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OECD Boulogne building.
A new energy paradigm

In the 1970s, as the world faced an energy crisis echoed in some ways by the one we’re experiencing today, countries began to envisage new systems to produce, store and transport energy. Hydrogen was identified as a promising solution, and while it has not since become a mainstream component of global energy systems, that could change in coming years as a growing number of countries include it in their decarbonisation plans.

Hydrogen is a well-known quantity. It is the most common element in the universe and its potential as an energy vector was contemplated as far back as 1875, when Jules Verne famously prophesied the advent of hydrogen as a fuel to replace coal in his novel *L’Île mystérieuse* (The Mysterious Island).

Today, the potential role of hydrogen to decarbonise hard-to-abate sectors such as heavy transport and industrial applications is once again at the centre of energy policy discussions. Leveraging decades of research and development and public-private partnerships, countries are entering a critical period for turning the vision of the hydrogen economy into reality.

In a first instance, hydrogen can help decarbonise different industrial processes and transport. In the longer term, it is expected to contribute to the flexibility of electricity grids with larger shares of variable renewables.

However, hydrogen can contribute to net zero targets only if it is produced from low-carbon sources. In recent years, low temperature electrolysis, which requires inputs of water and electricity, has reached the required technical and economic maturity for large-scale production of low-carbon hydrogen. Throughout this process, approximately 50 kWh of electricity is required to produce one kilogram of the gas. In other words, decarbonising the current worldwide hydrogen consumption of about 90 million tonnes would require 4.5 TWh of low-carbon electricity.

In the future, many analysts expect hydrogen demand is likely to increase by several orders of magnitude as its use spreads beyond industry to function as a store of energy and a vector in sectors like heating. This gives a sense of the challenge that lies ahead.

Nuclear power is the second largest source of low-carbon electricity worldwide and therefore has a key role to play. As of 2022, 13 countries representing 80% of global installed nuclear capacity have climate strategies identifying nuclear energy as a competitive source of energy to produce low-carbon hydrogen. Amortised nuclear reactors in long-term operation can produce hydrogen at the lowest cost, at about USD 2 per kilogram. The cost of hydrogen produced by new nuclear reactors is similar to that produced from solar or wind in most parts of the world. Very high-temperature gas reactors in the future may usher forth even lower costs.

Nuclear energy’s reliability and power density make it ideal to partner with variable renewable energy sources.

For the world to be on track to meet the objectives of the Paris Agreement, this decade must be one of practical yet dramatic action. A new energy paradigm is coming into view that could require massive production of clean electricity, heat, clean water and hydrogen. Realising that paradigm will require investment in research and development in innovative energy systems, such as new nuclear technologies, as well as modern, risk-informed approaches to ensure high levels of safety.

For several decades, nuclear energy has proved a competitive, reliable and dispatchable source of electricity. Building on this solid track record, nuclear energy has the potential to play a vital role in future low-carbon energy mixes where it will deliver an innovative range of products and services, including large-scale production of low-carbon hydrogen.

William D. Magwood, IV, NEA Director-General
The use of hydrogen is forecast to rise in coming years as part of government and private stakeholder plans to reach net zero emissions by the middle of the century. The creation of the so-called “hydrogen economy”, where use of the element spreads beyond the industrial sector to become an energy carrier for transport, heating and power applications, will require vast amounts of reliable low-carbon energy. Existing and future nuclear reactors can provide part of that energy and contribute to the global economy’s transition towards net zero.

According to the net zero pathway of the International Energy Agency (IEA, 2021), annual consumption of hydrogen will more than quintuple to over 500 Mt by 2050. That will require support for research, development and demonstration programmes, a strong and constant political commitment and the ability to set and agree upon technical and regulatory frameworks for hydrogen handling and trading.

Strategies for developing the hydrogen economy are typically characterised by three time horizons – 2025, 2035 and 2050.

The first priorities, in the short term to 2025, are to close the competitiveness gap between fossil fuel-based hydrogen production pathways and water electrolysis as well as to decarbonise existing uses of hydrogen.

By 2035, in the medium term, electrolytic hydrogen production is expected to ramp up as new GWe electrolyser capacity becomes available. Industrial applications will continue to lead demand for hydrogen, while new usages in the transport sector enter the market.

After 2035, the demand for low-carbon hydrogen is expected to increase due to its growing role in the transport sector as well as for other applications. Hydrogen will become increasingly commoditised and might no longer be structured...
around limited areas of production and consumption, referred to as “hubs” or “valleys”. By that time, given increasingly stringent carbon constraints, low- and high-temperature electrolysis using low-carbon electricity and heat will become the leading hydrogen production pathway.

The Nuclear Energy Agency (NEA) sees the early 2030s as the turning point for global hydrogen strategies, and has published *The Role of Nuclear Power in the Hydrogen Economy: Cost and Competitiveness* (NEA, 2022) detailing the role and potential of nuclear power in the hydrogen economy over this horizon.

**A competitive option at the plant level**

The most pressing challenge in establishing the hydrogen economy is to enable the decarbonisation of current hydrogen usages at a competitive price without impeding other decarbonisation objectives.

To do this, all low-carbon electricity sources are required. Indeed, producing through water electrolysis the amount of hydrogen currently consumed worldwide would represent a supplementary electricity demand of approximately 4,500 TWh, or more than 1.5 times the current European electricity demand. While variable renewables will represent the majority of future low-carbon sources, their deployment at such scales raises new challenges. To that extent, discriminating between different sources of clean electricity for low-carbon hydrogen production – including via hydrogen support policies that apply a colour label based on the energy source – will only hobble the ability to meet climate change goals.

Nuclear energy as a source of dispatchable and clean electricity and heat would make it possible to operate an electrolyser at high load factors without compromising hydrogen’s carbon intensity. NEA analysis shows that nuclear power is a competitive option to produce and deliver hydrogen in most parts of the world. Furthermore, the analysis shows that the use of nuclear energy for high-temperature water electrolysis holds significant promise due to the higher efficiency of this process compared to low-temperature alternatives.

When coupling an electrolyser to a specific source of electricity, electrolytic hydrogen production at large scale below USD 2.5 per kgH₂ will be hard to achieve in many parts in the world by 2035. However, in a context of high gas prices, the cost of producing hydrogen by steam methane reforming, the incumbent production pathway, is also expected to increase significantly. Indeed, assuming a gas price of USD 100 per MWh, below the prices in certain regions of the world in the second quarter of 2022, hydrogen production costs from steam methane reforming with carbon capture, utilisation and storage (CCUS) is estimated at USD 5.87 per kgH₂, to be compared with the least competitive option for electrolytic hydrogen in the NEA analysis (offshore wind) at USD 3.56 per kgH₂. In other words, the hydrogen market is likely to become increasingly fragmented, where regional resource endowment will largely determine the leading production pathway and the cost of hydrogen.

The business model of electrolysers, e.g. electrolysers coupled to a variable source of electricity or operated in baseload, is a key factor in the economic and the industrial feasibility of the hydrogen economy. In particular, while coupling a hydrogen production plant with a cheap electricity generation source might optimise the production cost – assuming tax and levies on electricity prices are avoided –

![Figure 1: The levelised cost of hydrogen (LCOH) for different production options](image)

*Note: LTO = Long-term operation; NA = North America; NB = New build; EU = European Union; ME = Middle East; CCUS = Carbon Capture Utilisation and Storage.*
it fails to take into account value chain costs. The NEA analysis highlights that if the hydrogen production and consumption profiles do not match, the infrastructure design for hydrogen transport and storage is likely to be inefficient. In particular, in the short term, most of the demand will come from industry, which requires a steady flow of hydrogen and would be best served by a steady production of hydrogen.

The NEA estimates infrastructure costs (e.g. hydrogen transport through pipeline over 200 km and storage in both geological caverns and compressed tanks) for an electrolyser operated in baseload at around USD 0.16 per kgH₂ for a 500 MW_e system that answers a continuous demand. For an electrolyser coupled to a variable production in a similar configuration, infrastructure costs are estimated at around USD 0.77 per kgH₂. In other words, the competitiveness of baseload electricity sources such as nuclear power or the grid improves compared to variable options as infrastructure costs are taken into consideration.

The NEA analysis also highlights possible synergies between nuclear and renewable systems that offer cheap electricity, such as solar photovoltaic (PV). By leveraging nuclear steadiness and solar PV low-cost electricity, such mixed systems optimise both hydrogen costs of production and delivery.

More affordable integrated energy systems

Costs of hydrogen production and delivery do not provide information on the costs of hydrogen integration in the power system. Indeed, a large hydrogen demand, if it is to be satisfied with electricity from the grid, will impact the power system and impose system-level costs – in particular in integrated systems with high shares of variable renewables (VRE). In such configurations the competitiveness of nuclear power must be assessed also through integrated system cost modelling that takes into account the simultaneous interaction, cost and generation profile of each technology.

Take, for example, scenarios (as illustrated in Figure 3) for a highly interconnected country with a varying carbon constraint (25 MtCO₂ and 0 MtCO₂), a varying share of nuclear power in the total installed capacity (constrained nuclear case and unconstrained nuclear case) and different exogenous hydrogen demand levels (0.5 MtH₂ and 1.5 MtH₂). In the constrained nuclear case, new nuclear build is not allowed, whereas in the unconstrained nuclear case nuclear power can expand to minimise system costs. By comparing the constrained nuclear and unconstrained nuclear cases, the value of nuclear power in an integrated power system can be demonstrated.

As integrated energy systems move towards net zero emissions, the role of nuclear power in lowering overall system costs becomes increasingly important. The system cost reduction enabled by nuclear new build increases from 7-11% under the 25 MtCO₂ carbon constraint to 40-50% under the net zero constraint (Figure 3). Indeed, displacing residual emissions is considerably more expensive if only variable renewables and storage are used. Around 190 GW of variable renewables and batteries are thus needed in the constrained nuclear case to meet the net zero carbon constraint, leading to a doubling of the system costs at the electricity grid level compared to scenarios with residual emissions. When nuclear new build is allowed to enter the system, only 30 GW of new nuclear power capacity is needed to displace the remaining emissions. The share of nuclear power that minimises the total costs of the combined power and hydrogen system is here around 40% of the total generation capacity. The resulting electricity mix combines the low plant-level costs of variable renewables with the dispatchability of nuclear power and thus makes it possible to meet a stringent carbon constraint and significant hydrogen production at the lowest cost.

In a net zero scenario, electrolysis is the favoured option to produce hydrogen. The electricity and hydrogen production systems thus become fully coupled and a new set of interactions between them comes into play, affecting overall system costs.

The whole system can take advantage of the ability of electrolysers to accommodate rapid load variations, especially in moments of excess variable renewable generation. This improves overall system flexibility and reduces the cost system gap at higher levels of hydrogen demand (Figure 3). Meanwhile, electrolysis will also increase the need for

Figure 2: The levelised cost of hydrogen delivery (LCOHD) for different production options

Note: LTO = Long-term operation; NA = North America; NB = New build; EU = European Union; ME = Middle East.
baseload electricity, improving first the availability of existing nuclear units followed by the deployment of new nuclear units as hydrogen demand increases. At the systemic level, there is thus a trade-off between the additional flexibility that hydrogen production provides for variable generation from renewables and the need for a stable supply of hydrogen for industrial purposes and the increased utilisation rates of electrolysers provided by dispatchable nuclear generation.

### Hydrogen used for industrial applications further improves nuclear power’s competitiveness in integrated energy systems

By 2035, it is expected that a sizeable share of the low-carbon hydrogen produced will be devoted to decarbonising industrial applications. Industry requires steady flows of hydrogen production, which can be supplied by electrolysers connected to the electricity grid and operated in baseload mode, especially if the hydrogen storage infrastructure is not available at scale. In such configurations, the case of nuclear power at the system level is further improved because the dispatchability of nuclear power allows for steady production of hydrogen, leading to lower power capacity requirements, and more efficient infrastructure designs for hydrogen transport and storage.

Taking as a baseline a scenario with hydrogen demand of 1.5 MtH₂ at net zero carbon emissions, shifting from a flexible to a steady hydrogen demand (i.e., baseload operation for electrolysers) requires an additional 23 GW of variable renewables and batteries at an additional system cost of USD 4 billion per year, or 12% of the total system costs in relative terms. Since the flexibility of electrolysers is hampered by the steady production of hydrogen, the need for batteries, demand response, load shedding and variable renewable curtailment rises rapidly, contributing to this additional cost burden. With nuclear new build, only 4 GW suffice to meet more steady hydrogen demands at an additional system cost that is nine times lower, or USD 0.4 billion per year. These results underscore again the competitiveness of nuclear power to meet steady industrial hydrogen demands.

The scale and dispatchability of nuclear power thus contribute to the cost-efficient design and operation of hydrogen value chains as part of integrated low-carbon energy systems, which will be needed to provide the large amounts of hydrogen required to achieve the objective of net zero carbon emissions by 2050.

### References


While deep geological repositories (DGRs) are the globally preferred and scientifically proven solution to store high-level radioactive waste, many societal questions remain. Given the long time frames associated with DGR development and implementation, and a rise in global interest in nuclear energy to meet urgent climate mitigation targets, building and maintaining human capacity is now even more of a priority.

Human capacity includes, but is not limited to, the transfer of knowledge management and expertise to future generations, alongside greater involvement and encouragement of young people to pursue a career in the nuclear sector, particularly in waste management. Human capacity also relies on trust as a critical component to DGR development. Repository facilities will be unable to operate without the proper social licence from key stakeholders, one that is established and built on trust from the earliest stages of pre-licensing of a DGR and renewed by the generations that follow.

Under the auspices of the Nuclear Energy Agency (NEA), the International Conference on Geological Repositories (ICGR) takes place every four years to bring together high-level decision-makers from government ministries, regulatory bodies, waste management organisations, research institutes and local stakeholders, as well as young professionals and students, to review current perspectives of geological repository development.

The sixth edition of the ICGR was held in Helsinki on 4-8 April 2022. ICGR-6 “Advancing Geological Repositories
from Concept to Operation” highlighted the progress made in DGR development and provided a forum to share current practices. It encouraged international DGR research co-operation initiatives (such as the international use and expansion of underground research laboratories), outlined ways to strengthen trust and confidence throughout the life cycle of DGRs and enhanced involvement of the younger generation in DGR development. Previous editions had been hosted in Denver (1999), Stockholm (2003), Toronto (2012) and Paris (2016).

Hosting ICGR-6 in Finland was timely and served as an important marker of progress for DGRs. As NEA Director-General William D. Magwood IV, underlined, “…the way has been cleared for Finland to build the world’s first commercial DGR. This is a huge milestone for all of us… I think that the global leadership that Finland has shown in this case will benefit the entire world.” More than 250 individuals from over 25 countries participated in the conference, and country-specific progress was highlighted for Canada, the Czech Republic, Finland, France, Germany, Japan, Norway, Sweden, Switzerland, the United Kingdom and the United States.

Almost every country representative emphasised the need to expand and reinforce human capacity in DGR development. Several sessions served to underline that the engagement of young students and professionals is critical to growing human capacity by replacing a highly specialised but ageing workforce. Transferring knowledge between individuals who are moving towards retirement to a younger generation will ensure the smooth handover of a body of information necessary to develop and establish DGRs. This includes dedicated tools, technology and processes. A summary of the NEA’s work, Intergenerational connections in radioactive waste management: involving children and youth (www.oecd-nea.org/FSC-youth), was recently released. This identifies specific objectives and related communications materials tailored to younger age groups (elementary school, secondary, university level and young adults). Engagement from a young age raises interest and understanding of a DGR’s development, and builds trust at the same time.

An entire day of ICGR-6 was dedicated to the younger generation, with presentations from the International Atomic Energy Agency and European Commission on education and career development in the nuclear field along with breakout discussions for young professionals. Some of the key takeaways from these discussions included:

- Addressing the common obstacles to young professionals in the nuclear field: short-term projects and uncertainty in work continuation, lack of funding, negative risk perception, deficiency of technical policy knowledge, and absence of knowledge transfer from older to younger generations, are all holding young people back from entering the field.

- Attracting more young professionals to the nuclear field: provide meaningful work, adequate funding for research, appropriate work-life balance, investment in education and capacity building, communication with the public, and attract qualified individuals from other sectors such as artificial intelligence, disruptive technologies and machine learning.

- Transferring intergenerational knowledge: work more closely together, share offices, network, establish mentoring programmes, expand funding for young professional roles, avoid gaps in work activities, and transfer knowledge to non-STEM groups through education and training.

In addition to attracting young professionals to the nuclear field and expanding opportunities, ICGR-6 participants addressed other ways in which to increase human capacity. Increasing co-operation with academia and research sectors through R&D projects, in co-ordination with implementers and technical support organisations (TSOs), can help in the establishment and review of DGR safety cases. Academia could also provide a platform for either a specialised and/or holistic curriculum on radioactive waste management. This includes opportunities to conduct exchange programmes, open calls for theses, and graduate programmes to expand and evolve human capacity in the nuclear field.

ICGR-6 participants also discussed the importance of increasing the competencies of regulators and implementers. Regulators traditionally encompass three key skillsets: regulatory, technical and behavioural. However, regulators would also benefit from expanded training in public communications and knowledge management to have a more holistic approach to the DGR lifecycle. Implementers must also prepare for human resource challenges in managing long-term DGR projects by remaining an attractive employer. Ways to address this include offering career training and evolution possibilities, providing financially competitive salaries for employees, fostering international
peer networking and mentoring opportunities, assuming corporate social responsibility, and ensuring a proper work-life balance.

One strategic international initiative in building human capacity in radioactive waste management, mentioned on numerous occasions at ICGR-6, is the European Joint Programme on Radioactive Waste Management (EURAD, www.ejp-eurad.eu). EURAD supports the implementation of the European Council Directive to establish a community framework for the responsible and safe management of spent fuel and radioactive waste. EURAD brings together EU member state waste management organisations, TSOs and research entities to support timely implementation of radioactive waste management activities, and serves to foster mutual understanding between participants. Establishing transboundary human capacity is essential, and EURAD certainly contributes to this shared knowledge. While DGRs may be located on one territory, sharing expertise, in particular with countries in the early stages of DGR development, will also build up the all-important human capacity.

Also highlighted at ICGR-6 was a national level initiative from the United States, the Sandia National Laboratories Nuclear Energy Fuel Cycle (NEFC) Knowledge Management Project. Established in 2019, it aims to have senior staff members transfer knowledge to younger staff before they retire. The NEFC Project includes a knowledge management plan, focus groups, workshops, an overview of lessons learnt and a database repository with a formal taxonomy of radioactive waste management work across the United States.

Beyond expanding human capacities, DGR development depends on obtaining a social licence to build such facilities. Safeguarding trust is critical to ensure the continuity of DGRs from concept to operation. The NEA Director-General highlighted that, in terms of DGR operation, “…the biggest challenge is one of public policy, not of science.” Science has proven that DGRs are a safe and reliable way to dispose of high-level radioactive waste. However, as discussed during ICGR-6, buy-in needs to happen at an individual level, not just at the organisational level, for DGRs to be created and to continue to operate.

The NEA Forum on Stakeholder Confidence (FSC) addresses this by providing an environment in which NEA member countries can exchange experiences. The FSC has enabled countries to adapt their policies and provide better communication and engagement strategies with key stakeholders on radioactive waste management. Pascale Küni, Chair of the FSC and Stakeholder Involvement Specialist at the Swiss Federal Office of Energy, cited in her ICG-6-6 session a recent NEA publication on stakeholder confidence, which states:

...trust is related to the behaviour of individuals and organisations; it has to be earned, and it is related to feelings of comfort and liking. Trust can also be defined as the willingness to be or become vulnerable, in order to have the possibility to benefit from some outcome that is not achievable otherwise (Stakeholder Confidence in Radioactive Waste Management. An Annotated Glossary of Key Terms – 2022 Update, p15).

Creating added value for DGRs, engaging and involving local communities in-person and online, communicating uncertainties, and establishing trust are all critical components to the realisation of DGRs.

Based on the success of ICGR-6 in Helsinki, Finland, plans are already underway for ICGR-7, to be held in Seoul, Korea, in 2024. ICGR-7 will provide a forum for the international community to discuss the progress made in establishing deep geological repositories for radioactive waste, in particular in the cases of Finland, France, Sweden and, most recently, Switzerland. It will also showcase the emerging stages of DGR development in Korea, which has the sixth largest nuclear power capacity in the world and approximately 18 000 tonnes of spent nuclear fuel.

Online resources


Further reading

Since the Fukushima Daiichi accident more than a decade ago, many lessons have been learnt that have helped improve preparedness for nuclear emergencies and awareness of the global risks that such accidents can entail. Some of the main lessons concern the multidimensional impacts of the accident, e.g., on health, including mental health and psychosocial support (MHPSS), the economy, or the environment, as well as their long duration (NEA, 2021a,b). These findings are confirmed by experience from other nuclear or radiological emergencies, such as the Chernobyl accident (e.g., Bromet and Havenaar, 2007; WHO, 2005). While the preparedness for immediate nuclear emergency response is well advanced in most countries and is regularly exercised in accordance with international basic safety standards, preparedness for the long-term recovery from such accidents is less developed (Council of the European Union, 2013; IAEA, 2014; 2015). Recently, and in accordance with the experience gained after the Fukushima Daiichi accident, multiple international bodies as well as national governments have started to reinforce their recommendations in the area of long-term impacts and recovery from nuclear and radiological accidents, outlining the need for a harmonised approach towards efficient recovery management (e.g., IAEA, 2018; Health Canada, 2020; ICRP, 2020; WHO, 2020).

The Nuclear Energy Agency has a long tradition of promoting co-operation and assistance among its member countries on preparedness matters related to nuclear or radiological emergencies in the short, medium and long-term. The NEA serves as a platform for sharing and analysing experience in policy, regulation and implementation of the system of radiological protection. One of the recent achievements in this framework has been the development of an operational framework of preparedness for recovery management that could be easily adapted to national conditions. The NEA Expert Group on Recovery Management (EGRM) has produced a report, largely based on experience of long-term recovery issues from the Chernobyl and Fukushima Daiichi accidents, to address these issues.
The report is intended to serve as a reference document to assist countries in developing their national plans and procedures for post-accident recovery preparedness in a harmonised manner.

This article lays out why recovery preparedness should be an important part of preparedness arrangements for nuclear and radiological accidents, and outlines the main features of the EGRM’s framework for preparedness. It looks at the next steps to take to help improve the management of such complex issues.

The importance of preparing for recovery

Recovery from a nuclear or radiological accident is a long, complex and resource intensive process. To facilitate efficient recovery, it is important to establish processes and procedures during the preparedness phase to activate the resources required and to involve the relevant stakeholders at all levels (NEA, 2021a). In that context, preparedness for recovery and emergency response should be co-ordinated to sufficiently consider the impacts of decisions taken during the emergency response phase on long-term recovery and to avoid unexpected consequences. Experience from past nuclear, radiological and non-radiological accidents suggests that a number of difficulties can result from a failure to prepare adequately for recovery, including (NEA, 2018; 2021a):

• confusion regarding roles and responsibilities;
• poor co-ordination between organisations and people on all levels (local, regional, national);
• lack of legislation to facilitate the swift implementation of recovery actions;
• failure to engage with key stakeholders; and
• adverse impacts on health, the economy and the environment.

Failure to prepare for recovery can translate into a lack of leadership and co-ordination at all levels and thus the inability to adapt to the capacity and capability demands of a situation, eventually inhibiting recovery and aggravating the environmental, societal, economic and psychosocial consequences.

Experience from past accidents has revealed long-lasting disruption to the daily life of residents in affected areas and beyond (WHO, 2005; Bromet and Havenaar, 2007; Hasegawa et al., 2015). This can have strong negative effects on the well-being of these people and can lead to a number of health issues, especially mental health and lifestyle diseases, caused by different factors such as disruptions to family relations, stress, lack of confidence, and fears about potential negative health effects (Fukasawa et al., 2017; Murakami et al., 2020; WHO, 2020).

Nuclear or radiological accidents can also have considerable negative economic impacts for individuals and states. These impacts include direct economic consequences due to the cost of decontamination and waste management, impacts on the agricultural and food sector and the stigmatisation and image loss of products or territories. Indirect economic effects such as those from demographic changes and loss of labour force also have the potential to undermine the economic fabric of affected regions (Bachev and Ito, 2014; NEA, 2021a,b; Schneider et al., 2021). In addition, accidents can have considerable and complex immediate and long-term environmental consequences, with negative impacts on ecosystems and natural resources (UNSCEAR, 2020).

To safeguard the health and well-being of people, the economy and the environment during recovery, a number of cross-cutting and topical strategies should be considered as part of recovery preparedness arrangements. These include, for example, food and drinking water management, remediation and waste management, and stakeholder engagement and communication. Each of these strategies can face a number of issues if there is inadequate preparedness for their implementation during recovery.

Post-accident recovery preparedness

The framework for recovery preparedness proposed by the EGRM follows a cyclical approach and can be divided into four main phases: i) the development of a framework for recovery; ii) the definition of recovery objectives; iii) the implementation of these recovery objectives through a number of strategies to achieve and assess the recovery objectives; and iv) the evaluation of the success of these strategies and the improvement of the overall framework through feedback from exercises or lessons learnt from real situations (Figure 1). The recovery objectives are meant to ensure the health and well-being of people, to support the economy and to protect the environment during the recovery process.

The EGRM report divides the process of building a framework for recovery preparedness into three sections, as outlined in Figure 1: 1) key elements of preparedness for recovery management, with a chapter outlining some general requirements to be considered when developing a national framework for recovery preparedness; 2) objectives of recovery, outlining the respective recovery objectives and suggested actions to be undertaken and planned for as part of preparedness; and 3) strategies to achieve and assess recovery objectives, introducing the respective strategies and actions to be taken as part of preparedness for recovery.

The strategies to achieve and assess the recovery objectives can be separated into cross-cutting aspects that need to be holistically considered throughout the process, and topical strategies with a focus on specific sectors or activities. Cross-cutting strategies encompass stakeholder engagement and communication and building resilience. Cross-cutting issues can be considered under the “all-hazards” approach to emergency management. The topical strategies suggested by the EGRM comprise food and drinking water management, remediation and decontamination, waste management, and monitoring and dose assessment.

The EGRM report contains a series of recommendations to help countries create a framework for preparedness for post-accident recovery. Box 1 below includes some key recommendations at the national level.

Box 1: Ten national-level recommendations for preparedness for post-accident recovery

- i) Adopt an all-hazards approach and clarify governance roles.
- ii) Establish indicators of well-being with relevant stakeholders.
- iii) Identify ways to support the economy in affected regions/commodities by addressing the potential loss of image, taking into account the long-term management of the radiological situation.
- iv) Develop a monitoring programme with clear objectives to support dose assessment.
- v) Embed specific post-accident recovery arrangements for the protection of the environment within national policy, strategy and legislation.
- vi) Develop recovery risk communication.
- vii) Develop a programme of exercises to test planning arrangements for recovery management and to build and reinforce resilience.
- viii) Plan for long-term protective actions to reduce or maintain activity concentrations in food products and drinking water below established levels.
- ix) Develop a holistic strategy for remediation and decontamination.
- x) Adopt a proportionate approach to waste management preparedness.
Way forward

Overall, the EGRM has found that the important and complex issue of recovery preparedness for nuclear and radiological accidents needs to be better considered in national and international guidance and regulations. Based on the proposed framework, countries should implement national recovery preparedness frameworks, taking into account national requirements. Other issues identified by the group include the need to conduct recovery exercises to reinforce knowledge and experience in this area. More research is needed regarding economic impacts of nuclear and radiological accidents, long-term mental health and psychosocial impacts and the optimisation of decision-making in response to and after such accidents.

The framework was published in May 2022. To disseminate the main messages developed in the framework, the NEA’s EGRM organised a workshop on 27-28 October 2022. During the event, countries had the opportunity to exchange experiences on recovery management and to update other countries on the status of national recovery management arrangements and regulations. Participants also discussed preparations for the sixth NEA International Nuclear Emergency Exercise (INEX-6), which will focus on the recovery phase. In this context, countries shared their experiences in exercising recovery and discussed the scope of INEX-6, which will potentially be run in early 2024.

References


Ensuring a decarbonised future while maintaining efficient, affordable and reliable energy generation represents one of the major challenges for humanity, and nuclear energy can be an important part of the solution. The growing global need for civil nuclear power is increasing demand for a skilled nuclear workforce. Significant numbers of trained personnel are required, particularly with respect to new builds and to compensate for the ageing workforce. As innovation in nuclear energy and its cross-sector applications grow steadily, new societal implications and challenges must be considered. How to transmit increasingly complex knowledge to the next generation of experts? What to do with nuclear waste? How to balance nuclear with other energy sources? How to foster innovation while maintaining a safe, reliable and sustainable energy source? These questions only touch on the many implications of nuclear energy’s multidisciplinary and complex nature.

To address current and future challenges and develop technologies and innovations that could address them it is necessary to invest in human resources, capacity building and development.

Generally speaking, the sector should focus on three key pillars of action in human resources: attract, train and retain. The NEA has worked with its member countries in these areas by fostering initiatives to invest in future experts’ education and capacity building, and to retain knowledge and stimulate technological innovation through knowledge transfer. The activities in these areas have thrived over the past three years, and the NEA has developed and launched two main initiatives.

First, the Nuclear Education, Skills and Technology (NEST) Framework was launched in 2019 to promote international collaboration around knowledge transfer through hands-on training activities in challenging research projects,
thus targeting the train and retain pillars in human resource development and capacity building. The NEST Framework includes six projects addressing challenges within nuclear energy: hydrogen containment experiments for reactor safety (NEST HYMERES); small modular reactors (SMRs); advanced remote technology and robotics for decommissioning (ARTERD); radioactive waste management of i-graphite, medical applications, nuclear technologies, radioprotection and safety (MANTRAS); and a program on building competence, expert knowledge, applied techniques, safe decommissioning and training fellows (BEAST). These international and multidisciplinary projects offer young nuclear professionals, NEST Fellows, a chance to develop their skill set and acquire practical experience under the supervision of mentors in a leading organisation.

Besides the necessary technical skills, the NEST projects aim to develop also non-technical skills such as the ability to communicate better with society, critical thinking and creativity, teamwork and collaboration, and entrepreneurship and leadership skills. These have been the subject of the NEST SMR Projects for which two large online events were organised in the past two years: the SMR Hackathon held in August 2020 and the SMR Prize Competition held in June-August 2021, which provided great opportunities for students to acquire experience through case studies while discussing with their peers and experts. The NEST SMR Project held its first SMR Workshop in Toronto, Canada, in October 2022. These events allowed more than 84 Fellows to participate and network with peers and leading experts.
These initiatives show that the pandemic did not stop the students and mentors from pursuing their efforts but rather enhanced their resilience and adaptability and offered real-life crisis response training.

Despite the travel restrictions, several NEST Projects were still able to allow physical fellowships to take place. The NEST HYMERES has hosted more than 15 Fellows since 2019. The Fellows acquired skills ranging from designing and building advanced flow instrumentation to running complex containment computational fluid dynamics calculations, all by working alongside mentors at the PANDA Facility at the Paul Scherrer Institute (PSI) in Switzerland. Fellows at PSI noted the high-valued training they received that furthered them in their career choice. Lea Zimmermann, who has moved into a career in industry upon completing her NEST Fellowship, said her mentor was “motivated to pass on his experience, which was very inspiring for me.”

The NEST BEAST Project concluded its first summer school, held in Aachen, Germany, in September 2022, during which 11 NEST Fellows from four organisations in three countries met. During the week-long activity, Fellows had the opportunity to attend lectures and receive practical training in the use of nuclear radiation measurement technology and gamma spectrometry software for the characterisation of radioactive waste or in the usage of nuclear simulation for decommissioning. The NEST Fellows were able to continue their training during the International Conference of Nuclear Decommissioning in November 2022, and to also get to know mentors from industry and regulators. Andreas Havenith, the NEST BEAST Project Leader, said “the professional exchange and discussions showed that young professionals are looking for innovative and efficient solutions for radiological characterisation.”

The value of a multilateral and multidisciplinary initiative like the NEST Framework will become more evident as it evolves and develops its fellowships and activities. It benefits member countries by establishing links and networks between universities and industries, research organisations and regulators, in turn strengthening university programmes.

Universities are important to build the talent pipeline, yet the NEA has so far had little direct engagement with them. To address this, the Agency established in January 2021 the Global Forum on Nuclear Education, Science, Technology and Policy, an inclusive network of experts from academia. The Global Forum aims to provide a platform for sustained co-operation among academic institutions, policymakers and key stakeholders in the nuclear energy sector and civil society. It is governed by a Council of Advisors, made up of 40 representatives from 20 academic organisations and 13 countries, and aims to provide creative solutions to some of the challenges the sector faces, with a particular focus on human resources and capacity building. Four priority areas were identified: gender balance, the future of nuclear education, the relationship between the nuclear energy sector and society, and the role of innovation in the nuclear sector. Each area will be led by a working group. By convening leading nuclear experts from the contributing countries, these working groups are the bodies through which the Global Forum can deepen co-operation in the nuclear sector and implement good practices.

Initial discussions have taken place over the past year and some early proposals have been advanced. To attract more students, the nuclear sector needs to address issues related to nuclear education, including: improving the curricula and making them more multidisciplinary; developing complementary training to enrich educational programmes; increasing cross-border co-operation and student exchanges; creating tools to improve the perception of nuclear energy in society; and instilling a culture of innovation from an early stage in nuclear curricula.
In an effort to promote the nuclear sector as a career choice for new students, Global Commencements have been conducted under the auspices of the Global Forum. To date, three events have taken place between 2020 and 2022. Each event featured renowned speakers debating, among other things, the role of early-career nuclear graduates in addressing climate change as well as the role of nuclear in servicing society.

The 2022 Global Commencement featured a keynote message from Bill Gates who, speaking in his capacity as Chairman of the Board of TerraPower, encouraged students and graduates to pursue nuclear science and engineering degrees and contribute through scientific breakthroughs to the improvement of lives around the world. The role that young nuclear professionals can play in society was also debated in a panel discussion with students and professionals moderated by Bret Kugelmass, CEO of Last Energy and Managing Director of the Energy Impact Center. All agreed that nuclear energy can contribute to many fields including medicine, agriculture and space exploration as well as the biggest challenge society is facing today, climate change. It will be up to new generations of professionals to rapidly develop the nuclear innovations in order to deliver the required solutions.

A student competition was also launched to showcase different perspectives from around the world on how nuclear energy can help society and how new professionals can contribute.

At the national level, a Global Forum Workshop on Nuclear Education was held in Japan in July 2022. The workshop brought together leading academics from Japan as well as government and industry stakeholders to explore key issues and provide new perspectives on the relevance, attractiveness, stability and support of nuclear education programmes. Addressing the challenges for nuclear education calls for closer co-operation among all stakeholders – academia, government, industry and international organisations – to establish an innovation ecosystem and to encourage students to pursue careers in nuclear energy.

Creating opportunities for exchange among stakeholders will be crucial for the nuclear sector’s success. In this context, the NEA participates in events organised with partners and stakeholders, such as NESTet (Nuclear Education and Training), which was held in November 2021 in Brussels, or the International Conference on Fast Reactors and Related Fuel Cycles: Sustainable Clean Energy for the Future (FR22), held in April 2022 in Vienna.

Technological progress is not solely a matter of research and development, but can also entail new societal concerns that can inhibit their application. At a time when the risk of knowledge loss appears to be growing, the need to address and anticipate challenges in this area will be key to achieving success in the nuclear field. Multilateral initiatives such as NEST and the Global Forum have been designed to respond to these challenges.
Scenarios for Switzerland to achieve net zero emissions in 2050: An NEA system cost analysis

by J. H. Keppler, A. L. Mazauric

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Switzerland aims to reach net zero carbon emissions by 2050, and while there is consensus across government and society to achieve this ambitious objective, the discussion about the appropriate generation mix to realise it remains ongoing.

In an innovative form of co-operation, the NEA has worked with Switzerland to analyse the system costs of different low carbon electricity generation mixes. On the basis of earlier work (NEA, 2012; NEA, 2019), the NEA developed a tool, the POSY model, that allows it to evaluate the total costs of low carbon energy system with different shares of nuclear energy and variable renewable energy (VRE) technologies such as wind and solar PV with a high degree of technical realism. It made the POSY model available to the study of Switzerland as part of an initiative by the NEA to study the system costs of low carbon power mixes.

The NEA report that resulted from this co-operation studies the system costs of different scenarios under which Switzerland would achieve net zero in 2050. A key feature differentiating the scenarios is the relative contribution of existing nuclear power plants and variable renewables (VRE), in particular solar PV, to the electricity supply in 2050.

1. Achieving Net Zero Carbon Emissions in Switzerland in 2050: Low Carbon Scenarios and their System Costs was launched at an NEA webinar on 27 October 2022 and is available on the NEA website at www.oecd-nea.org/7631.
The Swiss energy sector

As one of the NEA member countries with the lowest carbon emissions, Switzerland is well positioned to achieve its objective of net zero carbon emissions. Its main assets in this quest are a large endowment of hydroelectric resources and a high degree of interconnection with its European neighbours, allowing for high levels of exports and imports. However, the Swiss energy sector is not devoid of challenges.

Key questions pertain to the role of nuclear energy, the degree of interconnection with neighbouring countries and the evolution of demand. Switzerland voted in 2017 to no longer allow the construction of new nuclear power plants. Nevertheless, a preceding referendum in 2016 rejected proposals to limit the lifetime of existing nuclear power plants. As regards interconnection with neighbouring countries, a formal electricity agreement with the European Union remains elusive, even if it can be expected that due to its geographic location and the flexibility provided by its hydroelectric resources, Switzerland will remain integrated with European electricity markets. Finally, as regards the market outlook, demand for electricity in Switzerland is expected to be higher in 2050 due to both additional demand for energy services and higher needs of the energy sector itself due to increased charging of reservoirs and batteries as well as hydrogen production.

The current low carbon intensity of the Swiss electricity sector is due to high shares of hydroelectricity and nuclear energy, alongside a small share of solar PV and wind in the generation mix. Residual emissions are due to a number of small, decentralised cogeneration plants for both industrial and domestic electricity and heat consumption (see Figure 1).

Hydroelectric reservoirs and pump storage units provide flexibility. Nuclear power plants and run-of-the-river plants instead operate as baseload producers. Nuclear energy is Switzerland’s second largest source of electricity, contributing 13% of its capacity and 29% of its electricity. In 2022, nuclear energy was produced by four reactors, Beznau 1 and 2, Gösgen and Leibstadt. For the time being, the contribution of non-hydro renewables to electricity generation is modest. However, several studies including the Energieperspektiven 2050+ commissioned by the Swiss Energy Ministry foresee the addition of significant amounts of variable renewable energy capacity until 2050 (Prognos et al., 2021).

Modelling system costs under a net zero carbon constraint with the NEA POSY model

Accounting for the system costs of different generation mixes in order to attain ambitious net zero carbon emission objectives is indispensable for informed energy decision-making. System cost analysis was developed to offer a more comprehensive view than cost accounting based on the levelised costs of generating electricity (LCOE) at the plant level, which provided a simple and transparent tool to compare the lifetime costs of different baseload generation technologies, in particular, in regulated systems.

While LCOE accounting provided an intuitive starting point for more complex cost assessments, it does not provide a satisfying tool for systems with significant shares of electricity generated by variable renewable energies (VRE), such as wind and solar PV. The latter’s variability requires adopting a system perspective. No matter how much solar PV capacity is installed, dispatchable capacity is required to meet electricity demand at night. That dispatchable capacity, however, will run at lower load factors and hence higher average unit costs, raising the costs of the system.

Figure 1: Installed capacity and generation mix in 2021 (GW and TWh)

Note: PV = photovoltaic; CHP = combined heat and power.
as a whole. In the language of system cost analysis, this is referred to as profile cost, and it is by far the largest component of electricity system costs. On top of these are balancing costs, which arise from the uncertainty rather than the variability of electricity generation, grid costs in the form of added outlays for transport and distribution, which can be significant for decentralised renewables, and connection costs, to connect a power plant to the nearest bus of the transmission grid.

System cost analysis requires the use of advanced electricity sector models. This regards in particular models that use mathematical techniques such as linear programming (LP), and mixed-integer linear programming (MILP) to solve the cost minimisation problem involved in jointly optimising long-term capacity investment and short-term dispatch. Standard linear programming solves problems in which the functions, for instance the production of a generation plant, are linear. MILP models instead can work with variables that are constrained to take on integer values, typically that a plant can or cannot run under a given technical constraint. MILP is thus designed to solve far more complex problems than regular LP and substantially increases the technical realism of the electricity system studied.

The POSY MILP model was developed within the NEA to allow the assessment of the system costs of different mixes of integrated low carbon systems. With 8 760 time-steps per year, it has an hourly representation capable of capturing profile costs. The strength of this modelling effort is based, in particular, on a careful representation of the Swiss electricity system established in co-operation with experts from the electricity industry and academia.

The system costs of different net zero scenarios in 2050 in Switzerland

Switzerland’s large hydroelectric capacity and high level of interconnections for electricity trading provide a solid foundation for any effort to reach net zero carbon emissions in 2050. Hydroelectricity and imports alone, however, will be unable to fulfil all low carbon electricity needs, in particular as transfers from sectors such as heating and transport will increase. The key energy policy question is then, “Which low carbon technologies will provide the remainder of electricity supply”? Below are presented two viable and policy-relevant scenarios that could allow Switzerland to attain net zero carbon emissions while safeguarding the security of electricity supply. Three additional scenarios have been added for comparison purposes. Each scenario is analysed with different levels of interconnection capacity, which remains a crucial determinant for the total system costs of the Swiss electricity sector.

- The LTO (long-term operation) scenario assumes that in addition to the existing hydro capacity, Switzerland will dispose of 2.2 GW of nuclear capacity from the LTO of the two nuclear reactors at Gösgen and Leibstadt. In addition, the POSY model assumes as much solar PV and wind capacity as required, complemented by the necessary flexibility resources.
- In the VRE only scenario, the POSY model assumes – in addition to existing hydroelectric facilities – only solar PV and wind capacity, as well as flexibility resources, to satisfy the supply constraint. Given the realities of the Swiss policy debate, solar PV was assumed to contribute 90% of VRE generation and wind 10%.
In terms of the capacity mix (Figure 3), the high shares of solar PV and wind in the generation mix increase total capacity due to their comparatively low load factors. This may make land use a potential issue in the Swiss energy debate. In addition, in the autarchy scenario, the absence of interconnection capacity as a flexibility resource requires the adoption of new flexible capacity such as demand response or batteries. Their additional costs provide a first indicator of the stress to which the Swiss electricity system would be subjected in the autarchy scenarios.

Switzerland currently enjoys a secure, low carbon electricity system. The reliability of its baseload nuclear power and run-of-the-river hydropower plants, as well as its large interconnection capacity, allows flexible hydro reservoirs and pump storage units to engage in profitable electricity trading with its neighbours. In this context, the NEA system costs study leads to three conclusions based on a transparent and sound methodology to achieve net zero carbon emissions by 2050.

Note: LTO = long-term operation; VRE = variable renewable energy; ROR = run-of-the-river; PV = photovoltaic; CHP = combined heat and power.
First, scenarios built on a generation mix of renewables and nuclear baseload have consistently lower system costs than scenarios based exclusively on variable renewables such as solar PV and wind.

Second, Switzerland’s high level of domestic flexibility resources renders a VRE only strategy technically feasible, though more expensive, as long as the interconnection capacity allowing for electricity trade with neighbouring countries remains at today’s levels.

Figure 4 summarises the total system costs of different scenarios grouped along two axes, the amount of nuclear generation capacity and the degree of interconnection between Switzerland and its neighbours. It shows that higher degrees of interconnection always reduce system costs and that the LTO of Switzerland’s two newest nuclear power plants is the most cost-effective solution in terms of the contribution of nuclear power to achieving net zero.

The third conclusion is that a VRE only strategy to reach net zero in 2050 in autarchy would not only be very expensive but would also move the Swiss system away from security of supply resilience, despite the high level of Swiss domestic flexibility resources.

These three key results developed on the basis of reasonable assumptions and a sophisticated modelling tool appear robust. They will serve as parameters for the energy policy debates that Swiss politicians, energy decision-makers, stakeholders and consumers will need to have in the years to come to achieve a net zero target by 2050 while also preserving current levels of security of supply and economic efficiency.

References


NEA summer schools are back in person

by K. Nick and J. H. Kruse

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The NEA’s International School of Nuclear Law (ISNL) and the International Radiological Protection School (IRPS) were held in person this summer for the first time since before the COVID-19 pandemic, bringing together dozens of students and professionals from around the world.

The ISNL was held from 22 August to 2 September at the University of Montpellier in the south of France. Over 10 days, 56 graduates and professionals from 38 countries strengthened their understanding of the legal framework and major topics related to the peaceful uses of nuclear energy.

The safe, efficient and secure use of nuclear energy is supported by a complex body of international laws and legal regimes that uphold and enforce all aspects of nuclear safety, security, safeguards and liability. In 2001, the NEA established the ISNL in co-operation with the University of Montpellier to create an educational programme that offers an in-depth look at international nuclear law.

NEA Director-General William D. Magwood, IV, was present to welcome the new students and emphasise the critical role that nuclear law plays.

“The ISNL has been the central training ground for nuclear law practitioners since 2001, now with more than 1,200 alumni from 100 different countries around the world, representing different nationalities, diverse age groups and levels of education and experience,” said Director-General Magwood.

“The nuclear energy industry has reached a pivotal moment, with the role that it can play in helping governments to reach net zero targets at the forefront of international discussions. Legal frameworks are essential to the responsible deployment of safe, clean nuclear energy and we are proud of our collaboration with the University of Montpellier in developing the next generation of nuclear professionals.”

The ISNL’s programme consisted of lectures, group assignments and panel discussions. These classes touched on all aspects of nuclear law, including nuclear safety, environmental protection, transport, nuclear security, non-proliferation, safeguards, nuclear liability, international trade and management of spent fuel and radioactive waste. In addition, the ISNL ensured that participants had the opportunity to network with their new classmates and to discover Montpellier and its surroundings through social events, city tours and a graduation ceremony.

Since 2011, the programme has been led by Paul Bowden, Honorary Professor of Law at the Nottingham Law School and former partner of Freshfields Bruckhaus Deringer. The programme was delivered by around 30 specialists in nuclear law from international organisations, governments, academia and private industry.

The NEA awarded grants to a select number of graduate students from its member countries, and the International Atomic Energy Agency (IAEA) supported the programme by awarding financial support to a number of professionals from its member states. In addition, the IAEA provided lecturers from its Office of Legal Affairs.

Many participants will continue their studies by completing an examination and a written dissertation, with the intention of applying for the University Diploma in International Nuclear Law from the University of Montpellier.

The International Radiological Protection School, meanwhile, was held on 22–26 August at Stockholm University, Sweden, with 52 participants from 26 countries, both in person and online.

With the growing use of ionising radiation and nuclear technology over the last century, experts have worked to establish a system of radiological protection (RP). The experts who helped establish a global framework of guidance, standards, recommendations and best practices are also involved in applying this framework in their home countries. Today, many of these senior experts are either close to retirement or have retired, making it important to preserve their knowledge and pass it on to the next generation.

In this context, the IRPS was created in 2018 in partnership with the Swedish Radiation Safety Authority and Stockholm University’s Centre for Radiation Protection Research. Its mission is to outline the nuances and history of international guidance and working experience that will allow the next generation of experts to appropriately apply the radiological protection system in diverse and newly emerging circumstances, and to show how it is evolving.

“This course has evolved to become something special,” Director-General Magwood told the participants via video link. “It is not just learning about what we do in assuring radiological protection, but why we do it. Having the opportunity to engage with highly accomplished global experts and having dialogues with them on the radiological protection system will provide understandings and insights that will become more important in the future as the system continues to evolve.”

Over the 5-day programme, participants attended lectures from 23 global experts and joined workshops, Q&A sessions, quizzes and practical case studies. The scenarios gave the students the opportunity to propose solutions to hypothetical challenges in radiological protection regulation and implementation and to receive feedback from their mentors.

Prior to the IRPS on-campus week, participants were invited to join a dedicated online learning platform that introduced them to some of the lecturers and helped them in their course preparations.

More than 100 applications were received for the 2022 session, underlining the growing interest in the programme.
FIDES: Meeting the need for irradiation experiments

by T. Ivanova, M. Bales, M. Beilmann, R. Furstenau, G. Bignan, O. Marchand, D. Wachs

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The closure of several nuclear research reactors, particularly the Halden Reactor in Norway in 2018, revealed the vulnerability that comes from consolidating in-pile nuclear fuel and materials research at a handful of facilities. The NEA Framework for Irradiation Experiments (FIDES) was born from the need to provide continuity of research capabilities following the Halden closure, diversify the portfolio of in-pile facilities available for joint research, and safeguard the knowledge required to conduct nuclear fuel and materials research.

FIDES was launched in March 2021, connecting more than 20 participant organisations from regulatory bodies, technical support organisations, utilities, fuel vendors and research institutes. FIDES is designed to execute high-priority experiments on a cost-sharing basis, but also to focus on three key areas to enhance research outcomes: integration of modelling and simulation; data preservation and quality assurance; and training and education. The framework is already delivering on this ambitious vision.

In the area of experiments, the initial FIDES programme of work covers a wide range of research needs under Joint Experimental Programmes (JEEPs): fast power transients (HERA), slow power transients (P2M), loss-of-coolant transients (LOCA MIR) and steady-state conditions (INCA). Experiments will use advanced fuel designs including gadolinium-doped fuels (LOCA MIR), coated claddings (INCA) and high burnup fuel (HERA and P2M).

Regarding modelling and simulation, two JEEPs are enhancing their experimental planning through modelling and simulation exercises. Within P2M, experimenters have collaborated with over 40 modelling experts in an exercise using archive data to assess their code’s ability to predict fuel melting. Through analysis of their results, experts have improved understanding of the boundaries of existing models and generated ideas regarding experimental and examination needs that could improve modelling of fuel melting behaviour. Within HERA, experimenters are also looking to gain insights from blind predictions of the planned experiments to finalise the details of their experimental protocol.

On the subject of training and education, FIDES research facilities have organised specialised training on experimental methods. In addition, interns and students are being integrated into both experimental activities as well as modelling exercises.

Finally, in the area of data preservation, FIDES participants are considering how to establish quality assurance processes and revitalise the International Fuel Performance Experiments (IFPE) repository to meet their needs.

FIDES participants are working to produce a 10-year strategic plan to define key research needs for the industry and safety authorities in a variety of technical disciplines. This strategic plan will help participating organisations see how to best utilise a portfolio of research facilities that can operate simultaneously within the framework. The organisations will define experimental priorities and consider the demands brought by advanced modelling and simulation to innovate experimental instrumentation and post-test examination, all while maintaining a focus on the sustainability of the research infrastructure.

Participating organisations set up FIDES remarkably quickly, taking just a few years to move from preliminary discussions on the framework and starting irradiations in research reactors. But the conversation among stakeholders is not unique. The NEA continues to offer forums for stakeholders to come together to define and collaborate on the research infrastructure needed to support the nuclear community. Within the Committee on the Safety of Nuclear Installations (CSNI), the Senior Expert Group on Safety Research/Support Facilities for Existing and Advanced Reactors 2 (SESAR/SEFAR2) engaged experts to define their needs and, under the Nuclear Science Committee (NSC), delegates have recently acknowledged the importance of sustaining experimental capacities of zero power reactors and have formed a task force to define their experimental needs.
Enhancing networking in research and communication on low dose research

by J. Garnier-Laplace, D. Laurier, V. Chauhan, D. Klokov, J. H. Kruse, P. Locke, N. Priest, K. E. Tollefsen

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The effect of exposure to low dose radiation on the health of humans and ecosystems is among the most sensitive issues in international radiological protection due to the adoption of the so-called Linear Non-Threshold (LNT) model. This model remains controversial because of scientific uncertainties in the area of low dose/low dose-rate health risks. The uncertainties arise largely from assumptions needed to apply the LNT model to domains that differ from the one from which it was created: the Life-Span-Study (LSS) of A-bomb survivors in Hiroshima and Nagasaki. Interestingly, recent epidemiological studies support the continued use of the LNT model for radiological protection.

Considerable research has been undertaken, and continues worldwide, with national and regional funding organisations giving high importance to this topic. The aim is to improve the evidence and mechanistic understanding of the human and ecosystem health effects that might be caused by exposure to low radiation doses (i.e. less than 100 mGy or 0.1 mGy/min).

Within this framework, the NEA supports the development of a global networking initiative through its Committee on Radiological Protection and Public Health (CRPPH). The High-Level Group on Low-Dose Research (HLG-LDR) was formally launched in June 2021 as a cornerstone of ongoing work. The group believes it is possible to reduce uncertainties surrounding low dose/low dose-rate health risks by advancing research strategically, ensuring better use of results in policymaking, and improving the way research findings and policies are communicated to stakeholders. The group aims to facilitate global networking of low dose research funding organisations and research-implementing organisations through three key activities.

First, the HLG-LDR has developed a global register of low dose/low dose-rate research projects covering the sciences supporting radiological protection (e.g. radiobiology, ecotoxicology, epidemiology, dosimetry, social sciences). The register constitutes the first user-friendly tool of its kind to catalogue such projects, giving them visibility, promoting collaboration, and ultimately optimising research by keeping governmental bodies (e.g. technical support bodies, regulators and public funding agencies) informed of research progress and funding needs. The online version of the global registry is restricted to HLG-LDR members but will be opened to all in 2023.

The second activity is to explore the benefits of the Adverse Outcome Pathway (AOP) approach for radiation research and possibly, in time, regulatory implementation. The AOP framework, developed by the Organisation for Economic Co-operation and Development, helps to structure published evidence on mechanisms of toxicity from early molecular interaction to disease and other adverse health effects development. It is envisioned that radiobiological data can be better organised to improve understanding of health risks at low doses and dose rates. A horizon-style exercise was conducted in 2021-2022 to measure the radiological protection community’s knowledge of, interest in and hesitation to using the AOP approach. Over 250 questions were received and prioritised into 25 key issues that, if answered, could improve the description of radiation dose-response relationship for low dose/dose-rate exposures, as well as reduce uncertainties in estimating the risk of adverse health outcomes following such exposures. Other initiatives, such as working on case studies to demonstrate AOP development and use, continue in parallel.

The third activity is the development of a policy-oriented strategy to define the issues in the low dose area that would benefit from clearer communication, to identify tools to make communication more effective, and to find how to translate technical results into policy-oriented messages. It is believed that these activities will contribute to creating a fast track between research results and science-based policymaking.

The three activities of the HLG-LDR are unique at the international level. Each seeks to fill gaps in our knowledge concerning the effects of low dose radiation and contribute to the science underpinning the international radiological protection system, as well as to overall radiological protection policy, regulation and implementation.
In Memoriam: Donald Johnston (1936-2022)

It is with deep sadness that the NEA community learned of the passing of the Honourable Donald Johnston, OECD Secretary-General from 1996 to 2006.

During a career spanning over six decades, Donald Johnston made deep contributions to the fields of law, politics and international affairs. It was under his leadership that the OECD was transformed. A multi-talented professional, Johnston was as comfortable discussing public policy as he was at the piano.

Born and raised in rural Ottawa, Canada, Johnston attended McGill University, first as an art student, then transferring to its Law School in 1956. Upon graduating in 1958, he cofounded a law firm, Johnston Heenan Blaikie, which eventually became one of Canada’s largest corporate law firms. Through his work on taxation strategies, he was highly involved in the development of the Canadian film industry in the 1970s. He first met future Canadian Prime Minister Pierre Trudeau in 1957 and subsequently became his personal lawyer. Prior to his involvement in Canadian politics, Johnston taught fiscal law at McGill University from 1963 to 1976.

Johnston’s political career as a Member of the Canadian Parliament spanned from 1978 to 1988, during which time he held various Cabinet positions, first as President of the Treasury Board and then as Minister of State for Economic and Regional Development and Minister of Science and Technology under Trudeau from 1980 to 1984. When Trudeau retired in 1984, Johnston ran for Prime Minister, coming third behind John Turner and Jean Chrétien. He then served as Minister of Justice and Attorney General of Canada under Turner. Johnston was elected President of the Liberal Party of Canada in 1990, a role he held until 1994.

When Jean Chrétien became Prime Minister in 1993, he supported Johnston’s nomination to head the OECD. In 1996, Johnston became Secretary-General for the first of two five year runs, the only Canadian and first non-European to hold the title since the OECD was established in 1961.

During his tenure, he focused on modernising the organisation, with the OECD developing standards of corporate social responsibility, establishing the Principles of Corporate Governance and revising the Guidelines for Multinational Enterprises. The OECD facilitated the correction of harmful tax practices, while at the same time fostering sustainable development. With the aim of establishing metrics to compare international education, Johnston created the Education Directorate, which developed the Program of International Student Assessment (PISA), now a leading reference for international educational comparison.

NEA Director-General William D. Magwood, IV writes, “Don Johnston helped make the OECD a more efficient and effective organisation. He was a great supporter of the NEA’s work during his tenure. I first met him in 2004, at which time he personally advocated bringing the Generation IV International Forum to the NEA. He remained in touch over the years, often commenting on progress made by the NEA in areas related to nuclear energy and most recently recommending a promising student to serve as an intern with the Agency.”

Johnston stepped down from his position at the OECD on 31 May 2006, at which point he rejoined Heenan Blaikie as a member of the International Business Law Group.

He was chair of the McCall-MacBain Foundation in Geneva from 2007 to 2017. From 2006 until 2010, he was also chairman of the International Risk Governance Council (IRGC) in Geneva. And from 2006 to 2009, he was a distinguished visiting professor at Yonsei University in Seoul, Korea.

Johnston was awarded numerous distinctions for his work. As well as being made a member of the Queen’s Privy Council for Canada and the Queen’s Counsel, he was appointed an Officer of the Order of Canada for his contributions to public service and his achievements at the OECD.

He was awarded France’s Légion d’honneur, the Grand Cordon of the Order of the Rising Sun by Japan, and similar honours by Belgium, Hungary and the Slovak Republic. He also received honorary degrees from universities in Canada, the United Kingdom and Slovakia.

During his career, he wrote many articles on taxation, law and public affairs as well as several books, including a popular political memoir. Johnston was also a passionate pianist and composer. He notably composed a piece called Montreal, Montréal, which was arranged and played by the McGill Symphony Orchestra in 2019.

Described by former colleagues and students as a consummate professional, straight talker and dependable friend, Johnston will be remembered for the impact he had both in his fields of work and on the people who knew him.
the share of nuclear reactors used for district heating, desalination or other forms of non-electric applications of nuclear energy such as industrial heat applications and residential heating, which both continue to run mainly on fossil fuels. More than 65 nuclear reactors around the world have a significant role in avoiding carbon emissions. It has the potential to decarbonise the global energy sector even further by also providing heat for industrial applications, residential heating, and electricity generation. In order to further reduce carbon emissions, the share of nuclear reactors used for cogeneration needs to be expanded. However, until recently the economic competitiveness of thermal energy produced by nuclear power plants has been a challenge. Not accounting for climate change impacts, heat produced by gas- or coal-fired power plants has been cheaper. Yet, as fossil fuel prices rise and carbon costs are increasingly accounted for, the economics of nuclear cogeneration begin to look more favourable. A good understanding of the technical realities and economics of nuclear cogeneration, including its implications for electricity and energy systems, is essential to take advantage of this changed environment. This NEA report provides a thorough overview of nuclear cogeneration, with a view to helping energy decisionmakers and interested experts in assessing the costs and benefits of having nuclear energy provide both low-carbon electricity and low-carbon heat. Realising the contribution of nuclear energy to achieving net zero carbon emission in 2050 will require raising significant amounts of capital at competitive rates. On the basis of work under the aegis of the Nuclear Energy Agency (NEA) – International Framework for Nuclear Energy Cooperation (IFNEC) Initiative on Nuclear Financing, this report explores new frameworks for analysing the cost of capital for nuclear new build projects. Its key insight is that capital costs can be substantially lowered if the different risks pertaining to such projects such as construction risk, price risk or political risk are properly understood, optimally managed and fairly allocated. In a carbon-constrained world, the true capital costs of nuclear energy and other low-carbon generators will also be lower than customarily assumed due to their ability to offset systemic financial risk. The findings of this report apply equally to private and public investments. Governments nevertheless have important roles to play in ensuring credible net zero commitments, implementing frameworks for optimal risk management and by becoming involved as project participants, in cases where they judge that private actors do not realise the full value of a nuclear power project. Reducing industrial carbon emissions is one of the most difficult challenges on the path to net zero by 2050 due to the magnitude of greenhouse gas emissions from the industrial sector and technical requirements for heat in addition to power. High-temperature gas-cooled reactors (HTGRs) are a promising Generation IV nuclear technology that can supply process heat for a variety of industrial applications. The Nuclear Energy Agency investigated the potential and limitations of HTGRs for industrial heat applications. This study reviews the technical features and development status of HTGRs as a low-carbon heat source and explores how this technology could meet the process heat requirements of different industrial processes. It revealed the potential industrial applications of HTGR heat in the near term as well as further opportunities in the medium to long term while identifying the remaining challenges for the industrial deployment of this technology. All credible models show that nuclear energy has an important role to play in global climate change mitigation efforts. Despite clear analyses from many sources, including the NEA, that point to the need for a massive, “all-the-above” approach that includes nuclear energy, some multinational activities, financial institutions, and policy-makers avoid discussion of nuclear energy.
This dynamic is deeply problematic to the cause of carbon reductions. All low-carbon technologies, including nuclear energy, must be included in relevant discussions about the energy transition in order to maintain the integrity and evidence base of the policy dialogue. Without a significant contribution from nuclear energy, the prospects for meeting Paris targets will be significantly lower.

New analysis by the NEA identifies the potential contribution of nuclear energy to clean energy capacity and emissions reductions between 2020 and 2050, taking into consideration the potential contributions from power and non-power applications of nuclear technologies. Taken together, the contributions of long-term operation, new builds of Generation III nuclear technologies, small modular reactors, Generation IV systems, nuclear hybrid energy and hydrogen systems begin to reveal the full extent of the potential for nuclear energy and nuclear innovations to play a significant and growing role in pathways to net-zero by 2050.

The NEA estimates included in this report are not forecasts but represent what can be achieved with timely enabling decisions.

Net Zero Carbon Emission in Switzerland in 2050: Low Carbon Scenarios and their System Costs
NEA No. 7631. 132 pages.
Available online at: https://oe.cd/4KO
With an electricity system defined by high shares of hydropower, large capacity for interconnection with its neighbours and low carbon intensity, Switzerland is well positioned to attain its objective of net zero carbon emissions by 2050. However, the exact pathway remains the subject of discussion. First, what should the shares of nuclear energy and variable renewable energies such as solar PV and wind be in the energy mix? Second, what degree of electricity trade should Switzerland have with its European neighbours? New system modelling of different energy policy choices with the Nuclear Energy Agency’s POSY model shows that all considered scenarios are technically feasible. However, relying on variable renewables alone or decoupling Switzerland from neighbouring countries could increase total system costs by up to 250%. Instead, continuing to operate Switzerland’s newest nuclear power plants alongside existing hydropower resources, while maintaining interconnection capacity at current levels, emerges as the most cost-effective option to achieve net zero emissions in 2050. Ample data and technical documentation of a least-cost mixed integer (MILP) modelling with hourly resolution are also provided in order to allow replication, extension and discussion of this study’s findings.

Nuclear Energy Data 2021/Données sur l’énergie nucléaire 2021
NEA No. 7608. 72 pages.
Available online at: https://www.oecd-nea.org/jcms/pl_69894/nuclear-energy-data-2021
Nuclear Energy Data is the Nuclear Energy Agency’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 2040, where available. Country reports summarise energy policies, updates of the status in nuclear energy programmes and fuel cycle developments. In 2020 and 2021, the COVID-19 pandemic has highlighted the importance of electricity security in modern societies. Although the long-term implications for electricity generation are difficult to assess, during the crisis nuclear power continued to support the security of supply and has been, together with renewables, one of the most resilient low-carbon electricity sources. Governments committed to having nuclear power in the energy mix advanced plans for developing or increasing nuclear generating capacity, including plans for small modular reactor and advanced reactors. Further details on these and other developments are provided in the publication’s numerous tables, graphs and country reports. This publication contains “StatLinks”. For each StatLink, the reader will find a URL which leads to the corresponding spreadsheet. These links work in the same way as an Internet link.

The Role of Nuclear Power in the Hydrogen Economy: Cost and Competitiveness
NEA No. 7630. 88 pages.
Available online at: https://oe.cd/4OD
Hydrogen is expected to play important roles in decarbonised energy systems, as an energy source for otherwise hard-to-electrify sectors as well as a storage vector to enhance power system flexibility. However, hydrogen is not a primary energy resource and has to be produced using different chemical processes. Water electrolysis, which uses electricity to split water molecules to extract hydrogen, is expected to become a leading solution in this context. Electrolysis will, however, only be a feasible solution if the electricity used as feedstock comes from low-carbon sources. A significant number of countries are therefore considering a role for nuclear energy in their hydrogen strategies.

This report provides an assessment of the costs and competitiveness of nuclear-produced hydrogen across the hydrogen value chain and explores the impacts of hydrogen production on the overall costs of integrated electricity and energy systems. It shows, in particular, that nuclear energy can be a competitive source to produce and deliver low-carbon hydrogen for centralised industrial demand. The large scale and dispatchability of nuclear power can also improve the cost-efficiency of hydrogen transport and storage infrastructures, and reduce the overall costs of the energy system.
This report from the NEA Working Group on Human and Organisational Performance establishes a common understanding around the terms human performance (HP), organisational performance (OP), and human and organisational factors (HOF) through a simple model. The model presented illustrates the strong inter-relationship between the terms. It shows that HP includes both human activities and the results of these activities. HOF are the factors which have influence on HP in a positive or adverse manner in a given situation. They can be categorised as human-, technology- and organisation-related factors which are themselves under continuous interaction with each other. The report highlights the need for all managers to develop an understanding that the continuous application of a systemic approach is required to establish and sustain an effective management system and to foster safety culture.

This 29th Annual Report of the International System on Occupational Exposure (ISOE) presents the status of the programme for the year 2019. As of 31 December 2019, the ISOE included 76 participating licensees (348 operating units; 69 shutdown units; 11 units under construction and/or commissioning) and 28 regulatory authorities in 31 countries, and the ISOE database contained occupational exposure information for more than 500 units, covering over 89% of the world’s operating commercial power reactors. This report includes a global occupational exposure data and analysis collected and accomplished in the year 2019, information on the overall programme events and achievements as well as principal events in participating countries.

The transition from nuclear power generation to decommissioning carries a number of safety challenges tied to human and organisational factors. This report discusses these challenges and brings together the experiences of members of the NEA Working Group on Human and Organisational Factors. It includes an overview and topical case studies from global decommissioning activities and sums up the good practices and lessons learnt to help organisations in their own endeavours to decommission nuclear installations. This report can be used as a guide for self-assessment for both licensee organisations and regulatory bodies to manage the human and organisation factors in the various phases of their decommissioning activities.

Nuclear safety and regulation

A variety of new phenomena were identified for the examined ATF designs which challenged the applicability of existing performance metrics and analytical limits or created the need for new criteria. Recommendations to address these challenges are provided with the intention to inform future international research programmes and support ATF licensing.

One of the key areas in fuel safety is the analysis of fuel behaviour under reactivity-initiated accident conditions. Reactivity-initiated accident fuel rod codes have been developed for a significant period of time and they all have shown their ability to reproduce some experimental results with a certain degree of adequacy. However, they sometimes rely on different specific modelling assumptions whose influence on the final results of the calculations is difficult to evaluate. This report summarises three phases of benchmark conducted by the NEA between 2010 and 2019 with codes for calculating fuel behaviour in reactivity initiated accidents. Building on previous NEA reports, it provides recommendations for future research and code enhancements for safety analysis regarding reactivity accidents.

As a follow-up to the 2010 NEA report Nuclear Fuel Behaviour under Reactivity-initiated Accident (RIA) Conditions: State-of-the-art Report 2010, this report presents the state-of-the-art knowledge on nuclear fuel behaviour under reactivity initiated accident (RIA) conditions for light-water reactors (LWRs) and conventional fuels. It gives an overview of scenarios for RIAs in major types of reactors and a description of key phenomena in fuel rod behaviour under RIAs, including burn-up effects. It provides an overview of tests and experiments that have been conducted to study RIAs, a summary of results from experimental programs with integral RIA simulation tests, and a description of computer programs used for analyses of RIAs. As regards fuel safety analyses, it
discusses the transferability of test results to LWR RIA conditions and state-of-the-art methods for analysing postulated scenarios for RIAs in LWRs. It also gives a review of the regulatory acceptance criteria for RIAs applied in twelve NEA member countries. Finally, it provides recommendations as to the research work needed to fill the remaining knowledge gaps for RIA analyses.

Radioactive waste management

Clay Club Catalogue of Characteristics of Argillaceous Rocks – 2022 Update
NEA No. 7249. 244 pages. Available online at: https://oe.cd/4OZ

The NEA Clay Club has been gathering the key geoscientific characteristics of the various argillaceous formations that are – or have been – studied in NEA member countries in the context of radioactive waste disposal, resulting in the publication of the Clay Club Catalogue of Characteristics of Argillaceous Rocks in 2005.

This publication builds upon the 2005 NEA report by providing updated datasets for a select number of argillaceous formations presented in the previous report, as well as an expanded discussion of: the formations and their properties; the nuclear waste management organisations responsible for the implementation of the deep geological repository concept; the design concept proposed for a deep geological repository in the respective countries and rock formations; and some of the favourable properties of said argillaceous formations.

A key goal of this report is to present the data in a manner that allows reasonable comparability (in both scale and method) of the included parameters, in order to support the formal assessment and demonstration of the capacity of clay-rich formations to securely contain and isolate nuclear waste from the natural environment.

Nuclear science and Education

International Handbook of Evaluated Criticality Safety Benchmark Experiments
NEA No. 7592. 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 OECD Nuclear Energy Agency (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.

The evaluated criticality safety benchmark data in the 2021 edition are presented in nine volumes. These volumes span approximately 80 000 pages and contain 587 evaluations with benchmark specifications for 5 121 critical, near-critical or subcritical configurations, 45 criticality alarm placement/shielding configurations with multiple dose points for each, and 237 configurations which have been categorised as fundamental physics measurements that are relevant to criticality safety applications.

New to the 2021 edition of the handbook are experiments from the Kilopower Reactor Using Stirling Technology (KRUSTY) – shown on the front cover – and Thermal/Epithermal eXperiments (TEX) programs performed at the National Critical Experiments Research Center (NCERC) in the United States; highly enriched uranium experiments with Lucite at NCERC, pitch variation experiments at Sandia National Laboratory in the United States; and structural material experiments at the Valduc facility in France.

International Handbook of Evaluated Reactor Physics Benchmark Experiments
NEA No. 7593. DVD.

The International Handbook of Evaluated Reactor Physics Benchmark Experiments contains reactor physics benchmark specifications that have been derived from experiments that were performed at nuclear facilities around the world. The benchmark specifications are intended for use by reactor designers, safety analysts and nuclear data evaluators to validate calculation techniques and data. While co-ordination and administration of the International Reactor Physics Evaluation (IRPHE) project is undertaken by the Nuclear Energy Agency (NEA) at the international level, each participating country is responsible for the administration, technical direction and priorities of the project within their respective countries. The information and data included in this handbook are available to NEA member countries, to all contributing countries and to others on a case-by-case basis. Example calculations are presented; however, these do not constitute validation or endorsement of the codes or cross-section data.

The 2021 edition of the International Handbook of Evaluated Reactor Physics Benchmark Experiments contains data from 169 experimental series that were performed at 57 nuclear facilities. A total of 165 of the 169 evaluations are published as approved benchmarks. The remaining four evaluations are published as draft documents only. The cover of the handbook shows the ZPR-9 machine at Argonne National Laboratory-East in Illinois to support development of a gas cooled fast reactor (GCFR) in the United States. Newly evaluated criticality, control worth, and spectral characteristics measurements from the ZPR-9 have been added to this edition of the handbook.
Nuclear Law

Nuclear Law Bulletin
No. 107
Volume 2021/2
NEA No. 7598. 92 pages.
Available online at: https://oe.cd/nea-nlb-107

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 “Significant legal developments concerning “independent” regulatory agencies in the United States and what it could mean for the Nuclear Regulatory Commission” by Eric Michel; “Slovak legal system for ensuring feasible nuclear back-end system implementation Part 2: Outlook for future development” by Martin Macášek, Michal Šnírer and Vladimír Slugeň.

Principles and Practice of International Nuclear Law
NEA No. 7599. 416 pages.
Available online at: https://oe.cd/4r3

Principles and Practice of International Nuclear Law examines the various interrelated legal issues for the safe, efficient and secure use of nuclear energy. It provides an overview of the complex body of laws and legal regimes in international nuclear law, as well as the many developments that have unfolded in recent years impacting all aspects of nuclear safety, security, safeguards and liability. It also gives a concise overview of the main international institutions, and addresses such issues as radiological protection, nuclear safety, environmental protection, nuclear transport, nuclear security, safeguards, nuclear third party liability and compensation for nuclear damage, insurance, nuclear trade and project development.

The articles in Principles and Practice of International Nuclear Law are largely authored by lecturers at the International School of Nuclear Law (ISNL), which was established in 2001 by the OECD Nuclear Energy Agency (NEA) in co-operation with the University of Montpellier and which benefits from the support of the International Atomic Energy Agency. For over 20 years the ISNL has offered a unique educational opportunity to the next generation of nuclear professionals from more than 100 countries.

Publications of Secretariat-serviced bodies

Generation IV International Forum (GIF) 2021 Annual Report
GIF report. 84 pages.
Available online at: https://www.gen-4.org/gif/jcms/c_203335/gif-2021-ar

This fourteenth edition of the Generation IV International Forum (GIF) Annual Report highlights the main achievements of GIF in 2021. In 2021, GIF completed its second decade as the sole international organization dedicated to collaborative research and development (R&D) on Gen-IV systems. Since 2001, GIF has been promoting international R&D collaboration for six types of Gen-IV reactor systems using sodium, lead, gas, molten salt and supercritical water coolants.

During 2021, one of the significant activities and efforts that GIF addressed was substantive engagement with the private sector, as well efforts to deepen GIF’s role in climate change initiatives. GIF also made significant strides in advancing the safety framework of Gen-IV systems, including strengthened collaborations with the International Atomic Energy Agency (IAEA) and the Nuclear Energy Agency (NEA). Going forward, GIF will further reinforce Gen-IV system features to combat climate change and enhance engagement with industry, while continuing to support the Gen-IV talent pipeline.

Multinational Design Evaluation Programme (MDEP) Phase 1 Summary Report 2006-2021
28 pages.
Available online at: https://www.oecd-nea.org/mdep/annual-reports/MDEP_Phase1_SummaryReport7613.pdf

This report presents a summary of the Multinational Design Evaluation Programme (MDEP), undertaken between 2006 and 2021, with the intent to ensure an appropriate transition to a new MDEP framework beyond 2021. This report highlights the key milestones, successes and lessons learnt from the first 15-year period of MDEP, explains the documentation produced during this period and its future storage, and introduces the new MDEP framework from 2022 onwards.

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The Nuclear Energy Agency (NEA) is an intergovernmental agency established in 1958. Its primary objective is to assist its member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for a safe, environmentally sound and economical use of nuclear energy for peaceful purposes. It is a non-partisan, unbiased source of information, data and analyses, drawing on one of the best international networks of technical experts.

The NEA has 34 member countries: Argentina, Australia, Austria, Belgium, Bulgaria, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Korea, Luxembourg, Mexico, the Netherlands, Norway, Poland, Portugal, Romania, Russia (suspended), the Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Türkiye, the United Kingdom and the United States. The NEA co-operates with a range of multilateral organisations, including the European Commission and the International Atomic Energy Agency.

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