Massachusetts, United States, in August 2018. Preparations for Phase 6 are currently underway. TDB-6 will welcome a new participant, the Central Organisation for Radioactive Waste (COVRA), in the Netherlands. The agreement is expected to be signed by all 15 participants by the end of 2018 and work is expected to begin by April 2019.





Legal Affairs

The goal of the NEA in this sector is to help create the sound national and international legal regimes required for the peaceful uses of nuclear energy, including as regards nuclear safety, international trade in nuclear materials and equipment, public engagement, issues of liability and compensation for nuclear damage, and to serve as a leading centre for nuclear law information and education. The staff provides support to the Nuclear Law Committee (NLC) and its working parties in this area.

Highlights

- The Nuclear Law Committee (NLC) held two meetings, one in March 2018 and another one in November 2018, each gathering around 75 participants from NEA member and non-member countries, the European Commission, the International Atomic Energy Agency and the insurance industry. During those same weeks, the Working Party on the Legal Aspects of Nuclear Safety (WPLANS) and the Working Party on Nuclear Liability and Transport (WPNLT) also held meetings.
- The NLC celebrated the 50th anniversary and the 100th issue of the Nuclear Law Bulletin with a special session to which the former heads of the NEA legal affairs were invited and during which the delegations discussed the relevance and future of this unique publication.
- The seventh session of the NEA International Nuclear Law Essentials (INLE) course was held from 26 February to 2 March 2018 in Singapore, in co-operation with the National University of Singapore (NUS) and its Centre for International Law.
- An Alumni Directory and a commemorative brochure of the International School of Nuclear Law (ISNL) were published to enhance the ISNL community.

Development and harmonisation of nuclear legislation

The Nuclear Law Committee (NLC) met twice in 2018. At the meeting held in March 2018, the participants discussed current activities conducted under NLC auspices on nuclear third party liability and transport, nuclear third party liability and deep geological repositories and the legal aspects of nuclear safety, as well as recent developments relating to the international legal framework for public participation in nuclear decision making. Presentations on latest national developments in nuclear law were provided by Argentina, Japan, Luxembourg, Romania, the United Arab Emirates and the United States.

In November 2018, the NEA Office of Legal Counsel (OLC) and the NLC working party Chairs presented the NLC with updates on their programme of work and ongoing activities. Participants discussed nuclear third party liability and priority rules, the licensing framework and third party liability regime applicable to fusion projects, and recent developments with regard to the international legal framework for public participation. Reports on the latest national developments in nuclear law were provided by Brazil, China, Japan, Switzerland, Turkey, Ukraine and the United Arab Emirates. The meeting also included a special session to celebrate the 50th anniversary and the 100th issue of the Nuclear Law Bulletin, which featured former heads of NEA legal affairs who discussed the relevance and future of this unique publication. It acknowledged and stressed the importance of this publication in the development, strengthening and harmonisation of nuclear legislation, the dissemination of information on nuclear law and the training of current and future nuclear lawyers.

The NLC meetings gathered around 75 experts from member countries, the European Commission (EC), the International Atomic Energy Agency (IAEA) and the nuclear insurance industry, as well as several representatives from non-member countries which in 2018 included Brazil, Bulgaria, China, Ukraine and the United Arab Emirates.

The NEA member countries that are party to the Paris Convention on Third Party Liability in the Field of Nuclear Energy (the "Paris Convention") and the Brussels Convention Supplementary to the Paris Convention (the "Brussels Supplementary Convention") met twice in 2018 in order to continue discussing the application and interpretation of the Paris and Brussels Supplementary Conventions, and preparing for the entry into force of the 2004 protocols amending both conventions. The 2004 protocol to amend the Paris Convention has not yet entered into force as a result of a decision by the Council of the European Union (2004/294/EC) requiring that EU member states that are contracting parties to the Paris Convention (with the exception of Denmark and Slovenia), deposit their instruments of ratification of the protocol simultaneously. The protocol to amend the Brussels Supplementary Convention, on the other hand, requires ratification by all its contracting parties. Italy is the last EU member state to finalise its national legislative process, which will allow the 2004 protocols to enter into force.

In March and November 2018, the NEA Working Party on the Legal Aspects of Nuclear Safety (WPLANS) held meetings to address a number of topics, including the licensing of small modular reactors (SMRs), the legal

50th Anniversary and 100th issue of the Nuclear Law Bulletin, November 2018.

From left to right:
Nubuhiro Muroya (NEA, DDG), Willlam D. Magwood, IV (NEA, DG), Roland Dussart-Desart (NLC, Chair), Patrick Reyners, Julia Schwartz, Stephen G. Burns (former Heads of OLC), Ximena Vásquez-Maignan (OLC, Head).

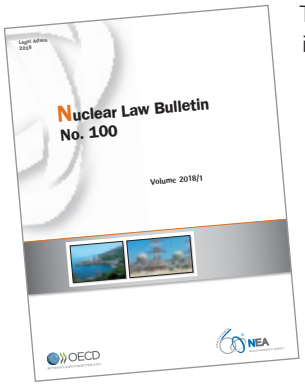
challenges to nuclear safety decisions and the long-term operation of nuclear power plants and research reactors. Around 35 participants from NEA member and non-member countries, the EC, the IAEA and the World Nuclear Association attended these meetings, providing updates on latest developments relating to their country legislative and regulatory frameworks as well as on their activities regarding the topics being addressed by the working party.

The NEA Working Party on Nuclear Liability and Transport (WPNLT) also held meetings back-to-back with the NLC, gathering each time around 35 participants from NEA member and non-member countries, the EC, the IAEA, the insurance industry and the World Nuclear Transport Institute (WNTI). The participants focused on an ongoing enquiry regarding national legislation and rules applicable to nuclear transport and transit in the NEA member countries and the identification of the challenges relating to nuclear third party liability when organising transportation of nuclear substances. They also exchanged on the latest developments relating to transport of nuclear substances in national and European legislations.

The NEA Working Party on Deep Geological Repositories and Nuclear Liability (WPDGR) held a meeting in September 2018, bringing together experts from the NLC, the Committee on Radiological Protection and Public Health (CRPPH) and the Radioactive Waste Management Committee (RWMC), as well as from the EC and the insurance industry. The discussions focused on several issues such as the description of the deep geological repository life cycle, the definition of "operator" under the international nuclear third party liability conventions, and nuclear third party liability coverage for deep geological repositories, in view of the preparation of a report on the application of the nuclear third party liability regime to this type of installations and the options available to address potential challenges.

The NEA continued to contribute to the work of the IAEA International Expert Group on Nuclear Liability (INLEX) and the World Nuclear Association, as well as to nuclear law educational programmes, such as the Winter Course on Nuclear Law organised in New Delhi, India, by the Nuclear Law Association India and TERI School of Advanced Studies and the IAEA Nuclear Law Institute. The NEA also continued to support the activities of the International Nuclear Law Association (INLA) by hosting meetings of its working groups, as well as co-sponsoring and contributing to the XXIII Nuclear Inter Jura Congress, which took place on 4-8 November 2018 in Abu Dhabi, United Arab Emirates.

Nuclear law publications programme



The Nuclear Law Bulletin (NLB) is a unique international publication for both professionals and academics in the field of nuclear law. It provides readers with authoritative and comprehensive information on nuclear law developments for the past 50 years. The first volume of 2018 is the 100th edition, which includes a "Special Feature" providing a history of the NLB, reflections and commentaries from the heads of the NEA legal affairs since its inception, as well as from the Chair of the NLC and one of the most published authors. It also includes the following articles and studies: "Legal challenges to the operation of nuclear reactors in Japan"; "Inside nuclear baseball: Reflections on the development of the safety conventions"; and "The Peaceful Nuclear Energy Program in the United Arab Emirates: Background and history"; case law, legislative and regulatory updates from France, Germany, Lithuania, Japan, Portugal, Slovenia, Switzerland and the United States; as well as a translation of the Chinese Nuclear Safety Law.

The second volume of 2018 includes articles and studies entitled "The impact of the major nuclear power plant accidents on the international legal framework for nuclear power", "Today is yesterday's pupil: Reactor licence renewal in the United States" and "Euratom competence in the areas of nuclear security and nuclear safety: An impossible parallel?". It contains case law, national legislative and regulatory updates from France, Germany, Lithuania, Slovak Republic, Slovenia, Switzerland and the United States; as well as a translation of the 16th Amendment to the German Atomic Energy Act.

All issues of the NLB are available free online at www.oecd-nea.org/law/nlb.

Country profiles on the regulatory and institutional framework for nuclear activities in member countries are available at www.oecd-nea.org/law/legislation. The NEA continues its concerted efforts to update this online repository of information and is grateful for the support of OECD and NEA member countries.

The 18th session of the NEA International School of Nuclear Law (ISNL) was held from 27 August to 7 September 2018 in Montpellier, France.

The NEA strives to keep the information on its website on nuclear law up to date. It has for example updated the *Table on Nuclear Operators' Third Party Liability Amounts and Financial Security Limits* that attempts to provide information on the applicable nuclear liability amounts and related financial security obligations imposed on nuclear operators in a wide range of countries, including non-OECD or non-NEA countries; as well as the *Table on Priority Rules on Compensation for Nuclear Damage in National Legislations* that outlines whether or not there are priority rules in the national legislations of 27 NEA member countries, and summarises the principles of the adopted priority rules. These tables, which are not official but rather for information purposes, can be downloaded at: www.oecd-nea.org/law/.

Nuclear law education programmes

The 18th session of the NEA International School of Nuclear Law (ISNL) was held from 27 August to 7 September 2018 in Montpellier, France, bringing together a diverse group of graduate students and professionals from across the world to learn more about the legal framework and major issues affecting the peaceful uses of nuclear energy. Organised by the NEA and the University of Montpellier, the ISNL is a unique educational programme that offers participants from the academic, private and governmental sectors an in-depth look at international nuclear law, focusing on areas such as nuclear safety, environmental law, security, safeguards and nuclear third party liability. The 2018 session was attended by 61 participants from 39 countries, including numerous non-NEA member countries, many of whom received support to attend the ISNL from the IAEA, which also provided several lecturers. The ISNL has attracted since 2001 more than 1 000 participants worldwide from an increasingly diverse range of countries, many of whom are now experts in the nuclear law field. Further information can be obtained at www. oecd-nea.org/law/isnl.

An alumni directory for the ISNL has been created in order to help its alumni and lecturers across the years maintain their connections and network. Access to the directory is password-restricted and available only to those alumni and lecturers who are listed. Online access is available at oe.cd/nea-isnl-alum. Participants, who wish to update their contact information or to be included in the directory, should e-mail isnl@oecd-nea.org to do so.

The NEA celebrated passing the 1 000th participant threshold and the nearly 20-year history of the ISNL with a commemorative brochure that reflects on the school's programme, past lecturers and participants. In this new ISNL brochure, alumni and lecturers describe the spirit of Montpellier and the community atmosphere of the programme. The brochure also includes a yearbook of all previous class years. The brochure, which will be updated annually, is available at www.oecd-nea.org/law/isnl/.

The seventh session of the NEA International Nuclear Law Essentials (INLE) course was held from 26 February to 2 March 2018 in Singapore, in co-operation with the National University of Singapore (NUS) and its Centre for International Law. This was the first time that the INLE was held outside of France. A diverse international group of 32 professionals from 15 NEA member and non-member countries participated in the programme, obtaining an overview of the international nuclear law framework, as well as other major issues affecting the peaceful uses of nuclear energy. Instructors from the NEA, the IAEA, NUS, nuclear regulatory authorities and the private sector gave lectures on topics related to nuclear safety, security, non-proliferation and liability. In addition, two special lectures were included featuring regional perspectives on nuclear law in both in China and Malaysia. Read more about the INLE at www.oecd-nea.org/law/inle/.

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Information and Communications

The goal of the NEA in this sector is to provide member governments and other major stakeholders with information resulting from NEA activities and to enhance awareness and understanding of the scientific, technical, economic and legal aspects of nuclear activities as well as awareness of the NEA itself.

Highlights

- The Agency produced 23 publications and 29 technical reports in 2018 all available for free download from the NEA website. Overall dissemination and downloads remained very strong.
- Thirty press and news releases were issued in 2018, including the first NEA regional ministerial meeting held in Romania, the 60th anniversary of the Agency and the first of its kind country-specific nuclear safety culture forum in Sweden.
- Online networking and multimedia platforms were used extensively throughout the year to communicate the Agency's latest publications, news and events and saw considerable growth.
- The Agency has continued to increase its visibility through participation of NEA management in major international fora and events in member countries and elsewhere.

The NEA is an intergovernmental agency specialised in studying the scientific, technical and economic aspects of nuclear energy. It strives to provide high-quality, factual information in a timely manner to its member countries as well as to other interested parties wishing to learn about nuclear energy's multiple aspects and the results of the Agency's work.

Relations with the media

Relations with the media in 2018 covered a wide variety of topics and questions concerning the development and use of nuclear power. Thirty press and news releases were issued, for example notifying the media of the first-of-its-kind country-specific nuclear safety culture forum held in Sweden; the release of the report entitled *The Full Costs of Electricity Provision*; the 60th anniversary of the Agency; the Director-General's first official visit to Poland; the NEA International Mentoring Workshops in Science and Engineering held in Japan and Spain; the first NEA regional ministerial meeting held in Romania; and the release of the 2018 edition of *Uranium – Resources, Production and Demand*, also known as the "Red Book".

Over the course of the year, the NEA and the NEA Director-General were cited in numerous news articles in specialised publications and the international press, including *Bloomberg, the Chosun Ilbo, Euronews, Denki Shimbun, Libération, New York Times, Physics World, Platts, Power Magazine* and *Sputnik News.*

Publications

In 2018, the Agency produced 23 publications, all of which are available free on the NEA website at www.oecd-nea.org/pub. A list of these publications is provided on page 68. A total of 29 NEA technical reports were also issued under the unclassified "R" series, directly downloadable from the substantive areas' web pages.

The most accessed online reports during the course of the year included *The Full Costs of Electricity Provision; Towards an All-Hazards Approach to Emergency Preparedness and Response*; and *Nuclear Energy Data 2017.*

The Agency's specialised journal, *NEA News*, keeps NEA correspondents and other interested professionals abreast of significant findings and advances in the Agency's programme of work. It provides feature articles on the latest developments in the nuclear energy field, as well as updates on NEA work, news briefs and information about NEA publications and forthcoming events.

In 2018, *NEA News* covered topics such as the progress in the reconstruction of Fukushima Prefecture, the restart of transient testing reactors TREAT in US and CABRI in France, the global uranium market, the *NEA State-of-the-Art Report on Light Water Reactor Accident-Tolerant Fuels* and the NEA Data Bank and its nuclear data activities. *NEA News* is available free on the Agency's website at www.oecd-nea.org/nea-news.

Online communication

The NEA's online presence and use of new media technologies play a key role in communicating the work and accomplishments of the Agency. Website traffic remained steady in 2018, with the following areas attracting the most views: the NEA Data Bank's Java-based Nuclear Data Information System (JANIS), general information about the Agency and the Joint Evaluated Fission and Fusion (JEFF) Nuclear Data Library.

Online networking platforms have helped strengthen communication of NEA activities. The Agency maintains a regular presence on Facebook, LinkedIn, and YouTube, and can be followed on Twitter @OECD_NEA. In 2018, the NEA continued to increase the frequency of its posts and engagement on all three platforms. The Agency's social media profile grew considerably in 2018 with a 58.17%

Webinar of 20 November 2018 to launch of the report *State-of-the-Art Report on Light Water Reactor Accident-Tolerant Fuels.*

increase in the number of followers on LinkedIn, a 50.25% increase on Twitter, and a 13.14% increase on Facebook.

Webinars remained an integral part of NEA online communications work in 2018. The NEA held webcast panel discussions to launch its reports *Towards an All-Hazards Approach to Emergency Preparedness and Response*; *The Full Costs of Electricity Provision*; *Country-Specific Safety Culture Forum: Sweden*; and *The State-of-the-Art Report on Light Water Reactor Accident-Tolerant Fuels.* Participants were able to join these events live online by sending comments and questions via e-mail and Twitter.

The Agency also continued to use video as part of its digital communications strategy in 2018. Five long-form and seven short-form videos were created and disseminated on Facebook, LinkedIn, Twitter and YouTube, helping increase the visibility of NEA results, publications and events. Topics covered in 2018 included the New NEA Committee on Decommissioning of Nuclear Installations and Legacy Management, *NEA News 36.1* and the second NEA International Mentoring Workshop in Science and Engineering held in Japan.

Subscriptions to the NEA Monthly News Bulletin have remained constant with approximately 20 000 subscribers. Distributed free of charge, the bulletin includes monthly updates on NEA work, activities and newly released reports. Online subscriptions can be made at www.oecd-nea.org/bulletin. Current and archive issues can also be viewed at www.oecd-nea.org/general/mnb.

Online interaction with NEA delegates continued to expand in 2018. Most NEA committees and their working groups rely extensively on electronic communication such as password-protected extranet pages, e-mail discussion lists or online collaborative work spaces. The Delegates' Area of the NEA website also continues to offer an important service for many NEA committees and working groups. This section of the website provides authorised users with official NEA documents, information on forthcoming NEA meetings, contact details for other committee members, as well as access to the presentations and background notes prepared for the Steering Committee policy debates.

Public affairs and visibility in international fora

NEA Director-General William D. Magwood, IV spoke in a variety of fora and countries in 2018 to communicate key messages about nuclear energy and the work of the NEA. These fora included the Japan Atomic Industry Forum (JAIF) annual conference in Japan in April; ATOMEXPO 2018 International Forum in Russia in May; the World Nuclear Association Symposium 2018 in the United Kingdom in September; American Nuclear Society (ANS) and Health Physics Society joint topical event on the Applicability of Radiation-Response Models to Low Dose Protection Standards in the United States in October; HTR 2018 International Conference on High Temperature Reactor Technology in Poland in October; and the International Conference on Dismantling Challenges: Industrial Reality, Prospects and Feedback Experience (DEM 2018) in France in October.

He also gave lectures and held discussions with students at a number of higher education institutions, including the Institute of Nuclear Techniques (NTI) of the Budapest University of Technology and Economics (BME), Shanghai Jiaotong University (SJTU), North Carolina State University, Purdue University and the World Nuclear University (WNU) Summer Institute.

During 2018, the NEA co-sponsored and organised information stands at several international events where the NEA Director-General or NEA experts intervened. These included:

- Joint International Youth Nuclear Congress (IYNC) 2018 and 26th WiN Global Annual Conference, Bariloche, Argentina, 11-17 March;
- International Symposium on Uranium Raw Material for the Nuclear Fuel Cycle: Exploration, Mining, Production, Supply and Demand, Economics and Environmental Issues (URAM-2018), Vienna, Austria, 25-29 June;
- International Symposium on Communicating Nuclear and Radiological Emergencies to the Public, Vienna, Austria, 1-5 October;
- WONDER 2018: Fifth International Workshop on Nuclear Data Evaluation for Reactor Applications, Aix-en-Provence, France, 8-12 October;
- SATIF-14: 14th Workshop on Shielding Aspects of Accelerators, Targets and Irradiation Facilities;
- 23rd Nuclear Inter Jura Congress, Abu Dhabi, United Arab Emirates, 48 November;
- Deepening Comprehension on Safety Case on Deep Geological Repository (DGR) and Public Confidence on Japan's DGR Programme, Tokyo, Japan, 28-29 November.

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Global relations

The goal of the NEA is to establish effective relationships with partner countries whose participation in the NEA programme can be mutually beneficial and to ensure complementarity and increase synergies with the International Atomic Energy Agency (IAEA), the European Commission (EC) and other international bodies. When relevant for its programme of work, the NEA develops exchanges with industrial organisations.

Highlights

- Representatives from Brazil, China and India participated in the NEA Steering Committee Strategic Briefing on 20 April 2018, presenting an overview of their countries' nuclear energy policies and programmes.
- The NEA, in co-operation with the government of Romania, organised a Regional Ministerial Conference on Nuclear Energy, Technology and Radioactive Waste Management in Bucharest on 25-26 October with the participation of ten countries from Central and Eastern Europe.
- An expert from China joined the NEA Secretariat in March 2018 to support the Division of Radioactive Waste Management and Decommissioning.
- The NEA welcomed in September two high-level delegations from China, led by the new Chairman of the China Atomic Energy Authority (CAEA) and the Deputy Administrator of the China National Energy Administration (C/NEA). Director General Magwood also visited China twice in 2018, and met with top-level representatives, also visiting the Hualong One and AP1000-equipped NPPs.
- Following the first official visit of Director-General Magwood in 2017, India became a Participant in the Committee on Nuclear Regulatory Activities (CNRA) in 2018 and was invited to become a Participant in the Committee on the Safety of Nuclear Installations (CSNI).
- Director-General Magwood met with the Director-General of Energy of the European Commission, Mr Ristori.

Brazil

Brazil's nuclear power programme has the potential for expansion. The country has also recently applied for accession to the OECD. Mr Daniel Iracane, Deputy Director-General and Chief Nuclear Officer, led a mission in March 2018 to attend the first Workshop on Information Exchange with the NEA in Rio de Janeiro, which was hosted by National Nuclear Energy Commission (CNEN), and during which the NEA delegation visited the Angra NPP.

Brazil presented the nuclear power policies and programmes during the NEA Steering Committee Strategic Briefing in April 2018.

CNEN delegates also attended Committee on Nuclear Regulatory Activities (CNRA) Working Group on Inspection Practices (WGIP) and Nuclear Law Committee (NLC) meetings in 2018, where they presented the regulatory activities of Brazil and their nuclear law framework.

People's Republic of China

The NEA's relationship with China continued to develop positively in 2018.

A cost-free expert from China joined the NEA Secretariat in March 2018, to support the Division of Radioactive Waste Management and Decommissioning.

The Deputy Director General of the Department of System Engineering of the China Atomic Energy Authority (CAEA) delivered a presentation on the Chinese nuclear power policies and programmes during the NEA Steering Committee Strategic Briefing held on 20 April 2018.

China continued its active participation in seven joint projects established under the auspices of the NEA.

Co-operation in the area of nuclear safety continued to be strong, as Chinese delegates participate in activities of the CNRA and the Committee on the Safety of Nuclear Installations (CSNI) and selected working groups, whereas their regulatory authority is also involved in the Multinational Design Evaluation Programme (MDEP). In 2018, a new group devoted to Hualong One was created within MDEP.

The participation of China also significantly increased in the area of radioactive waste management and nuclear law.

In September 2018, the NEA hosted two high-level delegations from China. The first was led by the new Chairman of the CAEA, the second by the Deputy Administrator of the China National Energy Administration (C/NEA), with whom NEA Director-General Mr William D. Magwood, IV held the first meeting in Paris after the signature of the Memorandum of Understanding for co-operation with C/NEA in April 2017. Both CAEA and C/NEA reaffirmed China's willingness to deepen and broaden the relationship with the NEA. The Director-General was received in Beijing

From left to right: William D. Magwood, IV, Director-General, Nuclear Energy Agency (NEA), Viorel Ştefan, Vice Prime Minister of Romania, Ludger Schuknecht, Deputy Secretary-General, Organisation for Economic Co-operation and Development (OECD) and Horia Grama, State Secretary, and President of the Romanian Nuclear Agency and for Radioactive Waste at the opening of the Regional Ministerial Conference on Nuclear Energy, Technology and Radioactive Waste Management, Bucharest, Romania, October 2018.

by the CAEA Chairman. He also visited the National Nuclear Safety Administration (NNSA), C/NEA, the China Institute of Atomic Energy (CIAE), and the AP1000 in Sanmen. In a previous mission to Shanghai, Director-General Magwood also visited the Hualong One-equipped Nuclear Power Plant (NPP) in Fuqing.

India

In April 2018, the Chairman and Managing Director of the Nuclear Power Corporation of India Limited (NPCIL) presented an overview of India's nuclear energy policies and programmes during the NEA Steering Committee Strategic Briefing.

Following the first mission of Director-General Magwood to Mumbai in 2017, India increased its engagement with the NEA and in 2018 became a participant in the CNRA and was invited to become a participant in CSNI. India is also a member of the MDEP.

Regional events and international fora

The NEA, in co-operation with the government of Romania, organised a Regional Ministerial Conference on Nuclear Energy, Technology and Radioactive Waste Management. The regional event was held in Bucharest on 25-26 October 2018. Ten countries sent ministers, deputy ministers, ambassadors, researchers, academics, industry experts and other senior officials to participate in discussions about the potential benefits of greater regional co-operation in areas related to nuclear energy. The unique characteristics of the region were highlighted, as well as the strong commonalities the countries share in terms of the issues that interest them, and the challenges they face. Participants at the meeting discussed a wide range of nuclear energy issues during plenary sessions on the region's electricity markets, radioactive waste management, nuclear safety and regulation, public communication on nuclear energy, and nuclear innovation and education. Participants identified areas such as the design of electricity markets, the financing of nuclear projects, safety culture and human resource development as key areas of interest. The NEA is developing options for possible next steps.

International organisations

The NEA is continuing its co-operation with the International Atomic Energy Agency (IAEA) by adhering to the co-ordination and consultation mechanisms provided for in the existing agreement between the two agencies, ensuring cross-participation in relevant committees and governing bodies and by undertaking activities, meetings and conferences jointly in appropriate areas. During 2018, the NEA and IAEA held their annual co-ordination meeting in Vienna and exchanged on several topics, such as the upcoming high-level event on climate change and nuclear energy, on small modular reactors (SMRs), research reactors, safety and human capital. Director-General Magwood was present during the IAEA General Conference in September and delivered opening speeches during side events organised by the NEA addressing the Country-Specific Safety Culture Forum and the CANDU Owners Group meeting.

During 2018, the NEA Director-General met for the first time with the Director-General of DG Energy at the European Commission in Brussels, exchanging views on the current situation of nuclear technology and identifying opportunities for engagement.

The Agency has continued to increase its visibility through the participation of senior management in international conferences and fora, such as the Clean Energy Ministerial, the G7 Nuclear Safety and Security Working Group (NSSG), the Energy Charter Ministerial and the European Nuclear Energy Forum (ENEF).

Liaising with industry associations and other stakeholders

The NEA signed MOUs with the World Association of Nuclear Operators (WANO) and the Electric Power Research Institute (EPRI) in 2017. These agreements have injected significant expertise into targeted activities that have important benefits for NEA member countries. In January 2018, the NEA and WANO organised the first Country-Specific Safety Culture Forum in Sweden (see page 38). The NEA, together with the IAEA and WANO, held a Supply Chain Management workshop on 5-6 November 2018. In 2018, the NEA also had many exchanges with EPRI on the development of accident-tolerant fuels and the sustainability of irradiated fuels and materials testing installations.

The representatives of the OECD/NEA and IAEA participated in the Practical Training Workshop organised in Moscow within the ROSATOM Target Programme on Human Resources Capacity Building for recruitment by international organisations (IAEA and OECD/NEA) in October 2018.

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Organisational Structure of the NEA

The Nuclear Energy Agency (NEA) is a semi-autonomous body of the Organisation for Economic Cooperation and Development. OECD member countries wishing to participate in the activities of the Agency must make a formal request to join. The NEA currently has 33 member countries:

Argentina	Luxembourg
Australia	Mexico
Austria	Netherlands
Belgium	Norway
Canada	Poland
Czech Republic	Portugal
Denmark	Romania
Finland	Russia
France	Slovak Republic
Germany	Slovenia
Greece	Spain
Hungary	Sweden
Iceland	Switzerland
Ireland	Turkey
Italy	United Kingdom
Japan	United States
Korea	

The NEA is governed by the **Steering Committee for Nuclear Energy**. This committee is primarily made up of senior officials from national atomic energy authorities and associated ministries. It oversees and shapes the work of the Agency to ensure its responsiveness to member countries' needs, notably in establishing the biennial programmes of work and budgets. It approves the mandates of the seven standing technical committees and one management board (see page 66).

In 2018, the members of the **Bureau of the Steering Committee** for Nuclear Energy were:

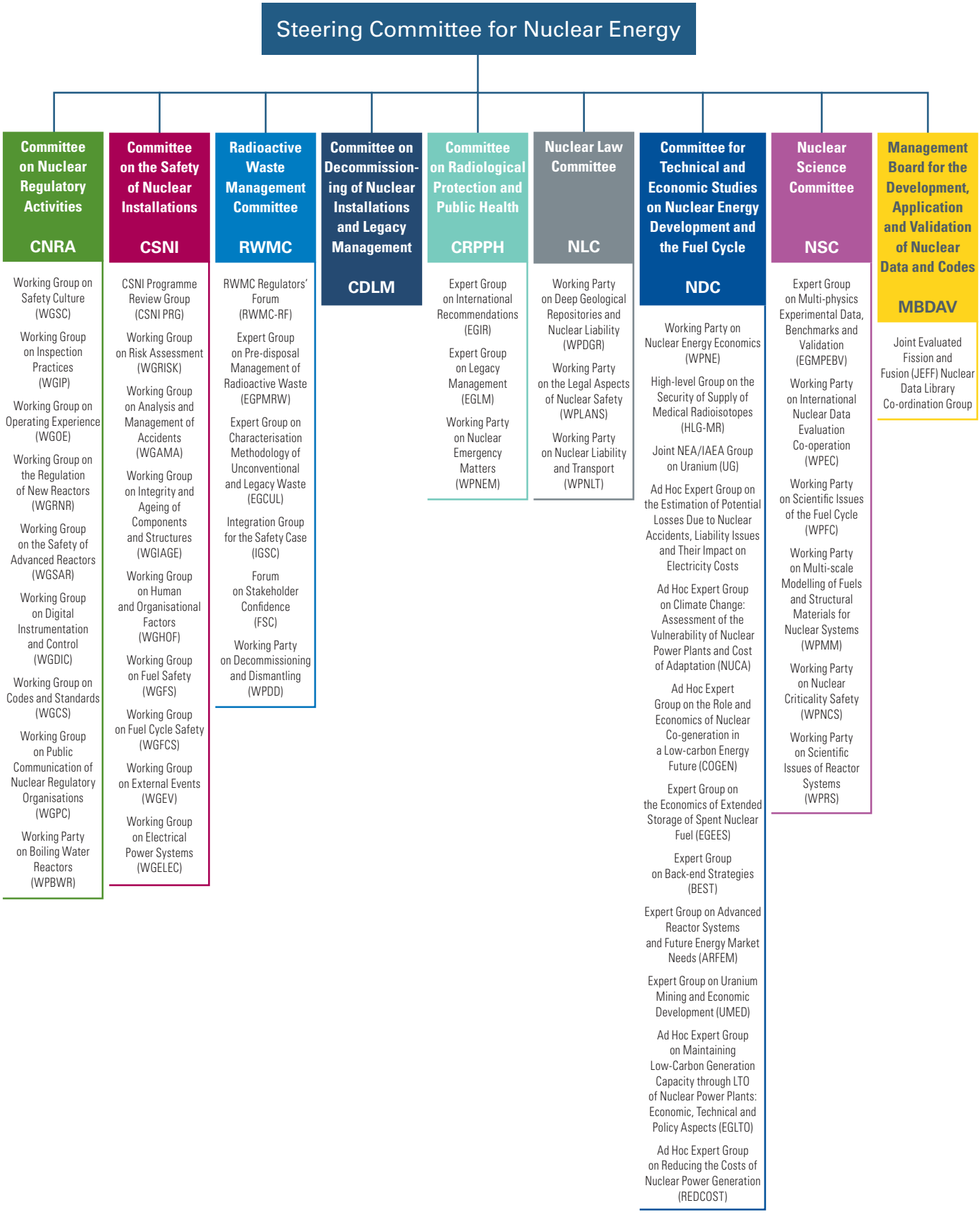
- Dr Marta ŽIAKOVÁ (Slovak Republic), Chair
- Dr Won-Pil BAEK (Korea), Vice-Chair
- Mr Jan BENS (Belgium), Vice-Chair
- Ms Anne LAZAR-SURY (France), Vice-Chair
- Mr Richard STRATFORD (United States), Vice-Chair
- Dr Hiroshi YAMAGATA (Japan), Vice-Chair

The **standing technical committees** and the **management board of the Data Bank** are composed of member country experts and technical specialists. These NEA bodies constitute a unique feature and important strength of the NEA, providing flexibility for adapting to new issues and helping to achieve consensus rapidly. Their main areas of work are listed in the chart on page 66.

The Steering Committee for Nuclear Energy and the Agency's eight standing technical committees and one management board are serviced by the **NEA Secretariat**, omposed in 2018 of 115 professional and support staff from 19 countries. Professional staff are often specialists from national administrations and research institutes, bringing their experience to the Agency for two to five years on average.

Participation in the work of the Agency by non-member countries is an established practice. Experts from selected **partner countries**, including China and India, take part in NEA activities on an invitee or participant basis.

OECD Boulogne building.


Steering Committee for Nuclear Energy
Committee on Nuclear Regulatory Activities
CNRA
Working Group on Safety Culture (WGSC)
Working Group on Inspection Practices (WGIP)
Working Group on Operating Experience (WGOE)
Working Group on the Regulation of New Reactors (WGRNR)
Working Group on the Safety of Advanced Reactors (WGSAR)
Working Group on Digital Instrumentation and Control (WGDIC)
Working Group on Codes and Standards (WGCS)
Working Group on Public Communication of Nuclear Regulatory Organisations (WGPC)
Working Party on Boiling Water Reactors (WPBWR)
Committee on the Safety of Nuclear Installations
CSNI
CSNI Programme Review Group (CSNI PRG)
Working Group on Risk Assessment (WGRISK)
Working Group on Analysis and Management of Accidents (WGAMA)
Working Group on Integrity and Ageing of Components and Structures (WGIAGE)
Working Group on Human and Organisational Factors (WGHOF)
Working Group on Fuel Safety (WGFS)
Working Group on Fuel Cycle Safety (WGFCS)
Working Group on External Events (WGEV)
Working Group on Electrical Power Systems (WGELEC)
Radioactive Waste Management Committee
RWMC
RWMC Regulators' Forum (RWMC-RF)
Expert Group on Pre-disposal Management of Radioactive Waste (EGPMRW)
Expert Group on Characterisation Methodology of Unconventional and Legacy Waste (EGCUL)
Integration Group for the Safety Case (IGSC)
Forum on Stakeholder Confidence (FSC)
Working Party on Decommissioning and Dismantling (WPDD)
Committee on Decommissioning of Nuclear Installations and Legacy Management
CDLM
Committee on Radiological Protection and Public Health
CRPPH
Expert Group on International Recommendations (EGIR)
Expert Group on Legacy Management (EGLM)
Working Party on Nuclear Emergency Matters (WPNEM)
Nuclear Law Committee
NLC
Working Party on Deep Geological Repositories and Nuclear Liability (WPDGR)
Working Party on the Legal Aspects of Nuclear Safety (WPLANS)
Working Party on Nuclear Liability and Transport (WPNLT)
Committee for Technical and Economic Studies on Nuclear Energy Development and the Fuel Cycle
NDC
Working Party on Nuclear Energy Economics (WPNE)
High-level Group on the Security of Supply of Medical Radioisotopes (HLG-MR)
Joint NEA/IAEA Group on Uranium (UG)
Ad Hoc Expert Group on the Estimation of Potential Losses Due to Nuclear Accidents, Liability Issues and Their Impact on Electricity Costs
Ad Hoc Expert Group on Climate Change: Assessment of the Vulnerability of Nuclear Power Plants and Cost of Adaptation (NUCA)
Ad Hoc Expert Group on the Role and Economics of Nuclear Co-generation in a Low-carbon Energy Future (COGEN)
Expert Group on the Economics of Extended Storage of Spent Nuclear Fuel (EGEES)
Expert Group on Back-end Strategies (BEST)
Expert Group on Advanced Reactor Systems and Future Energy Market Needs (ARFEM)
Expert Group on Uranium Mining and Economic Development (UMED)
Ad Hoc Expert Group on Maintaining Low-Carbon Generation Capacity through LTO of Nuclear Power Plants: Economic, Technical and Policy Aspects (EGLTO)
Ad Hoc Expert Group on Reducing the Costs of Nuclear Power Generation (REDCOST)
Nuclear Science Committee
NSC
Expert Group on Multi-physics Experimental Data, Benchmarks and Validation (EGMPEBV)
Working Party on International Nuclear Data Evaluation Co-operation (WPEC)
Working Party on Scientific Issues of the Fuel Cycle (WPFC)
Working Party on Multi-scale Modelling of Fuels and Structural Materials for Nuclear Systems (WPMM)
Working Party on Nuclear Criticality Safety (WPNCS)
Working Party on Scientific Issues of Reactor Systems (WPRS)
Management Board for the Development, Application and Validation of Nuclear Data and Codes
MBDAV
Joint Evaluated Fission and Fusion (JEFF) Nuclear Data Library Co-ordination Group

NEA MANAGEMENT STRUCTURE IN 2018

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NEA Director-General

Nobuhiro Muroya
Deputy Director-General for Management and Planning

Daniel Iracane
Deputy Director-General and Chief Nuclear Officer

Helena Potter
Head of the Office of Budget and Finance

Daniela Lulache
Head of the Office of Policy and Co-ordination

Andrew Macintyre
Head of the Central Secretariat

Daniela Lulache
Acting Senior Advisor for Multilateral Co-operation

Luc Chanial
Acting Head of the Division of Nuclear Safety Technology and Regulation

Yeonhee Hah
Head of the Division of Radiological Protection and Human Aspects of Nuclear Safety

Kenya Suyama
Head of the Data Bank

Ximena Vásquez-Maignan
Head of the Office of Legal Counsel

Gloria Kwong
Acting Head of the Division of Radioactive Waste Management and Decommissioning

Tatiana Ivanova
Head of the Division of Nuclear Science

Sama Bilbao y León
Head of the Division of Nuclear Technology Development and Economics

All NEA publications are available free of charge on the NEA website.

General Interest

Annual Report 2017

NEA No. 7404. 72 pages.

http://oe.cd/nea-2017-en

Rapport annuel 2017

AEN n° 7405. 72 pages.

http://oe.cd/nea-2017-fr

NEA News, No. 35.2

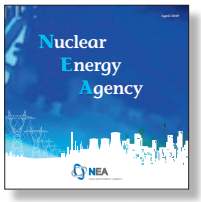
NEA No. 7348. 32 pages.

https://oe.cd/NEA-35-2

NEA News, No. 36.1

NEA No. 7430. 36 pages.

https://oe.cd/NEA-36-1

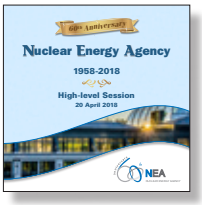


Nuclear Energy Agency

28 pages.

Also available in French Chinese and Russian.

Available online at: http://oe.cd/neabrochure



NEA 60th Anniversary brochure

16 pages.

Available online at: www.oecd-nea.org/general/history/60th

Nuclear technology development and economics

Energy Data 2018/ *Données sur l'énergie nucléaire 2018*

NEA No. 7416. 102 pages.

Available online at: http://oe.cd/nuclear-data-2018

Nuclear Energy Data is the NEA's annual compilation of statistics and country reports documenting nuclear power status in NEA member countries and in the OECD area. Information provided by governments includes statistics on total electricity produced by all sources and by nuclear power, fuel cycle capacities and requirements, and projections to 2035, where available. Country reports summarise energy policies, updates of the status in nuclear energy programmes and fuel cycle developments. In 2017, nuclear power continued to supply significant amounts of low-carbon baseload electricity, in a context of strong competition from low-cost fossil fuels and renewable energy sources. Governments committed to having nuclear power in the energy mix advanced plans for developing or increasing nuclear generating capacity, with the preparation of new build projects making progress in Finland, Hungary, Turkey and the United Kingdom. Further details on these and other developments are provided in the publication's numerous tables, graphs and country reports.

Measuring Employment Generated by the Nuclear Power Sector

NEA No. 7204. 92 pages.

Available online at: https://oe.cd/nuclear-employment-2018

The nuclear energy sector employs a considerable workforce around the world, and with nuclear power projected to grow in countries with increasing electricity demand, corresponding jobs in the nuclear power sector will also grow. Using the most available macroeconomic model to determine total employment – the "input/output" model – the Nuclear Energy Agency and International Atomic Energy Agency collaborated to measure direct, indirect and induced employment from the nuclear power sector in a national economy.

The results indicate that direct employment during site preparation and construction of a single unit 1 000 megawatt-electric advanced light water reactor at any point in time for 10 years is approximately 1 200 professional and construction staff, or about 12 000 labour years. For 50 years of operation, approximately 600 administrative, operation and maintenance, and permanently contracted staff are employed annually, or about 30 000 labour years. For up to 10 years of decommissioning, about 500 people are employed annually, or around 5 000 labour years. Finally, over an approximate period of 40 years, close to 80 employees are managing nuclear waste, totalling around 3 000 labour years. A total of about 50 000 direct labour-years per gigawatt. Direct expenditures on these employees and equipment generate approximately the same number of indirect employment, or about 50 000 labour years; and direct and indirect expenditures generate about the same number of induced employment, or 100 000 labour years. Total employment in the nuclear power sector of a given national economy is therefore roughly 200 000 labour years over the life cycle of a gigawatt of nuclear generating capacity.

The Costs of Decarbonisation: System Costs with High Shares of Nuclear and Renewables

NEA No. 7299. 220 pages.

Available online at: http://oe.cd/nea-system-costs-2019

Executive Summary

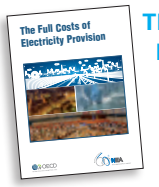
NEA No. 7335. 16 pages.

Available online at: https://oe.cd/2uj

Under the Paris Agreement, OECD countries agreed to aim for a reduction of their greenhouse gas emissions sufficient to hold the increase in the global average temperature to well below 2°C above pre industrial levels. This commitment requires a massive effort to decarbonise energy and electricity generation, a radical restructuring of the electric power sector and the rapid deployment of large amounts of low-carbon generation technologies, in particular nuclear energy and renewable energies such as wind and solar PV.

This study assesses the costs of alternative low-carbon electricity systems capable of achieving strict carbon emission

reductions consistent with the aims of the Paris Agreement. It analyses several deep decarbonisation scenarios to reach the same stringent carbon emission target but characterised by different shares of variable renewable technologies, hydroelectric power and nuclear energy.



The Full Costs of Electricity Provision

NEA No. 7298. 212 pages.

Available online at: http://oe.cd/nea-full-costs-2018

Extended Summary

NEA No. 7437. 24 pages.

Available online at: https://oe.cd/2pM

Electricity provision touches upon every facet of life in OECD and non-OECD countries alike, and choosing how this electricity is generated – whether from fossil fuels, nuclear energy or renewables – affects not only economic outcomes but individual and social well-being in the broader sense. Research on the overall costs of electricity is an ongoing effort, as only certain costs of electricity provision are perceived directly by producers and consumers. Other costs, such as the health impacts of air pollution, damage from climate change or the effects on the electricity system of small-scale variable production are not reflected in market prices and thus diminish well-being in unaccounted for ways.

Accounting for these social costs in order to establish the full costs of electricity provision is difficult, yet such costs are too important to be disregarded in the context of the energy transitions currently under way in OECD and NEA countries. This report draws on evidence from a large number of studies concerning the social costs of electricity and identifies proven instruments for internalising them so as to improve overall welfare.

The results outlined in the report should lead to new and more comprehensive research on the full costs of electricity, which in turn would allow policy makers and the public to make better informed decisions along the path towards fully sustainable electricity systems.

Uranium 2018: Resources, Production and Demand

NEA No. 7413. 458 pages.

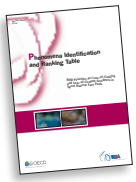
Available online at: http://oe.cd/nea-red-book-27

Uranium is the raw material used to produce fuel for long-lived nuclear power facilities, necessary for the generation of significant amounts of baseload low-carbon electricity for decades to come. Although a valuable commodity, declining market prices for uranium in recent years, driven by uncertainties concerning the evolution in the use of nuclear power, have led to significant production cutbacks and the postponement of mine development plans in a number of countries and to some questions being raised about future uranium supply.

This 27th edition of the "Red Book", a recognised world reference on uranium jointly prepared by the Nuclear Energy Agency (NEA) and the International Atomic Energy Agency (IAEA), provides analyses and information from 41 producing and consuming countries in order to address these and other questions.

The present edition provides the most recent review of world uranium market fundamentals and presents data on global uranium exploration, resources, production and reactor-related requirements. It offers updated information on established uranium production centres and mine development plans, as well as projections of nuclear generating capacity and reactor-related requirements through 2035, in order to address long-term uranium supply and demand issues.

Nuclear safety and regulation



Phenomena Identification and Ranking Table

R&D Priorities for Loss-of-Cooling and Loss-of-Coolant Accidents in Spent Nuclear Fuel Pools

NEA No. 7443. 82 pages.

Available online at: https://oe.cd/2pN

The present report is a follow up to the status report documenting the results of a Phenomena Identification and Ranking Table (PIRT) exercise conducted by the NEA. This PIRT exercise identified SFP accident phenomena that are of high importance and yet are highly uncertain, thus highlighting their primary interest for further studies. The report recommends further support for existing experimental programmes and the establishment of a number of new programmes to focus, for example, on large-scale thermal-hydraulic experiments on the coolability of partly or completely uncovered spent-fuel assemblies and the investigation of spray cooling for uncovered spent-fuel assemblies in typical storage racks.

Radiological Protection and Human Aspects of Nuclear Safety

Country-Specific Safety Culture Forum: Sweden

NEA No. 7420. 52 pages.

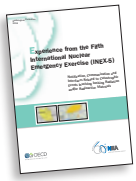
Also available in Swedish.

Available online at: https://oe.cd/nea-cssc-sweden-pub

One of the many important lessons learnt about nuclear safety over the years has been that human aspects of nuclear safety are as important as any technical issue that may arise in the course of nuclear operations. The international nuclear community can work together to identify and address issues associated with components and systems and compare operational experiences, but identifying how human behaviour affects safety and the best approaches to examine this behaviour from country to country remains less common.

Practical experience has nevertheless shown that there are important differences in how people work together and communicate across borders. People's behaviours, attitudes and values do not stop at the gate of a nuclear installation, and awareness of the systemic nature of culture and its deeper aspects, such as the dynamics of how values and assumptions influence behaviours, continues to evolve.

The NEA safety culture forum was created to gain a better understanding of how the national context affects safety culture in a given country and how operators and regulators perceive these effects in their day-to-day activities. The ultimate goal is to ensure safe nuclear operations. The first NEA safety culture forum – a collaborative effort between the NEA, the World Association of Nuclear Operators (WANO) and the Swedish Radiation Safety Authority (SSM) – was held in Sweden in early 2018. This report outlines the process used to conduct the forum, reveals findings from the discussions and invites the nuclear community to further reflect and take action.



Experience from the Fifth International Nuclear Emergency Exercise (INEX-5)

NEA No. 7379. 60 pages.

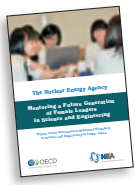
Available online at: https://oe.cd/2oG

The NEA has a long tradition of expertise in the area of nuclear emergency policy, planning, preparedness and management. Through its activities in this field, it offers member countries unbiased assistance on nuclear preparedness matters, with a

view to facilitating improvements in nuclear emergency preparedness strategies and response at the international level. A central approach to this has been the preparation and conduct of the International Nuclear Emergency Exercise (INEX) series.

The Fifth International Nuclear Emergency Exercise (INEX-5) was developed specifically in response to member countries' desire to test and demonstrate the value of changes put in place following the Fukushima Daiichi nuclear power plant accident. Exercise objectives focused on notification, communication and interfaces related to catastrophic events involving ionising radiation and/or radioactive material. The exercise was held during 2015 and 2016, with 22 countries participating in the exercise.

This report summarises the major evaluation outcomes of the national and regional exercises, policy level outcomes, recommendations and follow-up activities emerging from INEX-5 and the discussions at the INEX-5 International Workshop. A set of key needs were identified in areas such as real-time communication and information sharing among countries and international partners, improving cross-border and international co-ordination of protective measures and considering the mental health impacts on populations when implementing protective measures.



Mentoring a Future Generation of Female Leaders in Science and Engineering

NEA No. 7454. 12 pages.

Available online at: https://oe.cd/2pP

The NEA mentoring workshops are in line with the initiatives being undertaken by countries around the world to ensure that expertise is maintained in highly technical areas such as nuclear safety, radiological protection and other critical disciplines. Capacity-building efforts focusing on science, technology, engineering and mathematics (STEM) fields need to be sustained and reinforced – particularly those aimed at young women, who are significantly under-represented in many areas. It is in this spirit that the NEA partnered with Japan's National Institutes for Quantum and Radiological Science and Technology (QST) in 2017 to organise its first International Mentoring Workshop in Science and Engineering, on 25-26 July 2017 in Chiba, Japan. The success of this first workshop has led to the organisation of two additional workshops in 2018, both of which are introduced in this brochure – one in Tokyo, Japan, and the other in Ávila, Spain.

These workshops are a clear manifestation of the NEA's commitment to maintaining, and further strengthening, its momentum in encouraging a future generation of female leaders in science and engineering fields.

Proceedings of the Fifth International Nuclear Emergency Exercise (INEX-5) Workshop

NEA No. 7442. 54 pages.

Also available in Swedish.

Available online at: https://oe.cd/2pO

The Fifth International Nuclear Emergency Exercise (INEX-5) Workshop was held in early 2017. Representatives from 22 member countries, the International Atomic Energy Agency and the European Commission attended the workshop, where participants identified elements emerging from INEX-5 that would help improve international and national arrangements for notification, communication and interfaces related to catastrophic events involving radiation or radiological materials.

The workshop was an interactive experience structured around invited presentations, moderated discussions and breakout groups that addressed the four broad topics of communication and information sharing with other countries and international partners; cross-border and international co-ordination of protective actions; mid- and long-term aspects of recovery; and connections with the work of other international organisations and networks. These proceedings provide a summary of the proposals and recommendations for future work in emergency management.

Towards an All-Hazards Approach to Emergency Preparedness and Response

NEA No. 7308. 100 pages.

Available online at: http://oe.cd/nea-all-hazards-pub-2018

Executive Summary

8 pages.

Available online at: https://oe.cd/2ul

The field of emergency management is broad, complex and dynamic. In the post-Fukushima context, emergency preparedness and response (EPR) in the nuclear sector is more than ever being seen as part of a broader framework. The OECD has recommended that its members "establish and promote a comprehensive, all-hazards and transboundary approach to country risk governance to serve as the foundation for enhancing national resilience and responsiveness". In order to achieve such an all-hazards approach to emergency management, a major step in the process will be to consider experiences from the emergency management of hazards emanating from a variety of sectors.

The NEA Working Party on Nuclear Emergency Matters (WPNEM) joined forces with the OECD Working Group on Chemical Accidents (WGCA), the OECD Public Governance Directorate's High-Level Risk Forum (HLRF) and the European Commission's Joint Research Centre (JRC) to collaborate on this report, which demonstrates similarities between emergency planning and preparedness across sectors, and identifies lessons learnt and good practices in diverse areas for the benefit of the international community. A set of expert contributions, enriched with a broad range of national experiences, are presented in the report to take into account expertise gathered from the emergency management of hazards other than those emanating from the nuclear sector in an effort to support and foster an all-hazards approach to EPR.

Radioactive waste management

Metadata for Radioactive Waste Management

NEA No. 7378. 68 pages.

Available online at: https://oe.cd/2uk

National programmes for radioactive waste management require very large amounts of data and information across multiple and disparate disciplines. These programmes tend to run over a period of many decades resulting in a serious risk of data and information loss, which in turn can threaten the production and maintenance of robust safety cases.

Metadata and associated tools and techniques play a crucial role in modern data and information management. The Radioactive Waste Repository Metadata Management (RepMet) initiative has prepared the first international study on the application of metadata to the field of radioactive waste management. This report introduces the concept of metadata, explains how metadata can help to facilitate data management, and gives advice on the issues arising when developing metadata within radioactive waste management programmes. It is aimed at readers looking to obtain a high-level overview of metadata, and associated tools and techniques, and the strategic importance they can play in Radioactive Waste Management Organisations (RWMOs).

Microbial Influence on the Performance of Subsurface, Salt-Based Radioactive Waste Repositories

NEA No. 7387. 68 pages.

Available online at: http://oe.cd/2hy

For the past several decades, the NEA Salt Club has been supporting and overseeing the characterisation of rock salt as a potential host rock for deep geological repositories. This extensive evaluation of deep geological settings is aimed at determining – through a multidisciplinary approach – whether specific sites are suitable for radioactive waste disposal. Studying the microbiology of granite, basalt, tuff and clay formations in both Europe and the United States has been an important part of this investigation, and much has been learnt about the potential influence of microorganisms on repository performance, as well as about deep subsurface microbiology in general. Some uncertainty remains, however, around the effects of microorganisms on salt-based repository performance. Using available information on the microbial ecology of hypersaline environments, the bioenergetics of survival under high ionic strength conditions and studies related to repository microbiology, this report summarises the potential role of microorganisms in salt-based radioactive waste repositories.

Preparing for Decommissioning During Operation and after Final Shutdown

NEA No. 7374. 160 pages.

Available online at: http://oe.cd/2i0

The transition from an operating nuclear facility to the decommissioning phase is critical in the life cycle of every facility. A number of organisational and technical modifications are needed in order for the facility to meet new objectives and requirements, and a certain number of activities must be initiated to support the transition and preparation for the dismantling of the facility. Thorough preparation and planning is key for the success of global decommissioning and dismantling projects, both to minimise delays and undue costs and to ensure a safe and efficient decommissioning process. The aim of this report is to inform regulatory bodies, policy makers and planners about the relevant aspects and activities that should begin during the last years of operation and following the end of operation. Compiling lessons learnt from experiences and good practices in NEA member countries, the report supports the further optimisation of transition strategies, activities and measures that will ensure adequate preparation for decommissioning and dismantling.

Nuclear science and the Data Bank

International Handbook of Evaluated Criticality Safety Benchmark Experiments

NEA No. 7360. DVD.

The International Criticality Safety Benchmark Evaluation Project (ICSBEP) Handbook contains criticality safety benchmark specifications that have been derived from experiments that were performed at various critical facilities around the world. The benchmark specifications are intended for use by criticality and safety analysts as well as nuclear data evaluators to validate calculational techniques and data. The handbook is produced by the ICSBEP working group, under the aegis of the NEA. While co-ordination and administration of the ICSBEP is undertaken by the NEA, each participating country is responsible for the administration, technical direction, and priorities of the project within their respective countries. Access to some of the information and data included in this handbook may be restricted; full conditions for access are available online.

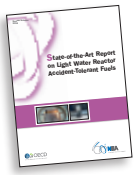
The 2018 edition contains data evaluated criticality safety benchmark data in nine volumes that span over 70 000 pages. The handbook contains 567 evaluations with benchmark specifications for 4 913 critical, near-critical or subcritical configurations, 45 criticality alarm placement/shielding configurations with multiple dose points for each, and 215 configurations that have been categorised as fundamental physics measurements that are relevant to criticality safety applications.

International Handbook of Evaluated Reactor Physics Benchmark Experiments

NEA No. 7361. DVD.

The International Handbook of Evaluated Reactor Physics Experiments contains reactor physics benchmark specifications that have been derived from experiments that were performed at various nuclear facilities around the world. The benchmark specifications are intended for use by reactor designers, safety analysts and nuclear data evaluators to validate calculational techniques and data. The handbook is a product of the International Reactor Physics Evaluation (IRPhE) project, conducted by the OECD Nuclear Energy Agency (NEA). While co ordination and administration of the IRPhE project is undertaken by the NEA, each participating country is responsible for the administration, technical direction, and priorities of the project within their respective countries. Access to some of the information and data included in this handbook may be restricted; full conditions for access are available online.

The 2018 edition contains data from 159 different experimental series that were performed at 54 different nuclear facilities. Some 156 of the 159 evaluations are published as approved benchmarks. The remaining five evaluations are published as draft documents only. All draft documents were reviewed by the International Reactor Physics Evaluation (IRPhE) Technical Review Group (TRG). Example calculations are presented; however, these calculations do not constitute validation or endorsement of the codes or cross section data. The IRPhE project is patterned after the International Criticality Safety Benchmark Evaluation Project (ICSBEP) and is closely co-ordinated with the ICSBEP. Some benchmark data are applicable to both nuclear criticality safety and reactor physics technology. Some have already been evaluated and published by the ICSBEP, but have been extended to include other types of measurements besides the critical configuration.



State-of-the-Art Report on Light Water Reactor Accident-Tolerant Fuels

NEA No. 7317. 368 pages.

Available online at: https://oe.cd/nea-ATFs-2018

As part of a broader spectrum of collaborative activities underpinning nuclear materials research, the NEA is supporting worldwide efforts towards the development of advanced materials, including fuels for partitioning and transmutation purposes and accident-tolerant fuels (ATFs). This state-of-the-art report on ATFs results from the collective work of experts from 35 institutions in 14 NEA member countries, alongside invited technical experts from China. It represents a shared and consensual position, based on expert judgment, concerning the scientific and technological knowledge related to ATFs. The report reviews available information on the most promising fuels and cladding concepts in terms of properties, experimental data and modelling results, as well as ongoing research and development activities. It also includes a description

of illustrative accident scenarios that may be adopted to assess the potential performance enhancement of ATFs relative to the current standard fuel systems in accident conditions, a definition of the technology readiness levels applicable to ATFs, a survey of available modelling and simulation tools (fuel performance and severe accident analysis codes), and the experimental facilities available to support the development of ATF concepts. The information included in this report will be useful for national programmes and industrial stakeholders as an input to setting priorities, and helping them to choose the most appropriate technology based on their specific strategy, business case and deployment schedules.

State-of-the-Art Report on the Progress of Nuclear Fuel Cycle Chemistry

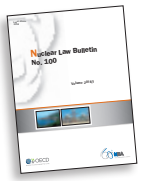
NEA No. 7267. 300 pages.

Available online at: http://oe.cd/2iF

The implementation of advanced nuclear systems requires that new technologies associated with the back end of the fuel cycle are developed. The separation of minor actinides from other fuel components is one of the advanced concepts being studied to help close the nuclear fuel cycle and to improve the long-term effects on the performance of geological repositories. Separating spent fuel elements and subsequently converting them through transmutation into short lived nuclides should considerably reduce the long-term risks associated with nuclear power generation.

R&D programmes worldwide are attempting to address such challenges, and many processes for advanced reprocessing and partitioning minor actinides are being developed. This report provides a comprehensive overview of progress on separation chemistry processes, and in particular on the technologies associated with the separation and recovery of minor actinides for recycling so as to help move towards the implementation of advanced fuel cycles. The report examines both aqueous and pyro processes, as well as the status of current and proposed technologies described according to the hierarchy of separations targeting different fuel components. The process criteria that will affect technology down selection are also reviewed, as are non proliferation requirements. The maturity of different reprocessing techniques are assessed using a scale based on the technology readiness level, and perspectives for future R&D are reviewed.

Nuclear law



Nuclear Law Bulletin No. 100

Volume 2018/1

NEA No. 7367. 148 pages.

Available online at: http://oe.cd/2jB

The *Nuclear Law Bulletin* is a unique international publication for both professionals and academics in the field of nuclear law. It provides readers with authoritative and comprehensive information on nuclear law developments. Published free online 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 and studies in this issue include: "Legal challenges to the operation of nuclear reactors in Japan"; "Inside nuclear baseball: Reflections on the development of the safety conventions"; and "The Peaceful Nuclear Energy Programme in the United Arab Emirates: Background and history".

Publications of Secretariat-serviced bodies

Generation IV International Forum (GIF) Annual Report 2017

GIF report. 182 pages.

This eleventh edition of the *Generation IV International Forum (GIF) Annual Report* highlights the main achievements of the Forum in 2017. During the year, several of the GIF Project Arrangements were extended for another ten years, new projects were prepared and others terminated, thereby setting the scene for long-term co-operation among GIF members. Australia, which joined the GIF in 2016, formally acceded to the Framework Agreement in 2017, and subsequently signed the Systems Arrangements for very high temperature reactors and the molten salt reactors. The safety design criteria and guidelines first developed for sodium fast reactors were extended to other systems, and the Education and Training Task Force successfully organised twelve webinars.

In the context of rapidly evolving energy markets and efforts to reduce global greenhouse gas emissions, the GIF continued to work on assessing and highlighting the benefits of deploying Generation IV systems with the support of the Economic Modelling Working Group and the Senior Industry Advisory Panel.

International Framework for Nuclear Energy Cooperation

IFNEC brochure. 8 pages.

Available online at: www.ifnec.org

Multinational Design Evaluation Programme (MDEP) Annual Report: April 2017-April 2018

MDEP report. 56 pages.

Available online at: https://oe.cd/2rQ

Nuclear Power Plant Operating Experience

From the IAEA/NEA International Reporting System for Operating Experience 2012–2014

NEA No. 7448. 56 pages.

Available online at: https://oe.cd/2pQ

The International Reporting System for Operating Experience (IRS) is an essential system for the exchange of information on safety related events at nuclear power plants worldwide. The fundamental objective of the IRS is to enhance the safety of nuclear power plants through the sharing of timely and detailed information on such events, and the lessons that can be learned from them, to reduce the chance of recurrence at other plants.

The first edition of this publication covered safety related events reported between 1996 and 1999. This sixth edition covers the 2012–2014 period and highlights important lessons learned from a review of the 258 event reports received from participating States during those years.

The IRS is jointly operated and managed by the NEA and the IAEA.

NEA Senior staff

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

The OECD is a unique forum where the governments of 36 democracies work together to address the economic, social and environmental challenges of globalisation. The OECD is also at the forefront of efforts to understand and to help governments respond to new developments and concerns, such as corporate governance, the information economy and the challenges of an ageing population. The Organisation provides a setting where governments can compare policy experiences, seek answers to common problems, identify good practice and work to co-ordinate domestic and international policies.

The OECD member countries are: Australia, Austria, Belgium, Canada, Chile, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Latvia, Lithuania, Luxembourg, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, Korea, the Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The European Commission takes part in the work of the OECD.

OECD Publishing disseminates widely the results of the Organisation's statistics gathering and research on economic, social and environmental issues, as well as the conventions, guidelines and standards agreed by its members.

NUCLEAR ENERGY AGENCY

The OECD Nuclear Energy Agency (NEA) was established on 1 February 1958. Current NEA membership consists of 33 countries: Argentina, Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Luxembourg, Mexico, the Netherlands, Norway, Poland, Portugal, Korea, Romania, Russia, the Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The European Commission and the International Atomic Energy Agency also take part in the work of the Agency.

The mission of the NEA 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 sound and economical use of nuclear energy for peaceful purposes;
- to provide authoritative assessments and to forge common understandings on key issues as input to government decisions on nuclear energy policy and to broader OECD analyses in areas such as energy and the sustainable development of low-carbon economies.

Specific areas of competence of the NEA include the safety and regulation of nuclear activities, radioactive waste management and decommissioning, radiological protection, nuclear science, economic and technical analyses of the nuclear fuel cycle, nuclear law and liability, and public information. The NEA Data Bank provides nuclear data and computer program services for participating countries.

Also available in French under the title:

AEN – RAPPORT ANNUEL – 2018

Cover page photo credits: Mixed oxide fuel (MOX), Shikoku Electric Power Co, Inc., Kagawa, Japan and International Mentoring Workshop in Science and Engineering, Chiba, Japan.

NEA publications and information

The full **catalogue of publications** is available online at www.oecd-nea.org/pub.

In addition to basic information on the Agency and its work programme, the **NEA website** offers free downloads of hundreds of technical and policy-oriented reports.

An **NEA monthly electronic bulletin** is distributed free of charge to subscribers, providing updates of new results, events and publications. Sign up at www.oecd-nea.org/bulletin.

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NEA No. 7462

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(as of 1 Avril 2019)

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